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Challenges and opportunities for reducing anthelmintic use in ruminant livestock systems: Insights from a sheep farmer survey in France

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ABSTRACT

Today's level of anthelmintic use in livestock production is a major threat to both the livestock industry and the environment. In this context, the research community is looking for ways to equip farmers with preventive and treatment strategies that can decrease livestock-industry dependence on anthelmintics. Production practices for a sustainable control of parasites have been advocated for almost forty years, but farmers' uptake of these practices has been too slow to address the issues at stake. In this paper, we examine the rationales behind the under-adoption of sustainable worm control practices in grassland-based livestock systems. This research builds on 25 semi-structured interviews with dairy sheep farmers in southwestern France. The interview material was analysed via qualitative discourse analysis. We highlight farmers' social representations and rationales underpinning adoption or non-adoption of the 'low anthelmintics use' strategy. We identify six profiles for nematode control according to the way each farmer included treatment and coprology in their on-farm practice. We identify that the low-use strategy has low adoption potential due to its low perceived relative advantage; low perceived trialability; unclear compatibility with previous experiences, needs, and values; and higher complexity than the status quo option. We show that holistic, pro-environmental, and collaborative attitudes are associated with adoption of the low-use strategy. We then discuss ways to improve uptake, such as increased communication, trainings, and farm visits involving farmers, extension agents and veterinarians.

1. Introduction

Anthelmintic resistance is increasing worldwide, to the point that it is jeopardizing the future of livestock farming (Kaplan and Vidyashankar, 2012; Rose Vineer et al., 2020). Modern livestock farming is heavily reliant on anthelmintics, in part because anthelmintic use enables significant gains in ruminant productivity: around 4% in dairy cattle, 28% in dairy sheep, and up to 75% in dairy goats (Charlier et al., 2020; Mavrot et al., 2015; Veneziano et al., 2004). Anthelmintics also reduce the complexity and uncertainty of livestock farming, because using an anthelmintic to prevent and treat parasitosis is a simpler and in some ways more reliable approach than the use of integrated health management practices such as biosecurity measures or alternative pasture or feed management methods (Bath, 2014).

Anthelmintic use inevitably leads to anthelmintic resistance (Shalaby, 2013), and the possibilities of finding new drugs that will eliminate the risks of resistance are limited. Resistance risk is exacerbated on dairy farms, as not all anthelmintics currently in use are compatible with lactation (e.g., only 5 out of 8 of the molecules authorized for use in France). Farmers tend to keep using the same molecule from year to year, which increases the probability of resistance. Veterinarians and other agricultural advisors, on the other hand, are increasingly calling for diagnosis before treatment instead of systematic, preventive use of anthelmintics (Vande Velde et al., 2018a). As Kaplan and Vidyashankar (2012) put it, the challenge is to move away from the 'Global Worming' approach, also known as 'blanket deworming', in which relying on anthelmintics alone is considered enough to prevent the risk of endoparasitosis.

Anthelmintics also carry wider sustainability concerns. First, they are responsible for ecosystem contamination and may lead to biodiversity losses (Beynon, 2012; Lumaret et al., 2012). Second, like any other input in farming, their production carries its own environmental footprint, and they create dependency among farm operations. To address these concerns, hopes have been focused on research and development to provide farmers with effective alternative prevention and treatment strategies (e.g. vaccines, bioactive forages, or biocontrol,

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along with biosecurity and specific pasture and feed management practices) to decrease industry dependence on anthelmintics (Charlier et al., 2017; Vercruysse et al., 2018).

Nevertheless, routine use of anthelmintics remains a widespread strategy among farmers to manage endoparasitosis. Integrated parasite management is hardly ever adopted in practice, despite almost forty years of advocacy (see Brunsdon et al., 1983; Edwards et al., 1986). For example, studies suggest that from 93% to 99% of British sheep farms use anthelmintics each year (Morgan et al., 2012; Burgess et al., 2012; see the review by Hennessey et al., 2020). Similar work in other countries has found much the same pattern on sheep and horse farms: anthelmintics are widely used by farmers, and the majority of reported practices contribute to the emergence of resistance (e.g. Patten et al., 2011; Ploeger et al., 2016; Elghryani et al., 2019; Claerebout et al., 2020 – studies in Belgium, Ireland, and the Netherlands). These studies offer valuable insight into farmers' practices, but because they are based on questionnaire-style surveys, they fall short of identifying specific barriers to sustainable worm control practices.

Research to investigate the rationales underpinning farmers' parasite control practices requires qualitative methods such comprehensive interviews or observational work (Vande Velde et al., 2018a). Very few qualitative studies have been carried out to date on anthelmintic use and alternative strategies (see Bellet, 2018; Vande Velde et al., 2018b), resulting in a lack of understanding as to why the adoption of sustainable worm control practices remains "slow and patchy" (Vande Velde et al., 2018a). Experts in parasitology advocate for a change in practices towards what we will call here **the "low anthelmintics use" or "low-use" strategy**. This strategy involves a suite of practices (Charlier et al., 2014; Stubbings et al., 2020; Vercruysse et al., 2018), including (i) moving from preventive, whole-herd treatments using broad-spectrum molecules towards targeted, selective treatments with more narrow-spectrum molecules[2], (ii) diagnosis before treatment via in vivo methods such as coprological and serological analysis and (iii) adopting substitutes for anthelmintics. In other words, this means only treating after an infection has been identified, treating only critically infested animals, and using narrow-spectrum drugs where possible.

This paper examines the socio-technical dynamics of the low-use strategy in grassland-based livestock systems. This involves moving from one coherent set of practices built around whole-herd treatment using a calendared schedule of observations, to another coherent set of practices that does not entail whole-herd treatment. It relies on diagnosis before treatment, and entails (i) making decisions based on laboratory results, and (ii) working with a veterinarian who will assess the situation and determine if using anthelmintics is appropriate. It may also involve using substitutes to anthelmintics (also called "alternative methods", including aromatherapy, phytotherapy, and bioactive forages), which means gathering information on what product or plant to use, when, at what dose, etc.–based on training opportunities, expert opinion or self-directed research.

In this article, we draw on 25 interviews with dairy sheep farmers in southwestern France to examine the rationales underlying farmers' practices for managing gastrointestinal parasites. We analyse the low-use strategy using Rogers' framework for understanding the barriers and drivers of innovation adoption. Rogers describes five factors on which the adoption potential of an innovation depends (Rogers, 1995): relative advantage, trialability, complexity, observability, and compatibility with previous experiences and current needs and values. We show that the low-use strategy currently has low potential for adoption, and conclude by discussing possible ways to improve uptake.

[2] Broad-spectrum molecules eliminate a wide variety of parasites, but are not recommended because they accelerate the development of resistance.

2. Methods

2.1. Theoretical background

This study was exploratory in the sense that we had no theories or detailed hypotheses as to farmers' practices or their rationales for those practices, although we were in possession of relevant empirical and theoretical information.

First, we had an overview of farmers' parasite management practices in the study area from a previous quantitative study (Sautier et al., 2022). Second, we were familiar with the literature on social representations (Guimelli, 1999), farming systems (Darnhofer, Gibbon, 2012), socio-technical transitions in agriculture (Vanloqueren and Baret, 2009), and innovation diffusion (Geels, 2011; Rogers, 1995). This body of literature may have implicitly shaped our data collection and data analysis.

2.1.1. Social representations

We understand social representation as a "modality of knowledge": "*the whole set of beliefs, knowledge and opinions that are produced and shared in a social group*" (Guimelli, 1999). Social representations affect farmers' practices, and vice versa. The set of practices that a farmer puts in place on his or her farm depends on the farmer's beliefs, knowledge and opinions about farming, animals, health, and the human–livestock relationship, among other factors (Bellet, 2018; Burton et al., 2012; Haggerty et al., 2009; Riley, 2011). Moreover, adopting a practice can also affect farmers' subsequent social representations of their environment and activity (Lamine, 2011; Legun and Sautier, 2018). Every farmer has their own specific set of practices, and their own specific way to comprehend their activity and their environment. In short, understanding the diversity of farmers' social representations can provide insight into the catalysts and barriers to innovations in farming practices.

2.1.2. Adoption potential of an innovation

Rogers (1995) states that the adoption potential of an innovation depends on five perceived attributes of innovations:

- compatibility: "the degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters". In most cases, the more compatible an innovation is perceived to be, the higher its adoption potential. In some contexts—for instance, the art world—the reverse might be true.
- relative advantage: the degree to which an innovation is perceived to provide benefits compared to the regime practice. In the case of preventive innovations, individuals tend not to perceive their relative advantage.
- complexity: "the degree to which an innovation is perceived as relatively difficult to understand and use".
- trialability: "the degree to which an innovation may be experimented with".
- observability: "the degree to which the results of an innovation are visible to others".

Rogers suggests that these perceived attributes are positively related to the adoption potential of the innovation, with the exception of complexity (the more complex an innovation is perceived to be, the less it tends to be adopted).

2.2. Case study

We studied practices, attitudes and beliefs among farmers in the dairy sheep industry in the Pyrenées-Atlantiques department in southwestern France. The area ranks first in the country in terms of the number of dairy sheep farmers and second in terms of sheep milk volumes (Agreste, 2010). It covers an area of 7645 km^2, spanning mountains, hills and plains, and a segment of the Atlantic coast. Elevation rises from sea level to 2900 m, with summer pastures up to 2700 m. The climate is temperate oceanic, with warm summers and no dry season (rainfall ranges from 1000 and 1700 mm/year, average minimum temperature 8 °C). This climate is highly favourable to continuous grass growth, in both summer and winter. However, it is also highly conducive to gastrointestinal nematode infestations (nematode larva thrive at 20–30 °C, in wet conditions (O'Connor et al., 2006)).

The dairy sheep industry represents one-fifth of employement in the department, and up to two-thirds in some local communities (Bonotaux and Guicheney, 2014). Sheep farming is a significant shaper of the physical landscape, with its mountain-grazed pastures and rangelands (around 171,000 ha). The main dairy sheep farming system in the area is a diversified livestock system with both dairy sheep and beef cows (70%), followed by dairy sheep with dairy cows (8%) or meat sheep (1%) (Bonotaux and Guicheney, 2014). Average flock size is 224 ewes, with half of farms having between 150 and 300 ewes.

The threat of a generalized resistance to any anthelmintic is a major concern for the industry in Pyrénées-Altantiques (CDEO, 2017; GIS id64, 2006). Resistances to the benzimidazoles class of anthelmintics have already been reported on most local farms (Geurden et al., 2014) and other resistances are now being reported for the other classes (Cazajous et al., 2018).

2.3. Selection of interviewees

We interviewed farmers (n = 25) to collect their discourse related to animal health management practices and their rationales in managing endoparasitosis risk. The farmers were selected according to their willingness to participate in the study and so as to achieve a sample representing the diversity of farm types in the area (Table 1). They were not selected to achieve a representative sample of the group.

The farmer sample included men (n = 20) and women (n = 5) and farms from four contrasting agroclimatic zones: Atlantic Coast (West), Adour (North), Montagne Basque and Bearn (East). Herd sizes ranged from 120 to 670 ewes and a diversity of sheep breeds were represented, with the majority of farmers using the 3 local breeds: Manech tête rousse (n = 13), Basco-béarnaise (n = 6), Manech tête noire (n = 2), or a mix of Manech tête rousse and Manech tête noire (n = 2). One farm had Lacaune and Manech tête rousse (n = 1) and another had Lacaune only (n = 1). The sample included the three types of commercial activity: selling milk (n = 9), processing milk into cheese (n = 14), or both (n = 2). It covers a range of different certification programs: Ossau Iraty cheese (Protected Designation of Origin; 24 farms), Organic (3 farms), IDOKI (community-supported farmhouse agriculture; 2 farms), Label Rouge (certifying particular production and transformation practices, and good organoleptic properties; 1 farm for its lamb production).

In all, we identified and contacted 35 farmers: 12 based on recommendations from an extension agent with the local Chamber of Agriculture and a coordinator for an associative farmers network, 15 from information found online and in the telephone directory; and 8 through the snowball method. We called each farmer to present who we were and the purposes of our survey, and we arranged meetings with the 25 consenting farmers.

We also interviewed local agricultural extension agents (n = 4), and veterinarians (n = 5). These interviews were not included in our analysis but provided broader insight into the local context and the barriers and enablers farmers might encounter. We contacted the extension agents and veterinarians by email to present our study and arrange a meeting; all agreed to participate.

2.4. Data collection

Data was gathered through qualitative semi-structured interviews. The interviews were held at each participant's own house or farm, in October 2020 and March 2021, or by phone in March 2021 (5 farmers). The interviews lasted between 50 min and 2½ hours.

They were recorded by dictaphone with the permission of the participants, who signed informed consent. Names and places were anonymised as per social sciences deontology.

The interview guide was structured in four parts. The first part aimed at gathering details on the farmer, the farm, and the flock; and on the farmer's motivations and values concerning their husbandry activity. The second part dealt with perceptions and practices for herd health management and gastrointestinal parasite control. The third part was about the farmer's professional environment and how they relate to it. The last part related to the farmer's attitude to their ewes and vision of the future of sheep farming.

Our goals for the interviews were to (1) record individual practices for managing gastrointestinal nematodes, (2) understand how farmers conceived health, their work and their herd, and (3) capture farmers' social representations of topics such as health management, farming, and societal trends.

We sought not to restrict ourselves to parasite management but to understand how parasite control was connected to the overall functioning of the farm and the farmer.

2.5. Data analysis

The second author transcribed the first seventeen interviews in full. The other eight interviews were partly transcribed, focusing on particular moments in the interviews that were relevant for our study. Data were analysed using the qualitative data analysis software Nvivo 12 Plus (Lumivero, Denver, the United States).

In Nvivo, we analysed the transcripts through thematic analysis (Braun and Clarke, 2008). First, we set the wider themes for coding the

Table 1
Diversity of farms and farmers represented in the sample.

Sheep breed	Number of farmers	Size of herd	Gender of operator	Activity	Quality label
Basco-bearnaise	6	Min – Max: 120 – 480 Mean: 263.33	Male: 6	On-farm milk processing into cheese: 6	Label Rouge: 1 PDO Ossau-Iraty: 6
Manech tête rousse	15	Min – Max: 130 – 500 Mean: 314.67	Male: 10 Female: 5	On-farm milk processing into cheese: 7 Bulk milk delivery to a processor: 7 Both: 1	PDO Ossau-Iraty: 15 Bleu Blanc Coeur: 1 Organic & IDOKI: 1
Manech tête noire	1	380	Male	On-farm milk processing into cheese	PDO Ossau-Iraty
Manech t ê te noire + tête rousse	1	400 (50 tête rousse, 350 tête noire)	Male	On-farm milk processing into cheese	Organic & IDOKI + PDO Ossau-Iraty
Lacaune	1	200	Male	Bulk milk delivery to a processor	Organic
Manech tête rousse + Lacaune	1	467 (60 lacaune, 407 tête rousse)	Male	Bulk milk delivery to a processor	PDO Ossau-Iraty: 1

interviews according to the interview sections. This methodological choice was intended to focus on our research topic while also allowing us to grasp the rich material covered in the interviews. We then iteratively built up new and more precise codes through successive readings of the transcripts. For example, we created codes to classify farmers' practices according to their use of preventive treatment, coprology, and alternative treatments. In our analysis, "alternative treatments" included phytotherapy (the use of plants for health) and aromatherapy (a branch of phytotherapy making medical use of essential oils).

In a final phase, we organized and examined outputs from the thematic analysis using Rogers' framework. We decided on this angle as we were writing the manuscript.

3. Results and discussion

The number of farmers for each profile and each treatment strategy is reported in our results so the reader have a better idea of the corpus. Our study do not include a representative sample, these numbers should not be interpreted.

3.1. Farmers' practices

We identified six profiles for nematode control according to the different ways that treatments and coprology were included in each farmer's practice (detailed in the section below and summarized in Table 2 and Fig. 1).

3.1.1. Ways of combining treatments and coprology

The **"Preventive treatments"** profile groups farmers who used anthelmintics as a preventive treatment and considered their practice as appropriate. They administered preventive anthelminthic treatment to the whole flock at least twice a year. These treatments were scheduled at a set period or prior to specific events, such as turning out to pasture, lambing, or tupping, all of which can cause stress to the animals and/or are critical periods for farm economic success. These farmers described their practice as an automatic reflex: they treat every year, and the practice is embedded in their routine. They neither look at animal body condition nor do coprological analysis before treating. They also explained that they were sceptical about coprological analysis because (1) they felt that the sample collection method could be biased (for collective analysis) and (2) they believed that the need for examination or for treatment based on coprological screening was a point of controversy among veterinarians. One of the farmers had done a coprological analysis a few months before the interview, on the advice of a veterinarian who suspected an infestation by *Haemonchus contortus* and wanted to verify the diagnosis and treatment efficacy. This farmer, 'Iraguy', declared that they would not repeat coprological analysis in the future and instead preferred preventive treatment, as it was easier and faster than a coprological diagnosis. The farmer was aware that coprological analysis could help choose the right treatment, but felt that the

Table 2
Farmers' strategies and social representations concerning parasite management.

Pseudonym	Profile for nematode control	Social representation of gastrointestinal parasites	Treatments		Use of coprological diagnosis	
			Anthelmintic treatment: whole herd or selective?	Use of alternative treatments	Diagnosis before treatment	Criteria for doing a coprological diagnosis
Camino	Preventive treatments	Elimination	Selective		Never	nd
Iraguy	Preventive treatments	Elimination	Selective		Never	nd
Urueta	Preventive treatments	Elimination	Whole herd		Never	nd
Eleicegui	Preventive treatments	Elimination	Whole herd and selective		Never	nd
Ogombe	Preventive treatments	Equilibrium	Whole herd and selective		Never	nd
Eneco	Preventive treatments	nd	Whole herd		Never	nd
Eugui	Transitory	Elimination (in transition)	Whole herd and selective	x	Never	nd
Aroyo	Transitory	Elimination (in transition)	Whole herd and selective		Never	nd
Sorazu	2 in one	Equilibrium	Whole herd and selective		Sometimes	If symptoms
Urrecho	2 in one	Elimination	Whole herd		Sometimes	If symptoms
Elia	2 in one	Equilibrium	Whole herd	x	Sometimes	If symptoms
Calzada	Diag before treatment	Elimination	Selective		Always	If symptoms
Careche	Diag before treatment	Elimination	Selective		Always	If symptoms
Irue	Diag before treatment	Equilibrium	nd		Always	Set periods
Benitua	Diag before treatment	Equilibrium	Selective		Always	If symptoms
Chevalier	Diag before treatment	Equilibrium	Selective		Always	If symptoms
Ralde	Diag before treatment	nd	Selective		Always	Set periods
Eulz	Alternative treatments	Equilibrium	Whole herd and selective	x	Always	If symptoms
Barrueta	Alternative treatments	Equilibrium	Selective	x	Always	If symptoms or at a set period
Bortari	Alternative treatments	Equilibrium	Selective	x	Always	If symptoms or at a set period
Uharte & Bixta	Alternative treatments	Equilibrium	Selective	x	Always	Set periods & before and after alternative treatment
Ellari	Alternative treatments	Equilibrium	Selective	x	Always	Set periods
Teillary	Alternative treatments	Equilibrium	Selective	x	Always	Set periods
Oyaco	Alternative treatments	Equilibrium	Selective	x	Always	Set periods
Yrati	Only bioactive forages	Equilibrium	None	x	NA	Set periods & before and after feeding with chicory
Paper section	*3.1.1. Ways of combining treatments and coprology*	*3.2.1. Compatibility*	*3.1.2. Whole-herd* versus *selective anthelmintic treatment strategies*	*3.1.1. Ways of combining treatments and coprology*	*3.1.1. Ways of combining treatments and coprology*	*3.1.1. Ways of combining treatments and coprology*

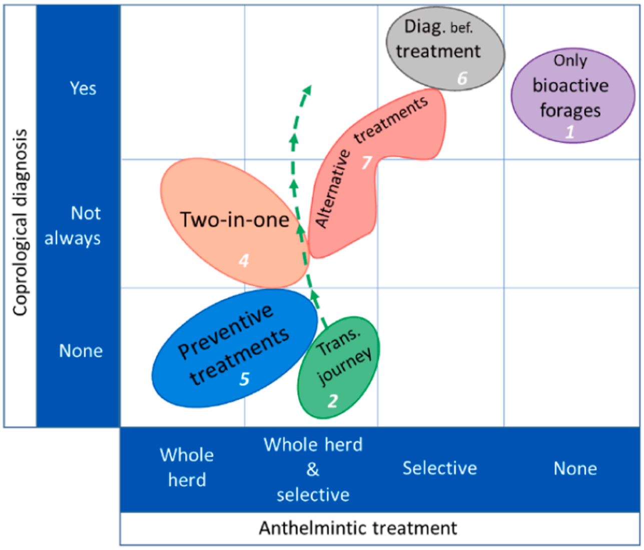

Fig. 1. The six farmers' profiles for nematode control represented according to the various different ways that treatments and coprology are combined. When a profile crosses two spaces, it means that both practices have been reported. The arrow emerging from the "Transitory journey" profile represents how practices in this profile may evolve. The numbers represent the respective size of each group.

costs of sampling outweighed the benefits. They preferred to treat preventively rather than *'struggling'* to pick up droppings.

The **"Transitory journey"** profile groups farmers who used anthelmintics as a preventive treatment but questioned whether their practice was appropriate. They currently administered two or three worming treatments a year, but were thinking about changing the way they managed nematode risk. A new experience (an overwhelming infestation with endoparasites and being involved in a research project on parasite control, respectively) prompted a reconsideration of current practices. For these farmers, preventive treatment was no longer self-evident, and they were thinking about including coprological analysis in their routine practice. At the time of the interview, however, they had not yet integrated coprological diagnosis into their routine management.

The third profile, called **"Two-in-one,"** includes farmers who performed preventive treatment as well as coprological analysis. They administered preventive treatment once a year, in autumn, or on lambs during their first year. They used coprological analysis if they noticed symptoms of infestation at other times, and then treated or not depending on the result of the coprological analysis. Their motivation for using coprological analysis prior to treatment was to prevent the risk of developing in-flock resistance, which they feared most during the milking period. They said they avoided unnecessary treatment if symptoms were not related to worm infestation. For example, 'Urrecho' ran a coprology test each spring to check whether the flock needed treating, and administered treatments preventively in September after the cessation of lactation.

The fourth profile, called **"Diagnosis before treatment"**, groups farmers who only treated after a coprological diagnosis. They used the coprological analysis to decide whether to treat and which molecule to use. Some of them decided to do coprological analysis based on observation of the animals and a detection of parasitosis symptoms, while the others did coprological analysis to monitor parasite infestation at pre-set periods that they considered had high infestation risk.

The fifth profile, called "**Alternative treatments**", describes the farmers who used alternative treatments as a complement to anthelmintics to manage nematode infestations. These farmers did not consider these alternatives as 'substitutes' for anthelmintics. They cited two modes of action for the alternative treatments: stimulating the immune system, and curing endoparasitosis. All of these farmers used alternative treatments curatively and said they had observed the effectiveness of these alternative treatments. Three used alternative treatments to stimulate the immune system: they felt that essential oils gave the ewes vigour and helped them react against a decline in health. A farmer in this fifth profile used coprological analysis for two purposes: monitoring infestation risk at set periods, and verifying product efficacy (comparing faecal egg count results before and after the alternative treatment).

The last profile, called **"Only bioactive forages"**, comprises one farmer, 'Yrati', who did not use any anthelmintics. Instead, Yrati fed animals with distributed or grazed chicory, a tannin-rich plant, for short periods. Feeding with chicory serves as a substitute for treatment. He stopped using anthelmintics around two years prior to our interview, as he considered they no longer worked. He declared he was satisfied with his new strategy. The first year, Yrati did coprological diagnosis before and after chicory feeding to verify its effectiveness against infestation. Now, coprological analysis allows him to monitor the risk of endoparasitosis and test the ongoing effectiveness of chicory. He said he had never experienced a situation that demanded anthelmintic treatment.

3.1.2. *Whole-herd versus selective anthelmintic treatment strategies*

Twenty-four interviewees detailed their treatment practice and specified whether they were used to treat the whole herd or a subgroup of the herd (also called selective treatment).

Twelve farmers **only used selective treatment**. If an animal presented parasitosis symptoms, they would sample their faeces to do a coprological analysis. The result tells the farmer whether to treat. Practices differed in terms of the decision to perform coprological analysis: they either process an analysis when the animal presents parasitosis symptoms, at set periods, at set periods and before and after treatment, or when the animal presents parasitosis symptoms and at set periods.

Six farmers **mixed whole-herd and selective treatment**. Four of them did a first run of whole-herd preventive treatment before key events, then performed selective treatment during lactation on ewes that they considered to be in bad health. The others had recently integrated coprological diagnosis into their practice and did not practice selective treatment on a routine basis.

Six farmers **only used whole-herd treatment**. Five of them treated preventively and one treated after most of the ewes presented parasitosis symptoms. Two said they practiced whole-herd treatment for the sake of convenience, as it concentrates the workload of treating and reduces the mental burden.

> *"We let all the animals get properly infested, then after a few days, when we feel many of them are coughing, we intervene […]. Not intervening also stimulates their power of adaptation […] As soon as all the animals are in the same state, we intervene. But it became complicated, in fact, it was a lot of work, a heavy burden [to treat case by case]. Because the next day, there are 5 more, and the next day 10 more, and the next day 3, and you just don't get to the end of it."* (Elia)

3.1.3. *Broad-spectrum anthelmintic treatment*

Two farmers declared they used a broad-spectrum treatment and said that it allowed them to decontaminate ewes. They used these products preventively on the entire herd. Since these two farmers target internal parasites as much as external parasites, and since they treat the entire herd, they do not see any value in doing a coprological analysis. They are satisfied with this practice because they see it as simple and effective.

3.2. *A low adoption potential*

3.2.1. *Compatibility*

We identified two divergent social representations of gastrointestinal parasites that relate differently to the low-use strategy in terms of compatibility (Section 3.2.1.1. and 3.2.1.2.).

We also highlighted in the farmer interviews two personal values that increase the compatibility of the low-use strategy: (1) producing "quality" products, and (2) reducing agricultural inputs (Section 3.2.1.3.).

3.2.1.1. A disease that has to be eliminated: negative perceptions of parasites. Nine farmers had a negative image of parasites and **aimed to eliminate them** (see Table 2). Their discourse on parasites was mainly negative: they related parasites to symptoms such as diarrhoea and problems affecting animal performance (milk production and ewe reproduction), and declared that their goal was to eradicate parasites. Even if they considered parasites as a part of nature, they all stated that they used preventive treatments two to three times a year. Their rationale was that treatment removes parasites, and they justified this practice through (i) habit, (ii) the objective of eliminating parasites, and (iii) preserving optimal production and performance.

> *"Parasites. we have to treat it! Yeah, now there are studies that try to find other solutions, but for the moment [.] For the moment, it's true that there's not much, nothing really effective is proposed."* (Urueta)

At the same time, these farmers express a form of resignation: there is a sense that they cannot do otherwise than accept they have to live with parasites, despite their frustrating effects.

> *"Afterwards, I think they have always been around. I mean, it's nothing new; just part of the cycle. Strongylida is like flies, like a whole thing I mean. People complain about flies, but if there are no flies, there wouldn't be much life."* (Camino)

Some interviewed farmers had a perception of parasites as a disease, or more vaguely as something that must be eliminated with a treatment. Three farmers linked parasites with disease. Here, seeing parasites as damaging pests translates a degree of hostility. These three farmers saw parasites as a threat and responded by explaining the damage that parasites cause, how they seriously impair proper functioning of the farm, and the measures that can be used to get rid of them.

Others were very clear and expressed opposition to parasites and had the aim of getting rid of them. "*Parasitism. Ah! That must be treated!*" (Urueta), "*We know they are here. We know we have to treat to eliminate them, and that's it.*" (Eugui).

3.2.1.2. A population and an equilibrium to maintain. Fourteen farmers did not express the negative aspects of parasites. Instead, they exhibited a **desire to maintain parasite populations at an "equilibrium"** (Table 2). They referred to a dynamic balance in which parasites have their own role and meaning: parasites are part of sheep, and ewes need parasites to strengthen their immune systems. Killing pests would be like leaving space for something else, which could ultimately prove worse.

> *"It is my belief that we should not try to kill everything. We should try to live with a controlled population of parasites and not to try to eradicate everything in order to live in a balance with these small hosts."* (Ellari)

Farmers in this category were the ones who already used the lowest amounts of anthelmintics within the sample or were exploring ways to cut down on anthelmintics through alternative parasite management methods (alternative treatment, grazing management, diagnosis before treatment, working on ewe resistance). For these sheep farmers, parasites are not harmful per se and could even be "good" for ewes. It is only when the number of parasites overshoots a threshold that they consider the situation a risk. They see parasites as providers of services by strengthening the ewe immune system. Some compared ewes with humans in their shared ability to react to a foreign body. They asserted that there was no need to 'over-react' (meaning, use a chemical treatment) to a low-level infestation, and considered that a treatment had to be motivated by a "high" level of infestation.

> *"The thing is that if parasitism takes over our farm, negative parasitism, because for me a parasite is not only negative... then there will be a drop in production. Yeah, it's pretty much a daily thing. Afterwards, it is not every day that we treat, but it is every day that we scrutinise the level of parasites in our flock. The positive aspect of parasitism is that if it does not get out of hand, it strengthens the immune system of the animals."* (Bortari)

All these farmers agreed with the idea that treatment decreases animal resilience. As an illustration, three farmers said that anthelmintics kill good elements as much as bad elements. Their strategy is to strengthen the ewes' defences so as to avoid typical veterinary treatments. To do so, some use phytotherapy and aromatherapy to stimulate immunity or for curative purposes.

> *"I think it works, for example a ewe after lambing, the first day, if I see that the next day she is not well, not in a good shape, then I prefer a tonic in order to make her react and if it does not work immediately, I know that there is a real problem"* (Teillary)

They nevertheless place value and use anthelmintic treatments. They say that anthelmintics are required in "unbalanced" situations, which could be a heavy infestation or a very low state of animal immunity.

3.2.1.3. Commitment to personal values

Being accountable to consumers. The farmers we interviewed used a discourse marked by a commitment to producing quality products: milk, cheese, and lamb. They did not explicitly define what 'quality' means, but they linked it with criteria such as the absence of foreign bodies, "good milk", taste, healthy sheep, etc. Farmers who sell cheese directly to customers had a much more extended discourse on quality as a driver to explain how they manage animal health than did farmers selling milk. These farmers expressed a moral commitment to their customers to provide them with tasty, healthy food. They distanced themselves from industrial production and positioned themselves as artisans.

> *"to make a healthy product that I believe in, that I can sell without any problem, and that corresponds to what I want and what people expect today [.] I think that by doing direct sales, this awareness that we have a commitment to the people who are going to buy our meat, we have a moral commitment."* (Ellari)

> *"Like I tell my clients, as I process everything into cheese production, there is no point in force-feeding the animals with antibiotics if they will end up in our food"* (Careche)

Being engaged for a low-input agriculture. In addition to feeling accountable to consumers, some farmers were motivated by personal values connected to low-input or low-impact agriculture. They saw alternative health management practices, such as the use of essential oils, medicinal herbs, or bioactive plants, as practices that connect to their ideal. For example, Uharte persisted in not using any anthelmintics on the flock after treating with a new herbal treatment, even when the coprological analysis was showing an increasing level of parasite eggs. Uharte believed the new herbal treatment was effective. After coprological analysis, Uharte had to wait until one month after treatment to see a reduction in the infestation. Without strong convictions about phytotherapy, Uharte would not have continued using the herbal treatment.

3.2.2. Relative advantage

The adoption potential of the low-use strategy is mixed when examined in terms of its "relative advantage". The relative advantage of this innovation depends both on its own characteristics and on the ones of the existing practice (preventive treatment). Preventive treatment was described as effective, habitual, and convenient. On the other hand, the low-use strategy was perceived as economical, purposeful, and satisfying. Still, only those who had already transitioned towards the low-use strategy perceived these relative advantages. We elaborate on these tensions in the sections below.

3.2.2.1. Preventive treatment: efficacy, habit and convenience. Interviewees mostly used the efficacy argument to justify their use of anthelmintics, whether or not they integrated coprological diagnosis into their practice. They had experienced that treatments had the expected anthelmintic effects, and said they knew of no alternative that would be as reliable as treating.

Several farmers referred to habit to explain why they applied preventive treatment. Here, the practice is ingrained and difficult to change. Also, five farmers who treated preventively and were aware of resistance risk nevertheless felt that anthelmintic resistance would not occur on their farms. They considered “high annual number of treatments” and not “preventive treatment” as the key factor in resistance development.

Two farmers used whole-herd treatment and not selective treatment because of increased convenience.

3.2.2.2. Low use strategy: mixed views. Most of the farmers we interviewed had not begun using the low use strategy. The reason invoked was a **lack of sufficient information**.

Six farmers doing systematic treatments declared they would try other methods if they had more information about how to use them or how effective they were. They wanted experiential feedback from other farmers, experimental results, or simply details as to how to proceed. Camino expressed a need for testimony from other farmers who used substitutes to anthelmintics. Eleicegui and Sorazu raised the same point:

> *“Afterwards, we are open to doing things with plants and all that, there is no problem there. We are not stuck in one way of doing things. Today, our treatments work, but why not change? Afterwards, there is a cost issue. From an economic point of view, you have to show me the efficacy of a thing. In absolute terms, you just have to tell me if it works. I know there are things with garlic, with. there are things that are done. It is just that I need to have proof. Treat animals with essential oils? Why not, but you need some knowledge.”* (Eleicegui)

Among the farmers who had tested substitutes to anthelmintics, four were not satisfied with the results. They had tested plant-based products for deworming their ewes and found that they were not successful. This experience left them sceptical about other alternative methods, and so they went back to classical anthelmintics. They stated they would need further evidence of the effectiveness of these plant-based products before using them again.

All interviewees had already heard about coprological diagnosis, but nevertheless voiced several reasons not to include it in their health management routine. As stated in the “Farmers’ practices” section, there was scepticism about the method and about the constraint of collecting ewes’ droppings. These factors make it hard for some farmers to adopt coprological diagnosis, which in turn perpetuates preventive treatments, whole-herd treatment, and broad-spectrum treatments.

Still, some farmers did identify a relative advantage for the low-use strategy. They situated this advantage (i) in **lower costs** as they could treat less often, (ii) in **greater meaningfulness** of their work as they could adopt a holistic way of managing animal health, and (iii) in **greater satisfaction** as it looked to them like the right thing to do. In the same vein, eleven farmers justified the use of coprological diagnosis using an economic argument, and seven farmers talked about the consequences of anthelmintics for the environment.

3.2.3. Trialability

The farmers we interviewed appeared to perceive the trialability of the low-use strategy as low due to operational, value-related and cost constraints. Moving from preventive treatments to more sustainable treatments costs time and labour (for sampling faeces and sending them to a laboratory), dead time (1–2 days before the results come in), money (the cost of analysis), and autonomy (farmers have to depend on the vets doing the coprology analysis). One farmer reduced the dead time and preserved his autonomy by having his own microscope and doing his own egg counts. Other than this set-up, no further improvement can be expected on this point. The current technologies used in routine coprological testing have already been optimized to give quicker and cheaper test results.

In cases in which veterinarians pushed farmers to not treat and to run a coprology screen instead, or even when coprology tests were offered free of charge, some farmers still refused to do them. Here it seems that the farmers’ risk perception for changing their practices was higher than the one for maintaining the existing practice. The reasons invoked were losing production or having animals in bad health.

3.2.4. Complexity

Farmers referred to the complexity of the low use strategy when they detailed reasons for not using diagnosis before treatment, or not trusting fecal egg counts as a diagnosis method. Diagnosis before treatment was perceived as more difficult to use and to include in the farm management routine by farmers in part because it involves more steps than preventive treatment. As for fecal egg counts, some farmers thought the method was not yet robust and needed time for further development before it would be dependable. They attributed this to a perceived lack of homogeneity and clarity in the diagnostic procedure. According to these farmers, there is a controversy among veterinarians with regard to parasite management: even veterinarians working in the same clinic may not have the same recommendations regarding the need for a diagnosis or a treatment.

In fact, the observed differences arise from (i) differences in analytical methods and (ii) the subjective interpretation of the results. Conclusions are subjective because they are based on understanding and anticipating the complex adaptive system of the host-parasite-environment relationship. Like any complex system, the dynamics of this system cannot be predicted, only forecast (Holling, 2001). Fig. 2.

3.3. Fostering adoption: Catalysts for more rational use of anthelmintics

In this section, we detail the factors and rationales that could foster a shift in practices towards reduced use of anthelmintics (Fig. 2).

3.3.1. Triggering incident and experience

Some farmers moved away from preventive treatment after a triggering incident. Incidents act like tipping points, prompting farmers to change their vision and practices. An ineffective preventive treatment can lead farmers to question their practices and the products used. The incident disrupts their perception of their practices, of anthelmintics, and of health management in general, as well as their way of thinking and acting. For instance, Yrati stopped antiparasitic treatments after several failures using deworming drugs. Before 2018, he preventively treated twice a year. After several unsuccessful treatments, he tried treating one batch of ewes with anthelmintics and a second batch with a chicory-based diet. Only the chicory-fed batch showed a substantial decline in symptoms. He has now turned away from anthelmintics and placed his trust in chicory.

Change may also arise from major health problems on the farm, even if it does not concern the sheep flock. For example, Teilary changed health management practices after a health crisis they witnessed while raising pigs on contract for a cooperative linked to a renowned superior-quality standard. During the third year of production, some pigs died at "60 kilograms", which was unusual. Neither the farmer nor the cooperative were able to identify the cause of these deaths. The cooperative sent technicians to “jab” the pigs. The farmer questioned their profession and practices, thinking there was “no reason to raise animals that would die in the end”. After this experience, and after taking a training course

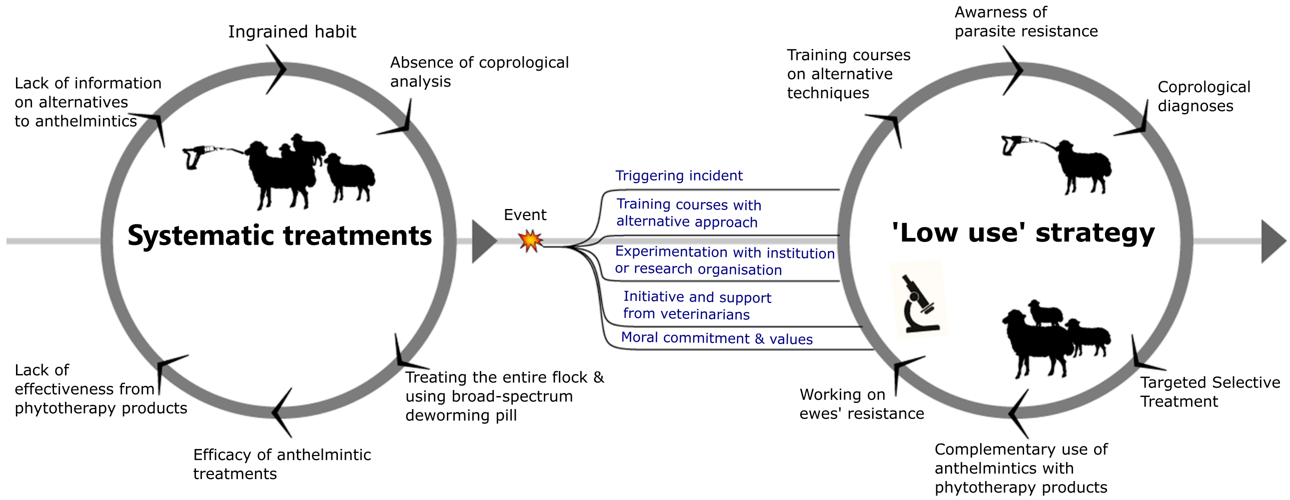

Fig. 2. Factors underpinning farmers' practices in parasite control management.

offered by a non-profit outreach organisation, the farmer modified their animal health practices, including for their ewe flock.

Another farmer dealt with a case of misuse of anthelmintic treatment that led to animal deaths. He and his parents used to treat preventively, but one year, the treatment failed to achieve the expected level of protection, and the lambs' health deteriorated. The farmer described the situation as an overdose. After this experience, which he narrates as a decisive moment in his career, he decided to stop preventive treatments. He started coprological analysis before treatment, and still does it. He learned from this experience, and changed his health management practices accordingly.

> *"Oh yes, my father, we often had disagreements. He always tended to treat, but far too much. Until one year when we had a problem with a batch of ewe lambs that were not doing well, that my father was treating and that we were going to withdraw. He told me that they were still not doing well, so we took the lambs out of service. I think it was a drug overdose. Given that the ewe lambs remained weak, it was a failure. […] And so that day I decided to stop doing treatments and started coprological analyses. In fact, since we started doing coprological tests, the results have shown that we didn't need any treatment"* (Barrueta)

Two other farmers opted for the low-use strategy based on their observation of their parents' practices and logics. They described the ingrained pattern of preventive treatment used by their fathers and declared they would not repeat the "mistakes" of their parents. Their parents treated the herd even when the ewes were in good condition, i.e. "when treatments were not necessary".

3.3.2. Exposure to parasite resistance or narratives of resistance

Every farmer we interviewed was concerned about resistance to anthelmintics appearing on their own farm. They had heard about the phenomenon of nematode resistance at least once. In the study sample, awareness of anthelmintic resistance was related to previous bad experiences, stories about anthelmintic resistance heard from neighbouring farmers, veterinarians' advice, or during farmer training sessions on animal health management.

Farmers who practiced preventive treatment were satisfied with their logic and perceived their practices as normal and efficient. They had not yet experienced any resistance phenomena and did not see any risk of developing resistance with this practice.

On the other hand, those who practiced coprological analysis before treatment justified this practice by their awareness of anthelmintic resistance. Twelve farmers declared that the coprological diagnosis offered them "security", and expressed two security-related aspects: coprological diagnoses reduce resistance risks by preventing unnecessary treatments, and also eliminate the risk of failing to detect an asymptomatic infestation. Here, coprological diagnosis is a tool to "see inside the ewes".

> *"I'm reassured by the coprological diagnoses. If a coprological diagnosis says 'it's not right', I would have seen it on the ewes before, I think. It makes me feel better about not treating." (Barrueta)*

3.3.3. Groups and networks

3.3.3.1. Veterinarians. Veterinarians can help farmers adopt the low-use strategy by reducing its perceived complexity (e.g., providing information about biological processes relating to parasites and their management; making the health-related decisions) and by facilitating trials (e.g., offering incentives, giving reassurance). The majority of the farmers in our sample trusted their veterinarian and said that they follow their veterinarian's advice. This result is similar to the situation reported among dairy farmers in Belgium (Vande Velde et al., 2018b). Vande Velde et al. identified trust as a key driver of adoption of diagnosis before treatment, along with the sense that the veterinarian is an appropriate authority on health matters.

Trust in the veterinarian also appeared to be a key factor in diagnosis before treatment adoption in our study, but only if the veterinarian pushes for the practice. Veterinarians were central to some farmers' practices: as a partner for implementing coprological analysis (8 farmers); for using phytotherapy products (2 farmers); or for moving from preventive or whole-herd treatment to curative treatment (2 farmers). Four farmers reported that veterinarians were encouraging farmers to do more coprological surveys than before. One respondent mentioned a veterinary office using coercive measures to promote coprological examinations before treatment: "no coprological diagnosis, no prescription".

> *"Our veterinarians, they proposed a coprological survey. Because they saw the practices we had been employing for years. We went to buy our Panacur, I used Panacur preventively. Afterwards, they [veterinarians] started to explain the effects of overuse. At some point, your animals or parasites, they adapt."* (Calzada)

Other farmers were suspicious of veterinarians, however. They had developed the idea that veterinarians were subject to conflicts of interest that damaged the integrity of their advice[3]. We found that farmers doing

[3] In France, veterinarians prescribe and sell veterinary drugs, and a large share of their turnover comes from these sales.

preventive treatments were also those who were suspicious about their veterinarian. This mistrust in veterinarians did not appear in Vande Velde's study (2018b). Veterinarians do not have the same status from one region to another and their capacity to facilitate changes thus varies across regions and cultures.

Finally, some farmers reported that their veterinarian was happy not doing a diagnosis and moving straight to treatment. This was further corroborated in interviews with veterinarians: some veterinarians declared they could not change farmers' practices and would agree to provide anthelmintics if requested.

3.3.3.2. Farmers' associations, networks and institutions. Social interactions, groups, and institutions may foster the transition towards the low-use strategy. Interviewees who had moved to new practices had received support from farmers' groups, extension agents, or institutions to make the transition. These experiences helped farmers adopt new values and develop new needs more compatible with the low-use strategy. It also increased the trialability of the innovation through financial, cognitive or social incentives.

Some farmers said that training had changed their understanding of animal health and their animal health management practices. They now perceived health as a set of interacting dimensions, a holistic concept in which flock management, in-barn atmosphere, knowledge of grasslands, ewes' resistance to disease and parasitism, feeding, etc., all converge to shape good flock health. They believe that each of these aspects are interdependent. Ellari, Elia, Bortari, and Teillary learned about coprological diagnosis and the use of phytotherapy through training courses delivered by non-profit organisations. These courses highlighted the link between soil quality and food quality, presented alternative treatments to anthelmintics like aromatherapy, and offered information on coprological diagnosis.

> *"I don't remember the name of it, the food, 'from farm to table' or something like that. so afterwards, by working in groups and with trainers, we really confirmed our doubts. We really have to pay proper attention to everything so that the product, in the end, is top quality. […] It was in fact, when we said 'from farm to table', we went through all the steps [from feeding animals to processing the milk]. We [the training group] did blood tests, we started with that, then [looked at the] plants we planted on our soils, and then we looked at the link with the sheep, the rotational grazing. And then [we learned] about parasite management, coprological analyses that we never did before."* (Teilary)

Agricultural institutions and research organisations are other arenas where farmers can get information about other ways to manage parasites. Three farmers changed their parasite management practices after participating in experiments led by these organisations. Yrati and Eugui started to do coprological analysis and feed animals with chicory through a research program led by the local Chamber of Agriculture. Aroyo participated in a research program in which he learned about coprological analysis and resistance to anthelmintics. This experience led him to change his practices, using coprological analysis (see below) and delaying the spring treatment before tupping:

> *"**Aroyo:** I have started to do coprological analyses, because I am in the European project for the efficiency and resilience of small ruminants. Anyway, the vet came up with the idea of parasites: "You shouldn't preventively treat all the ewes. You have to maintain a low level of parasites."*
>
> *"**Interviewer:** The coprological diagnoses so far, did you do them in the context of the European project?*
>
> ***Aroyo:** Yes, but I will also do it afterwards. I will continue afterwards."* (Aroyo)

Farmers' groups and outreach associations are not necessarily transformative, however. One interviewee did her first coprological analysis with a farmers' association, and continued the following year. The association covered the costs of analysis. The third year, she stopped participating in this subsidised operation, and did not continue with coprological analysis. She considered that preventive treatment was effective and that coprological analysis was not worth doing.

Finally, we identified differences in the degree to which farmers were exposed to discussions about parasites. Some interviewees were not discussing parasites with anyone. This aligns with previous studies which found that parasite management is not a topic of conversation among farmers, either in southwestern France (Sautier et al., 2022) or in Flanders (Vande Velde et al., 2018b). As shown above, extension initiatives that intentionally expose farmers to discussions about parasite management, can increase the uptake of "low anthelmintics use" strategies by changing how the low-use strategy is perceived by farmers with respect to Rogers' five attributes.

In conclusion, farmer interviews suggest that veterinarians are not the only agents that can foster greater adoption of the low-use strategy. Efforts to facilitate change towards integrated and sustainable animal health management should be made by a range of actors across the area via a coordinated programme. This would accommodate the diversity of farmers' perceptions as to which agents are the most reliable on this topic.

4. General discussion

4.1. Specificities of southwestern France and impacts on results

The results presented above provide insights on farmers' motivations and practices for parasite management on their farms. Even if readers can see similarities with their own experience or with farmers in other areas, the need remains for wider research to develop generic trends or guidance for the "farmer community". Here we detail the socioeconomic dynamics of the area under study which may have influenced the motivations and practices of the farmers we interviewed.

First, as stated in the Methods section, sheep milk production structures the rural sector in the Pyrénées-Atlantiques. Second, livestock is a major industry in the area (Borowczyk, 2022; Chambre d'Agriculture Nouvelle Aquitaine, 2022). Third, the physical and cultural landscape of the Pyrénées-Altantiques is highly dependent on the sheep industry.

These three characteristics of the rural environment in the Pyrénées-Altantiques may correlate with farmers being able to plan for projects and move towards new practices, such as moving from preventive treatments towards more sustainable and rational treatments, or testing alternative treatments. In other words, inhabiting a dynamic territory and practicing an activity that is viewed positively may give farmers higher adaptive capacity than if they were farming in less favourable conditions. Furthermore, farmers in the territory have an array of options for obtaining technical advice adapted to their type of agriculture (e.g. conventional versus organic). In our interviews, no issues were raised around financial resources, social pressures, or professional isolation. On the contrary, some farmers engaged in resource-consuming or risky activities such as soliciting professional advice from consultants or engaging in research trials, all of which can be considered as signs of financial and operational flexibility. On the other hand, such characteristics may weaken innovation (Dowd et al., 2014) in the sense that being embedded in a tight network and engaging in an activity exposed to the public eye may increase self-censorship.

On another note, the influence of Spain, just across the border, may have impacts on farmers' motivations to limit the use of anthelmintics. Some farmers said it was common practice to go to Spain to buy cheaper anthelmintics 'over-the-counter'. This possibility lowers the financial benefit of reducing anthelmintic use, which in turn reduces the relative advantage of moving from preventive treatment to a low-use strategy.

4.2. Observability

The theme of observability did not emerge in our interviews, but looking at the literature we can argue that the low-use strategy does not score high on the observability scale. In a study similar to ours, Vande Velde et al. (2018b) showed that gastrointestinal nematode infections have low visibility on Flemish dairy farms that treat preventively. This low visibility resulted in low infection awareness and thus low intention to adopt "low anthelmintics use" practices. In other words, if infections are not visible, there is no *visible* need to change practices and the results of modifying practices are not visible to others. This also ties into the arguments for a low relative advantage identified above.

Looking at our interviews we can also highlight the fact that coprological diagnosis increases the observability both of nematode infections (providing a quantitative and qualitative description of the parasitic burden of the flock) and of the effectiveness of nematode control strategies (when done twice: before and after the intervention) for the farmer. Some interviewed farmers use this "observability function" of coprological diagnosis for managing gastrointestinal parasites.

4.3. Motivations to change

The interviewees know about parasite resistance, and yet preventive anthelmintics treatment is still common practice. This shows that there are a range of farm-level barriers to reducing the use of anthelmintics and that ignorance of resistance issues is not one of them. This agrees with the analysis made on the motivations of Belgian dairy farmers to adopt sustainable practices in gastrointestinal nematode control, in which awareness of anthelmintic resistance does not necessarily impact practices (Vande Velde et al., 2015).

In our case study, few farmer-level factors could drive greater adoption of the low-use strategy. However, our method may have had an influence on this result. Transitions towards sustainability require systemic innovations which impact practices at the farmer, farm, and system levels (Kernecker et al., 2021), and our study highlights factors situated at the farmer and system levels (e.g., perceived low usability of coprological diagnosis; access to networks and farmers' associations). Methods that are more focused on the farm level may identify additional barriers and opportunities.

4.4. Untangling unsustainable, and yet convincing, practices

Farmers' lack of information on the effectiveness of alternative control methods partly explains the under-adoption of "low anthelmintics use" strategies. This resonates with the idea that moving towards pro-sustainability practices implies making the invisible visible (Carolan, 2006): the effectiveness or non-effectiveness of alternative control methods have not yet been evaluated, so this part of the argument remains invisible and cannot be communicated. Other aspects also need to be made visible: the parasite burden on the animal, the resistance phenomenon, the effects of alternative control methods, and the positive effects of decreased anthelmintic use, for example on biodiversity. Without these changes, the transition to low anthelmintic use will be limited to those who have "seen" the invisible (resistance, biodiversity loss, limits to occidental medicine) through the experience of a specific shock on the farm (cf. Section 3.3.1).

The challenge in these complicated and 'locked-in' situations is adopting new concepts (i.e. creating attachments to new things), shifting away from the "preventive-treatment" system of practices (i.e. facilitating detachment from the current system of practice) despite the weight of path-dependence and existing institutions (Le Velly et al., 2020). Creating new attachments while detaching from others constitutes the dynamic of "innovations through withdrawal" as described by Goulet and Vinck, 2012 in other contexts, like non-tillage agriculture (Goulet and Vinck, 2012), or short supply chains (Le Velly et al., 2020). In our study, we found that groups and alternative treatments hold the potential of being those new attachments, although it is less clear how to characterize the detached element.

To contend with this major challenge, opportunities stem from the social environment in which the farmer is embedded. This social environment constitutes the place for social learning and the diffusion of innovations (Oreszczyn et al., 2010). Our interviews highlighted how farmers' social environment can contribute to moving practices towards a more thoughtful use of chemical treatments: by engaging the conversation around parasites, and by integrating farmers into group-led action.

5. Conclusions

Analysis of farmers' practices and their associated rationales highlights how habit, and the lack of a reliable alternative, are major reasons for choosing how to control gastrointestinal nematodes. The diversity of farmers' profiles in the management of endoparasitosis risk shows that there is no single pathway toward more sustainable practices. We found that motivations to change can arise (1) from a change in perceptions after a triggering incident or participating in training sessions or (2) from the desire to provide consumers with a "good product", i.e. one that is healthy for consumers and produced according to "good practices". Group sessions, training, and field visits were places where farmers could develop the motivation to change their parasite management practices and to discuss their own self-interrogations and practices. Holistic, pro-environmental, and collaborative attitudes were associated with adoption. Unfortunately, even if extension agents can foster motivation to change through collective initiatives, the path to the low-use strategy proved to be steep and demanding: the low-use strategy fails to fit with the characteristics of a widely adoptable innovation.

The strategy has low perceived relative advantage; low perceived trialability; unclear compatibility with previous experiences, needs, and values; and higher complexity than the business-as-usual option. In addition, parasite management is associated with two invisible phenomena (infestations and resistance) and thus results in a low sense of control if farmers change their practice, whereas it is precisely this sense of control that is thought to foster action. Given the current context of dairy sheep production in southwestern France, there is very little willingness for changing practices concerning the use of anthelmintics. Change will depend on triggering incidents and, as in Flanders, will only progress in a "slow and patchy" way.

In conclusion, we advocate for developing networks and groups in which parasite management can be discussed along with other farming topics. We suggest developing extension programs that aim to support or create groups and networks where information about parasite management can freely circulate. Discussion around parasite management practices or experimental results requires forums enabling farmers to share their experiences with other farmers, rather than top-down 'education' sessions.

Along these lines, change towards integrated parasite management will redraw the identities of both veterinarians and livestock farmers. Veterinarians will move from experts to partners, while farmers will move from autonomous to collaborative actors. Transforming veterinary and agricultural training paths can help foster the process. This issue shows how a microscopic parasite can transform entire socio-technical systems, from animal health management practices to professional identities and educational curricula.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.prevetmed.2023.106078.

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