



Anthelmintic stewardship: An essential step towards sustainable dairy farming

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ABSTRACT

Helminth infections in grazing dairy cattle can lead to asymptomatic infections, subclinical- or clinical disease. Whether the course of infection leads to disease depends on various factors, leading to a broad variety of prevalence rates and severity of disease between farms, between groups of cattle in a farm and between individual animals.

Production losses related to helminth infections, the difficulty in diagnosing helminth disease and the wide availability and high efficacy of anthelmintics have led to overreliance on these products. Combined with management and other factors, this results in the development of anthelmintic resistance and an environmental hazard of drug residues. To slow down the development of anthelmintic resistance and to reduce the consequences of anthelmintic use on the environment, anthelmintic stewardship (AHS) is urgently needed.

We define AHS as a systematic approach to optimize the management of helminth infections with the goal to minimize their negative consequences through minimizing the usage of anthelmintics, reducing the development of anthelmintic resistance and reducing environmental contamination.

Implementation of AHS requires an approach that considers the complexity of helminth infections weighing different interests, while transferring them to practical applications. An integrated approach implementing AHS on dairy farms is proposed, consisting of four steps: risk assessment, prevention, diagnostics, and treatment. For each of these steps, implementation possibilities and gaps are reviewed. Although there are knowledge and implementation gaps in each of the steps, enough tools are currently available to implement AHS based on the proposed four step approach on dairy farms.

1. Introduction

Helminth infections can affect welfare and health of dairy cows and calves and can lead to economic loss on dairy farms. The most relevant helminths in temperate regions are liver fluke (*Fasciola hepatica*), lungworm (*Dictyocaulus viviparus*), and gastrointestinal nematodes (GIN), of which *Ostertagia ostertagi* and *Cooperia oncophora* are the most important (Charlier et al., 2020; Myers and Taylor, 1989; Van Dijk et al., 2010). Exposure to infective stages of GIN and lungworm is common on dairy farms, as these are considered ubiquitous in most pastures (Charlier

et al., 2023). A light exposure of first grazing season (FSG) calves to both lungworms and GIN is ideal as it allows youngstock to develop immunity (Taylor, 2012). The exposure of cattle to liver fluke is dependent on the presence of an intermediate host. Several species of amphibious mudsnails of the Lymnaeidae family are intermediate hosts of *F. hepatica* around the world. The species *Galba truncatula*, *Galba cubensis*, *Galba viator*, and *Pseudosuccinea columella* are described among others (Vázquez et al., 2019). The presence and absence of intermediate hosts is dependent on the availability of a suitable habitat (Knubben-Schweizer and Torgerson, 2015). This potentially leads to

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high exposure in some areas, while other areas are completely devoid of exposure (Caminade et al., 2015; Gaasenbeek et al., 1992).

Helminths are mainly acquired by cattle through ingesting infective stages during grazing or via fresh cut grass fed indoors. The survival of the infective stages is dependent on the environmental conditions on pasture. Drought and high temperatures are detrimental to helminths on pasture. Cold temperatures (below $\pm 10^{\circ}\text{C}$ (Christensen et al., 1976; Wang et al., 2022)) slow the metabolism of helminths, which helps them to survive temperate winters. A moist, warm environment (around $\pm 20^{\circ}\text{C}$) is where most free-living helminth stages thrive and in general leads to higher numbers of infective stages on pasture (Charlier et al., 2016b; Rose et al., 2015; Van Dijk et al., 2010). This is specifically the case for liver fluke, which not only requires humid conditions for its own survival, but also for its intermediate host *G. truncatula*, which resides on the edges of puddles and ditches (Knubben-Schweizer and Torgerson, 2015).

The potential effects of climate change on helminth abundance, seasonality and spread have been reviewed for the UK, as an example of temperate regions (Van Dijk et al., 2010). Wetter and milder winters, which are predicted to occur more often in the future in, for instance, the UK, could increase the period where *G. truncatula* can reproduce, potentially leading to more exposure to *F. hepatica*. In the Netherlands, the regional water authorities are in the process of elevating water levels in peat meadow areas in order to reduce carbon emissions (Harbers and Heijnen, 2022; Hulsbeek, 2023). This is likely to increase the risk of helminth infections on farms, as most helminths benefit from moist environments. Additionally, the elevation of ground water levels makes pastures a more suitable habitat for *G. truncatula* and therefore also increases the risk of liver fluke infections.

Helminth infections can exhibit a wide range of manifestations, ranging from asymptomatic infections to clinical or subclinical disease. Prevalence rates of manifestations vary between farms. (Agneessens et al., 2000; Melville et al., 2025; Ploeger, 2015; Ploeger et al., 2012). A similar variation in prevalence has also been found on a smaller scale: within subherds of cattle exposed to a similar infection burden (Agneessens et al., 2000; Melville et al., 2025; Ploeger, 2015; Ploeger et al., 2012). Studies have shown a large variety in the prevalence of *O. ostertagi* on farm-level and individual level (Agneessens et al., 2000; Kowalczyk et al., 2018; Melville et al., 2025). However, the presence of helminth infections does not necessarily mean the presence of clinical disease. Infections with *O. ostertagi* commonly occur without disease or production losses (Charlier et al., 2023). *D. viviparus* appears less prevalent than GIN but can cause significant disease (Charlier et al., 2020; Springer et al., 2021). Ploeger et al. (2012) demonstrated the value of bulk tank milk ELISA in detecting moderate or severe helminth infections. They found a wide variety in within-herd prevalence, between 0 – 69.6% for shedding larvae and 0 – 85.2% for antibody positivity. For *F. hepatica*, similarly wide variations (8 – 60%) were found in infected herds in Germany (Hecker et al., 2024). Although these results show that herd-level diagnostics can detect herd-level infections, the translation of the herd status to an individual disease status with the possible subsequent need for treatment is not straightforward (Ploeger, 2015).

The clinical diagnosis of disease caused by helminths is difficult, due to the subtle and non-specific symptoms. Reduced growth, weight loss, reduced milk yield and a poor coat are common non-specific symptoms associated with helminth infections. Lungworm infections more often cause specific clinical symptoms as these parasites infect the lungs and can cause parasitic bronchitis and pneumonia. This, combined with the onset of symptoms during pasture season, gives a stronger indication of the parasitic cause of the symptoms. Clinical fasciolosis in cattle might cause anemia and hypoalbuminemia with consequential oedema when juvenile flukes migrate through the liver. However, most infections are subtle, causing only a limited loss in milk yield or bodyweight. Because of the subtle signs of helminth infections, additional diagnostics are needed to confirm them (Charlier et al., 2023; Vercruysse and Claerebout, 2001). Diagnostics such as fecal egg counts (FEC) for GIN and

F. hepatica or fecal larval counts (FLC) using Baermann's technique for lungworm larvae are often used for direct diagnosis of helminth infections. With exception of the first exposure of GIN, the correlation between FEC and clinical disease, growth reduction and production loss, however, is poor (Eysker and Ploeger, 2000). Determining GIN FEC therefore generally is not considered useful to diagnose GIN disease in adult cattle, as they usually have had previous exposure to GIN (Charlier et al., 2009). Thus, other diagnostic methods are needed for these animals. Insufficient ability to diagnose individual (sub)clinical cases of helminth infections leads to difficulty selecting patients that might require treatment. This, the production loss related to helminth infections, and the wide availability of efficacious anthelmintics often leads to indiscriminate treatment of herds or subherds to reduce disease burden.

The use of anthelmintics has serious disadvantages such as selection for anthelmintic resistance (Fissiha and Kinde, 2021). This has frequently been reported as a reason for treatment failure in sheep (Bosco et al., 2020). Although resistance appears to develop more slowly in cattle (Sutherland and Leathwick, 2011), waiting until treatment failure is widely present will result in preventable losses (Ehnert et al., 2025; Kaplan and Vidyashankar, 2012). In recent years, anthelmintic resistance in both beef and dairy cattle has been demonstrated worldwide (Borges et al., 2024; Ehnert et al., 2025; Mauger et al., 2022; Sauermann et al., 2024). Resistance development should be minimized to prevent losses and prolong the time we can effectively use anthelmintics. Clinical cases of unsuccessful treatment of helminth infections are rare but are also reported (Costa et al., 2011; Holzhauer et al., 2017). A further increase in anthelmintic resistance worldwide is likely, given the reported increase in resistance cases diagnosed (Rose Vineer et al., 2020).

In addition to selecting for resistance, anthelmintics may be hazardous to the environment. Anthelmintics and their metabolites are mostly excreted through feces or urine and therefore pose a potential risk to non-target species in the environment. The hazard is higher for substances with a broader spectrum of activity (Floate et al., 2005; McKellar, 1997). Ivermectin treatment, for instance, poses a risk for decomposing organisms invading and colonizing the fecal pat, leading to a significantly longer time until the pat is fully degraded (Schmitt and Römbke, 2008). Recent research has shown that macrocyclic lactones are hazardous to aquatic organisms (Bundschuh et al., 2016; Wagil et al., 2015). Lumaret and Errouissi (2002) reviewed the potential hazards of several anthelmintics for non-target fauna. One of their findings was that benzimidazoles have a relatively lower hazard for pasture-based nontarget fauna. However, Gkimprizi et al. (2023) found that the benzimidazole albendazole has a toxic effect on the plant symbiont *Arbuscular mycorrhizal*, a fungus that forms a symbiotic relationship with 70 – 90% of terrestrial plants (Parniske, 2008). Similarly, Navrátilová et al. (2023) found that sheep manure from sheep treated with albendazole induced an abiotic stress response in both clover (*Trifolium pratense*) and alfalfa (*Medicago sativa*). These results suggest that the potential hazards of anthelmintics are not limited to pasture-based fauna.

The potential effect of helminth infections on animal health, welfare and production merit intervention, which has long been indiscriminate treatment with anthelmintics. Given the undesired consequences of anthelmintic treatments, more sustainable helminth management strategies are to be advocated (Taylor, 2012). Farmers and veterinarians should be guided in the implementation of sustainable helminth management and should be provided with the tools to do so. Our first step on that path is defining anthelmintic stewardship (AHS) as a systematic approach to optimize the management of helminth infections with the goal to minimize their negative consequences, through minimizing the usage of anthelmintics, reducing the development of anthelmintic resistance and reducing environmental contamination.

The rationale of an integrated approach to helminth management is not novel. Approaches integrating diagnostics, prevention, monitoring

and anthelmintic treatment have been suggested in literature before (Matthews et al., 2016; Molento et al., 2009; Rendle et al., 2024; Sands et al., 2024; Šlapeta et al., 2024; Voinot et al., 2020). Most often, these are specific practices utilizing specifically available diagnostics with treatment in a research setting (Merlin et al., 2017; Ravinet et al., 2014; Ravinet et al., 2017). The wide variety of conditions on farms, farming methods and risk of disease between farms hinder straightforward adoption of one specific integrated method. This leads to the question of how an integrated parasite management approach can be feasible for implementation on a wide variety of dairy cattle farms, with different practical, financial and management constraints. In this article we will review a stepwise approach for farmers and veterinarians to implement AHS on dairy farms worldwide. We will discuss gaps in the practical implementation and scientific knowledge of the different steps within AHS. This article will focus on the previously mentioned helminth species (*F. hepatica*, *D. viviparus*, *C. oncophora* and *O. ostertagia*) in dairy cattle because of their high impact in this sector. Although AHS is equally important in beef cattle, the different methods of farming prohibit straightforward comparison of helminth management to dairy cattle.

2. Steps in anthelmintic stewardship

Translating AHS into practice requires guidance. Given the complexity of the subject and facilitating on-farm decision making, a four-step approach was developed, which will be discussed below. The four steps are:

3. Risk assessment
4. Prevention
5. Diagnostics
6. Treatment

Step 1 is assessment of the risk of infection and/or disease, which can be done based on the information on regional/national, (sub)herd and

pasture level. Based on risk assessment, prevention of disease on (sub) herd-level (step 2) can be applied more specifically. Prevention can be applied in two ways: decreasing exposure to infection and increasing host resistance or resilience. The third step is the diagnosis of helminth disease, based on a combination of subherd-level and/or individual diagnostics. Ultimately step 3 will lead to selection of animals or subherds for anthelmintic treatment. The fourth step discusses the considerations to be made when selecting an anthelmintic for treatment when a diagnosis has been made. Fig. 1 below displays a graphical overview of the four-step approach developed.

3. Step 1: Risk assessment

The aim of risk assessment is threefold: 1. To assess whether a risk of helminth infection is present in a herd; 2. To assess what these risks are; and 3. To assess which subherds are at risk of helminth infections. The risk of disease due to helminth infections is dependent on parasite exposure and the resilience or resistance of animals. Risk assessment primarily focuses on exposure to infective stages, as host-related factors such as resilience and resistance are inherently difficult to quantify in field conditions. Although these factors are biologically relevant, their effect can only be estimated using indirect and subjective indicators such as farm history and animal age. Exposure is highly dependent on the actual conditions on pasture and can vary in a small area, even within the same pasture. Assessment of the risk of disease in practice, therefore, is generally similar to assessment of the risk of infection. In this paragraph, we will discuss several methods to assess the risk of infection for GIN, *F. hepatica* and *D. viviparus* on several scales: national or regional level, herd-level and pasture-level. We will also discuss the development of models developed for risk assessment and their implementation.

3.1. Risk assessment on national or regional level

At the national or regional level, risk assessment mostly focuses on patterns of infection by integrating weather data and data from other

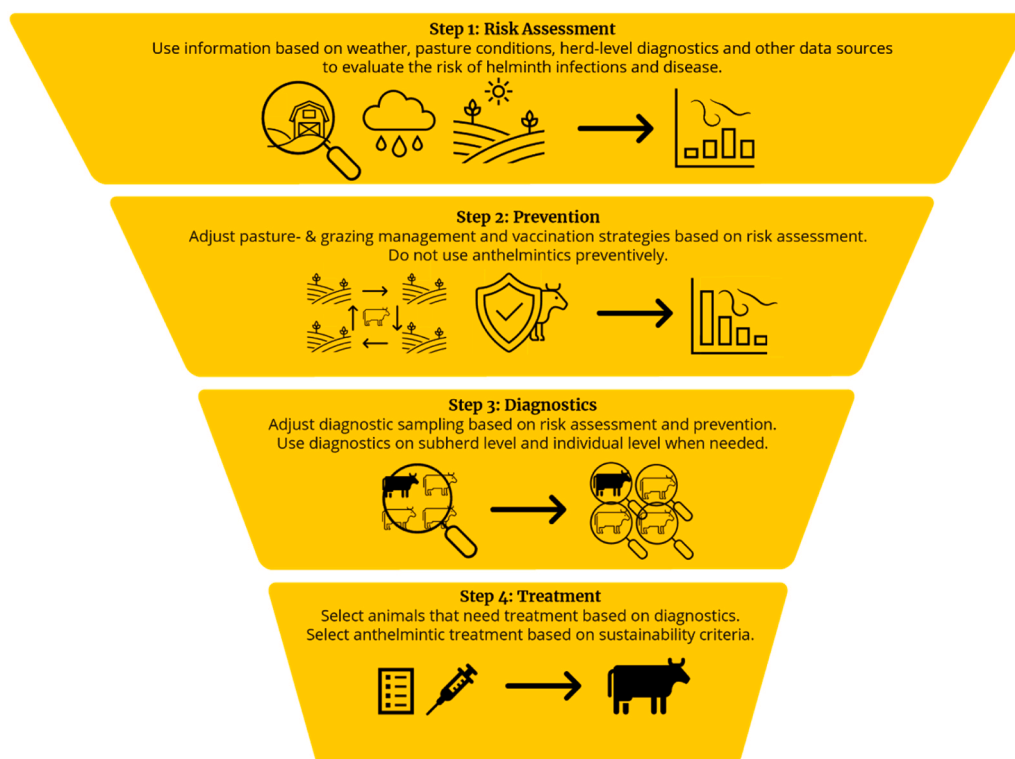


Fig. 1. The four-step anthelmintic stewardship approach on dairy cattle farms summarized.

surveillance systems such as slaughterhouses. Ollerenshaw and Rowlands published a method of forecasting *F. hepatica* incidence as early as 1959 (Fox et al., 2011). This method has historically been the most used risk assessment for liver fluke on a national or regional level (DAFM, 2025; NADIS, 2025). Additions to the original method include *G. truncatula* counts and slaughterhouse data, as was used in the Netherlands (Gaasenbeek et al., 1992).

To our knowledge, there is currently no implemented risk assessment method on a national or regional level for GIN or lungworms in cattle in temperate regions. Prediction methods have been developed and validated for GIN in cattle for temperate and non-temperate regions (Beck et al., 2015; Villa-Mancera et al., 2018) but have not yet been implemented. For the UK and parts of Ireland, Sustainable Control of Parasites (SCOPS) provides a regional forecast for *Nematodirus battus* risk for sheep, based on the hatch data of *N. battus* eggs (SCOPS, 2026). They provide a risk assessment for farmers based on data from the weather station closest to the farm. Although *N. battus* can infect cattle (Rehbein et al., 2022), clinically or economically it is not their most relevant helminth (Charlier et al., 2020). This method does, however, provide an example of an effective risk assessment tool on the regional level, using information on the life cycle of the nematode paired with regional weather data. Even though the life cycle of *N. battus* is significantly different from other GIN, the method of assessing the risk of a nematode burden based on data on life cycle and weather may be adapted for GIN more relevant for cattle. This would require models that can accurately predict the presence of GIN on pasture.

3.2. Risk assessment on herd level

On top of the information for all herds in a certain region, there is farm-specific information that may be valuable in assessing the risk, and subsequently in steering the prevention of disease caused by helminth infections at farm level. Two sources of information will be discussed here: farm history and herd-level diagnostics. Farm history is an obvious and readily accessible source of information that should be used in assessing risk and future prevention. Similarly, herd-level diagnostics can be valuable for risk assessment and consequentially, to decide on the application of preventive measures.

3.2.1. Farm history as a source of risk assessment

A history of a specific helminth infection on a farm indicates the potential of recurrence of that infection. In addition to earlier diagnosed infections, also other indicators can be included in the history of a farm. Examples of indicators suggestive of an earlier infection are liver condemnations in cattle (Takeuchi-Storm et al., 2017), and clinical symptoms in sheep grazing on shared pastures, especially during the grazing season because of their sensitivity to rapid development of fasciolosis (Vanhecke et al., 2021). Farms with a history of helminth infections or with suggestive indicators benefit from further progression through the other steps of AHS, starting with risk assessment. If there is no significant infection on a farm, further progression through the steps might yield unnecessary costs and treatments. Nevertheless, introduction of helminths (e.g. through introduction of animals and/or a change in pasture conditions) may result in a change in infection risk on these farms, which merits monitoring. If the infection status is unknown, further progression through the steps of AHS is merited to prevent unnecessary disease.

Introduction of new animals in a herd can be a risk for the introduction of helminths. Purchase of cattle has been demonstrated as a risk factor for infection of *F. hepatica* (Takeuchi-Storm et al., 2017) and of *D. viviparus* (Vanhecke et al., 2021). Purchasing and introducing cattle from other farms is very likely a way to also introduce resistance alleles of resistant parasites on farm (Antonopoulos et al., 2024; Jackson et al., 2006; Lawrence et al., 2006; Sutherland and Leathwick, 2011). Farms frequently purchasing cattle from other farms should also monitor the presence of helminth infections and AR development closely.

F. hepatica has a broad range of end-stage hosts, including sheep and wild ungulates (Lamb et al., 2021), as well as rodents (Ménard et al., 2000). The role of wildlife in the transmission, introduction and maintenance of *F. hepatica* on farms has not been studied in detail. If potential host wildlife is frequently present on pastures that are also grazed by cattle, they might pose a risk for introduction of infection.

Grazing history on specific pastures can be used to assess the risk for future grazing subherds. If certain subherds grazed on a pasture had a high excretion of free-living stages of a parasite, a high risk of infection on that pasture for other subherds can be expected after development to the infective stage is completed. This requires monitoring of subherds on their excretion of parasite load. Thus, diagnostics (further discussed in step 3) are useful as a risk assessment tool for future grazing. Parasitological diagnostics such as FEC that can quantify the excreted parasite load are most suitable for this goal. McFarland et al. (2022) demonstrated this use of diagnostics in risk assessment using a simulated model. However, as both the time of development to infective stages and the survival of parasite stages on pasture is dependent on many different factors, it is hard to accurately assess when a pasture is at a low risk from a parasitological perspective.

3.2.2. Herd-level diagnostics as a source of risk assessment

Bulk tank milk (BTM) testing is a cost-effective method of herd-level diagnostics. It can provide a first overview of the status of an entire herd (Howell et al., 2015; Ravinet et al., 2014; Takeuchi-Storm et al., 2019; Takeuchi-Storm et al., 2021; Villa-Mancera et al., 2018). If, for instance, BTM-ELISA for *F. hepatica* antibodies is low to zero for several years, it is unlikely that *F. hepatica* causes many infections or significant disease in the preceded period in the monitored cattle. In that situation adjustments of preventive management and further investigation do not seem to be useful. Herd-level diagnostics are valuable as a first assessment of the status of infection and can be the first indicator to adapt the preventive helminth management of a herd.

Immunodiagnostics such as BTM-ELISA to detect antibodies against helminths provide invaluable information for monitoring but also present inherent caveats. BTM diagnostics have the advantage that collection is easy; a single sample can provide quantifiable information on all helminth infections. It is therefore a cheap and easy tool to acquire valuable information for herd-level risk assessment. However, BTM has the inherent disadvantage that it only provides information on cows delivering milk to the bulk, youngstock and dry cows are excluded from BTM analysis. Also, antibody-based diagnostics only provide information on a (recent) historic infection. When the status of infection of, for instance, *F. hepatica* on a farm is already known, a qualitative diagnosis of the presence of *F. hepatica* antibodies provides limited added value (Opsal et al., 2024).

Byrne et al. (2018) found a seasonally dependent quantitative correlation between BTM-ELISA against *F. hepatica* and milk production. A quantitative correlation to production parameters has also been suggested by Sekiya et al. (2013), although they concluded these correlations are likely only detectable when comparing highly positive farms with negative farms. Takeuchi-Storm et al. (2021) suggested to use cut-offs for low, medium and high BTM results after finding a strong but non-linear correlation between milk production losses and within-herd prevalence of *F. hepatica*. Nijhuis et al. (2026) found a correlation between soil type and weather conditions and BTM results. These findings suggest that the BTM-ELISA can be used as more than just a diagnostic indicator and might play a role in risk assessment.

Ploeger et al. (2012) found that BTM-ELISA for *D. viviparus* was not well suited to monitor the prevalence of infection, but much better to confirm moderate to severe outbreaks and the presence of disease on a farm level. Especially with the rapid outbreaks that can occur with *D. viviparus*, monitoring the antibody response in BTM might result in a late detection of infection.

BTM-ELISA can be used to identify herds or regions with high exposure to *O. ostertagi* (Opsal et al., 2023; Villa-Mancera et al., 2018).

Although this may not be risk assessment in the sense that it predicts a risk, it can be used to determine whether a herd might be chronically diseased due to high exposure. The regional (re-)occurrence suggested by Villa-Mancera et al. (2018) and Opsal et al. (2023) indicate a potential use in risk assessment, for the years after a high BTM-level has been found.

3.3. Risk assessment on pasture-level

Pasture conditions can provide insight into the risk factors for helminth disease present. This is clearly illustrated by the risk for disease caused by *F. hepatica* (Knubben-Schweizer and Torgerson, 2015). Different pasture conditions lead to differences in risk of disease even though farms are in the same region. Conditions such as land elevation or water management can play an important role in the presence or absence of a habitat for e.g. *G. truncatula* (Beltrame et al., 2018). Other factors such as stocking density, external biosecurity and farm history on helminth infections also influence the risk of future helminth infections on pasture (Knubben-Schweizer and Torgerson, 2015; Nansen et al., 1988; Ravinet et al., 2014). The farm history and pasture conditions should always be considered when deciding on preventive helminth management on a dairy farm, which is preferably specified at the pasture level (McFarland et al., 2022). Although GIN and *D. viviparus* lack the clear indicators as described for *F. hepatica* because of the intermediate host snail, pasture-based risk assessment can still be performed. Using the grazing history combined with regular monitoring of the herd, for example with FEC and FLC, an assessment of excreted eggs or larvae can be made. This can be used to assess the risk for subherds subsequently grazing on certain pastures.

Several researchers have published practical guidelines that can be

used to assess the risk of *F. hepatica* infections at the pasture level. Most of these are hard to quantify but still provide added value through a subjective assessment. For example, Knubben-Schweizer and Torgerson (2015) have described control strategies based on the habitat of *G. truncatula*. Rondelaud et al. (2011) have described the use of indicator plants in finding habitats for *G. truncatula*. This can be used to select pastures, or even areas within pastures with a (subjective) high or low risk for *F. hepatica* infections.

3.4. Tools for helminth risk assessment

Several tools for risk assessment, based on regional- as well as herd-level information, have been developed. Table 1 provides an overview of models that are described in literature, as well as their level of implementation. So far, most of these are theoretical models, not yet used in farming practices.

3.5. Limitations in risk assessment

For GIN and *D. viviparus*, the currently available tools do not allow straightforward risk assessment at all levels. BTM-ELISA can be used to assess the presence of infection and is valuable as an indicator of historic risk. Potential for quantitative interpretation has been demonstrated and needs further development. Indicators for high-risk areas on pasture are not available. Prediction models might be used to track exposure status of pastures, resulting in a more continuous monitoring method.

4. Step 2: prevention

Prevention of disease can be reached via two routes: decreasing

Table 1

Regional and herd-level risk assessment tools for helminth infections in grazing dairy cattle caused by GIN (*Ostertagia ostertagi* and *Cooperia oncophora*), *Fasciola hepatica* and *Dictyocaulus viviparus*.

	Predictive tool	Reported aim	Implementation	Ref.
GIN (<i>O. ostertagi</i> and <i>C. oncophora</i>)	GLOWORM-FL	Simulate the population dynamics of free-living GIN, the effect of climate and of climate change on free living stages of nematodes.	Authors demonstrate model use on a regional level and recommend it to track pasture contamination. Practical implementation on farms has not been reported.	(Rose et al., 2015) (McFarland et al., 2022)
	Improved GLOWORM-FL	Incorporate nemabiome metabarcoding to improve the GLOWORM-FL simulation model.	ITS2 nemabiome metabarcoding improved the model specificity towards cattle GIN. Practical implementation on farms has not been reported.	(Wang et al., 2022)
<i>O. ostertagi</i>	Fuzzy rule-based system	Predict when L3 larvae are ready to migrate to pasture after excretion based on weather data.	Model allows the pasture management to adapt to expected migration of helminths to pasture. Practical implementation on farms has not been reported.	(Chaparro and Canziani, 2010; Chaparro et al., 2011)
	Parasit' Sim	Calculate the number of <i>Ostertagia</i> sp. infective larval generations for heifers grazing in their FSG.	The model is available in France and has been used in scientific experiments including risk assessment for calves.	(Constancis et al., 2022; Merlin et al., 2017)
	Time of Effective Contact (TEC)	Calculate the time in months that heifers have been in contact with infective larvae as a measure of infection and/or immunity.	Authors conclude that TEC has potential as a risk-assessment tool, but further practical implementation on farms has not been reported.	(Charlier et al., 2014a; Ravinet et al., 2014; Ravinet et al., 2017)
<i>F. hepatica</i>	Hydro-epidemiological model	Model the liver fluke life cycle based on weather data and hydrological and epidemiological conditions. Environmental suitability is predicted at a daily time step and 25 m resolution.	Practical implementation on farms has not been reported.	(Beltrame et al., 2018)
	Ollerenshaw index	Predict the risk of <i>F. hepatica</i> infection based on rainfall, evapotranspiration and temperature.	Regional and national predictions based on this index have aided in farm risk assessment. Insensitivity of the model might hinder use on its own. This model is used in Ireland to provide a national risk assessment chart.	(Fox et al., 2011; Gaasenbeek et al., 1992; Howell et al., 2023)
<i>D. viviparus</i>	GLOWORM-FL-DV	Models free-living stages based on weather conditions.	This model adjusts GLOWORM-FL for use in lungworm. It is developed with practical implementation in mind, but implementation has not been reported.	(McCarthy et al., 2022)
	Model simulating <i>D. viviparus</i> infections	Model the parasitic phase of the life cycle, predicting the excretion of infective stages of lungworm.	Further steps are needed to use this for risk assessment. Practical implementation on farms has not been reported.	(Ploeger and Eysker, 2000)

infection pressure and increasing and improving host resistance or resilience. Infection pressure can be decreased by intervening in the life cycle of helminths or by avoiding exposure of animals to heavily contaminated (parts of) pastures. Increasing host resilience or resistance can be achieved by improving immunity, for example through allowing low-grade exposure or, if available, vaccination. Table 2 provides an overview of methods to prevent disease by decreasing exposure to infection and increasing resilience or resistance of animals.

4.1. Decreasing infection pressure using pasture management

The conditions on pasture can, to a certain degree, be controlled by management measures. In this paragraph, we will discuss several pasture management methods that can be applied to decrease infection pressure of helminth stages on pasture. These examples are not meant to provide an exhaustive overview, but a sample of methods and their considerations that fit within AHS.

Mowing has long been considered a staple method to decrease infectivity of pasture for GIN (Morley and Donald, 1980). The mechanical removal of parasites or changes in microclimate in the habitat of infective stages are suggested to lead to a reduction in infection pressure (Armour, 1980). Mowing before turnout was found to be correlated with a lower herd mean pepsinogen level and a lower *O. ostertagi* BTM ODR (Bennema et al., 2010; Charlier et al., 2010a), suggesting a lower exposure. Mowing before turnout is a common

management practice performed in northwestern Europe. 99% and 66% of German and Swedish farmers, respectively, reported mowing pastures before turnout (Bennema et al., 2010). Similarly, mowing reduced the antibody levels against *D. viviparus* (Bloemhoff et al., 2015; Charlier et al., 2016a; Schnieder et al., 1993). Höglund et al. (2004) report inconsistency in the results of mowing in preventing exposure to *D. viviparus*. Evidence indicates mowing likely is a suitable method to prevent excessive lungworm exposure, although results may vary. From a practical perspective, the timing of mowing for the purpose of reducing exposure can be harmonized with silage- or hay production. This results in a feasible method to reduce exposure to GIN and lungworm on farms.

For *F. hepatica*, mowing was associated with lower BTM-antibody levels (Bennema et al., 2011). They suggest that mowing pasture in spring can remove last year's surviving metacercariae, lowering infectious pressure at the start of the grazing season. As the habitat for host snails is not destroyed by mowing, it is unlikely that this will provide a long-term solution. Milling ditches is known to destroy the habitat of the host snails for a longer time (Knubben-Schweizer and Torgerson, 2015). Lowering ground water levels also reduces the availability of a suitable habitat for the host snails.

Pasture management strategies are not without caveats or adverse effects. Some strategies require that pastures can be accessed by machinery. If the terrain does not allow access due to geography or soil conditions, managing the pasture can be challenging. Local environmental laws might prohibit certain pasture management procedures,

Table 2

Methods to prevent helminth infection and disease in grazing cattle caused by GIN (*Ostertagia ostertagi* and *Cooperia oncophora*), liver fluke (*Fasciola hepatica*) and lungworm (*Dictyocaulus viviparus*).

	Prevention method	Affected helminths	Implementation	Ref.
Decrease infection pressure	Mowing pastures	GIN <i>O. ostertagi</i> <i>D. viviparus</i> <i>F. hepatica</i>	Implementation varies per country. Data on implementation is mostly from western European countries.	(Bennema et al., 2010) (Charlier et al., 2010a) (Vanhecke et al., 2021) (Bennema et al., 2011)
	Late turnout	GIN <i>O. ostertagi</i> <i>D. viviparus</i>	Applied in several western European countries.	(Van Dijk et al., 2010) (Charlier et al., 2010a) (Vanhecke et al., 2021)
	Predation of helminth larvae by nematocidal fungi	GIN <i>D. viviparus</i>	Commercial products are available in Australia and New Zealand.	(Fernández et al., 2023; Zegbi et al., 2021) (Fernández et al., 1999)
	Milling ditches	<i>F. hepatica</i>	Practical feasibility depends on the pasture.	(Knubben-Schweizer and Torgerson, 2015)
	Lowering ground water levels	<i>F. hepatica</i>	Implementation unknown. Water levels in the Netherlands are raised to combat soil subsidence.	(Harbers and Heijnen, 2022; Hulsbeek, 2023; Knubben-Schweizer and Torgerson, 2015)
	Housing animals at the time of excreting eggs/larvae	GIN <i>D. viviparus</i> <i>F. hepatica</i>	The life cycle of pasture-borne helminths will be interrupted if the excreted stages never reach pasture.	
	Anthelmintic treatment	GIN <i>D. viviparus</i> <i>F. hepatica</i>	Treatment will reduce egg or larvae excretion, reducing future infection pressure. Preventive treatment based on EPG of at least 20 animals is currently advised for cattle GIN by WAAVP.	(Borgsteede et al., 1998; Sabatini et al., 2023; Vercruyse and Claerebout, 2001)
	Rotational grazing	GIN <i>D. viviparus</i>	A high infection pressure can be evaded by rotational grazing. Most temperate intensive farms use a form of rotational grazing.	(McFarland et al., 2022; Roche et al., 2017; Voinot et al., 2020) (Eysker et al., 1992; McCarthy et al., 2022)
	Fencing off habitat	<i>F. hepatica</i>	A habitat to be fenced off can be found using pasture-based risk assessment. Implementation could be facilitated by using precision livestock farming technologies such as virtual fencing (Beltrame et al., 2021; Goliński et al., 2022).	(Knubben-Schweizer and Torgerson, 2015) (Goliński et al., 2022)
	Housing cattle indoors	GIN <i>D. viviparus</i> <i>F. hepatica</i>	Contact with infective stages of helminths is avoided if cattle are housed indoors and no fresh grass is fed.	(Borgsteede and van der Burg, 1982; Phillips et al., 2013; Thamsborg et al., 1999)
Increase resilience or resistance	Vaccination	GIN <i>D. viviparus</i>	A vaccine for GIN is under development but is still unavailable. A live-attenuated vaccine is available and is routinely used in several countries.	(Claerebout and Geldhof, 2020; Pal et al., 2024) (Benítez-Usher et al., 1976; Claerebout and Geldhof, 2020; Jarrett et al., 1960; Pal et al., 2024)
	Breeding for reduced susceptibility	GIN <i>F. hepatica</i>		(Kloosterman et al., 1992; Šlapeta et al., 2024) (Hayward et al., 2021a; Hayward et al., 2021b; Jönsson et al., 2022)

such as lowering the soil water level (Harbers and Heijnen, 2022; Hulsbeek, 2023). Furthermore, pasture management often affects more than just the presence of the four mentioned helminth species. Milling ditches for instance, destroys the habitat for many insect species, and lowering soil water level increases soil subsidence in peat meadow pastures (Brouns et al., 2015; Harbers and Heijnen, 2022; Hulsbeek, 2023). Given the substantial variation in pasture conditions across cattle farms, preventive management is necessarily customized, influencing both its effectiveness and the potential risk of adverse effects. Any adverse effects of preventive measures need to be balanced to their benefits, similar to any adverse effects of anthelmintic use. If the adverse effects seem to be too severe to justify the potential reduction of helminth infection they should not be applied. Because conditions vary enormously between farms, regions and countries, further details balancing the adverse effects and benefits of pasture management fall outside of the scope of this paper.

4.2. Decreasing infection pressure using grazing management

Another way to decrease helminth infection pressure is by avoiding grazing on pasture that is (heavily) contaminated. More susceptible cattle especially should be managed with care to avoid severe infections and disease. This paragraph will discuss methods that can be used to plan the timing and location of grazing cattle.

Reducing the time cattle spend on pasture reduces exposure to infective stages. As helminth infections are much more prevalent in grazing cattle, keeping them indoors minimizes the risk of exposure (Borgsteede and van der Burg, 1982; Phillips et al., 2013; Thamsborg et al., 1999). Delaying turnout has been associated with a reduction in helminth infection pressure for grazing animals (Charlier et al., 2010a; Van Dijk et al., 2010; Vanhecke et al., 2021). Similarly, restricting access to high-risk areas on pasture can be applied when the habitat can be clearly determined. As *F. hepatica* and the intermediate host snails are localized around specific habitats on pasture, fencing off or otherwise hindering access to high-risk areas can reduce exposure (Knubben-Schweizer and Torgerson, 2015). Invisible or virtual fencing techniques allow for precise management of cattle pasture access and might be useful in this way (Bishop-Hurley et al., 2007; Goliński et al., 2022; Musinska et al., 2025). Their use in preventing *F. hepatica* exposure, however, has not been researched yet.

Rotational grazing is an approach that can further decrease the infection pressure for grazing animals (Sands et al., 2024; Vercruysse and Dorny, 1999; Voinot et al., 2020). Predictive models that incorporate both the parasitic and non-parasitic stages of the helminth's life cycle would be greatly beneficial for optimizing rotational grazing schemes. If these models could be used to predict when a pasture reaches a level of infective larval stages that likely causes disease, they could be particularly useful for practical implementation. This concept has been demonstrated by McFarland et al. (2022) in an experimental setting. They developed a contamination mapping model based on GLOWORM-FL for L3 stages of *O. ostertagia* on grazed pasture. The model demonstrated good agreement between predicted pasture contamination and pasture L3 counts. If pasture infectivity can be predicted using this or similar models in regular intervals during the grazing season, farmers could adjust grazing rotation to avoid high exposure. Similarly, the GLOWORM-FL-DV model displays promise in predicting the clinical onset and antibody levels of *D. viviparus* in grazing herds (McCarthy et al., 2022). Further development of this and other predictive risk mapping models, however, have not been reported. This indicates a clear gap in the development of preventive tools.

Co-grazing cattle with other grazing species has been suggested to reduce parasite burdens for cattle. Infective stages of a parasite ingested by animals that are not suitable hosts either die or establish at a lower numbers after ingestion (Rocha et al., 2008). Grazing cattle and sheep together has been studied as a method to reduce helminth burdens for sheep (Halvarsson et al., 2022; Mahieu and Aumont, 2009). *N. battus*

and *Haemonchus contortus* are known to cause significant disease in sheep. Although both can infect cattle (Rehbein et al., 2022), these helminths are neither clinically nor economically the most relevant parasites for cattle (Charlier et al., 2020). The same method could be applied inversely: Grazing sheep to reduce burdens of helminths relevant to cattle, but not harmful for sheep. However, Bam et al. (2022) found that pepsinogen levels in steers were higher in groups that sequentially grazed with lambs compared to groups that did not share pasture, indicating a higher level of infection. Mahieu and Aumont (2009) found that *Haemonchus* sp. were less abundant in lambs grazed alternately with heifers compared to controls that did not share pasture, but heifers had a higher abundance of *Haemonchus* sp. when sharing alternately with the lambs. This did not result in a significant reduction in growth for the heifers (Mahieu and Aumont, 2009). Burggraaf et al. (2009) have found that a rotational grazing system where sheep followed calves did not reduce the number of cattle parasite GIN L3 on pasture, even though sheep grazed closer to cattle fecal pats (and therefore might remove free-living cattle parasite GIN). So far, these results do not suggest a significant benefit to co-grazing for cattle. The influence of co-grazing on lungworm exposure has not been extensively researched. As many mammal species are suitable hosts for *F. hepatica*, co-grazing is not likely to reduce exposure for cattle. Co-grazing with different species requires more total land than just grazing the herd of cattle and requires a flock of another species. It also introduces an additional contamination risk for diseases that might be transmitted between cattle and other species.

Grazing management strategies require specific resources and infrastructure which might not be available to all farmers. Rotational grazing for example requires multiple fields for each subherd and additional fencing. Fencing off areas might restrict access of cattle to the habitat of intermediate host snails of *F. hepatica*, but may also hinder wildlife movement (Jakes et al., 2018). A late turnout will reduce the total time animals spent on pasture, which might affect eligibility of certain product certifications, such as organic farming (European Union, 2020). The main purpose of grazing is feeding cattle. Grazing management requires an integration between efficient grassland use and helminth infection pressure.

4.3. Decreasing infection pressure using preventive treatments

Preventive, group-wise anthelmintic treatment is frequently used as part of grazing management to prevent the development of disease in grazing animals (Takeuchi-Storm et al., 2019; Vande Velde et al., 2015; Vercruysse et al., 2018). Treatment to prevent disease will also prevent the excretion of free-living parasite stages, potentially preventing future disease. Risk assessment methods dependent on diagnostics detecting these excreted free-living stages will be harder to use, however. Preventive treatment can therefore lead to an underestimation of the actual helminth infection risk if a farm relies on this type of diagnostics. If treatment is highly efficacious and the life cycle of helminths is severely interrupted, this could lead to two further problems: a lack of refugia (Besier, 2012; Greer et al., 2020; Hodgkinson et al., 2019) and a reduced development of immunity, possibly due to reduced exposure (Claerebout et al., 1999). Preventive treatment should therefore only be applied when other preventive measures are not feasible and requires careful consideration to ensure that its use is aligned with AHS. It will have to provide more benefits in future disease prevention, resistance development and environmental risks imposed than the treatment itself imposes.

Preventive use of natural products with anthelmintic properties may prevent future disease or subclinical losses similar to conventional anthelmintics. In a recent review, studies investigating the anthelmintic effects of plant saponins and tannins as bioactive components have been summarized (Ramdani et al., 2023). These products reach a lower efficacy than anthelmintics (in most studies measured in FECRT or larval motility), which emphasizes their use in preventing disease rather than

curing it. Similarly, Hoste et al. (2012) reviewed the effects of bioactive nutraceuticals against nematodes. They also conclude that long-term use (at least several days) is needed to achieve an anthelmintic effect. Unfortunately, trials investigating the anthelmintic effect *in-vivo* are rarely performed in cattle, focusing on small ruminants instead (Ramdani et al., 2023). The practicality of implementing these products depends on the availability of the products, among other factors. Bark from coniferous trees, for example, contains tannins but has low digestibility. Implementing bark directly as feed is likely not feasible (Hoste et al., 2012). Natural products or fodder containing bioactive tannins or saponins could potentially represent a safer alternative to conventional anthelmintics in preventive use, if environmental hazards, risks and resistance development are lower or even absent (Hoste et al., 2012; Ramdani et al., 2023). If evidence indicates that natural anthelmintics do have an impact, their use should be subject to the same stewardship approach as conventional anthelmintics. Future research into the practicality, efficacy and possible detrimental impacts of using nutraceuticals and other bioactive components is required to provide a better indication of the role of these substances in a stewardship approach.

Nematocidal fungi have demonstrated efficacy in intervening in the parasite life cycle when used as a feed additive. *Duddingtonia flagrans* is perhaps the most well-known species: when excreted in the feces, the fungus traps nematode larvae (of GIN and lungworm), reducing their ability to spread to the environment (Fernández et al., 1999; Fernández et al., 2023; Ma et al., 2025; Zegbi et al., 2021). *Pochonia chlamydosporia* has demonstrated a similar effect against *F. hepatica* in cattle (Dias et al., 2012). Several other species have recently been reviewed by Mendoza-De Gives et al. (2022). They conclude that nematocidal fungi offer many advantages over anthelmintics. Availability of products containing nematocidal fungi appears to be limited so far to Brazil (Ma et al., 2025) and Australia (Bampidis et al., 2020).

4.4. Increasing resistance or resilience of animals

The risk of disease can also be reduced by improving resistance to infection or resilience to the consequences of infection. Improving adaptive immunity is one way to improve resistance (Gasbarre et al., 2001). Natural exposure to GIN and lungworm is considered an essential part of managing FSG calves, to allow them to develop immunity (Berk et al., 2016; Li et al., 2010; Vercruysse and Claerebout, 1997). This requires decreasing the helminth exposure of FSG calves to a level low enough to prevent disease, but high enough to allow immunity to develop. Animals that did not develop immunity because of limited exposure in their first grazing season remain susceptible to infection, possibly leading to disease by for instance *O. ostertagi* in subsequent seasons (Charlier et al., 2023; Ploeger et al., 1990). Estimating exposure using prediction models might aid in assessing optimal exposure for grazing animals (McFarland et al., 2022; Ravinet et al., 2014).

Assessment of the acquired immunity would be beneficial to guide further prevention, diagnostics and treatment. However, the possibilities to diagnose helminth immunity are limited. Blood pepsinogen levels in calves combined with GIN herd history have been suggested as a method to estimate immunity to *O. ostertagi* (Sabatini et al., 2023). BTM-ELISA results performed on herd-level indicating a historic infection with *O. ostertagi* can be relevant to assess subherd history of lactating animals. Similarly, herd-level BTM for *F. hepatica* can be used to assess historic infections. Subherds that have a history of infection or disease are more likely to have developed immunity, although this is far from guaranteed. The correlations between herd- and subherd-level diagnostics and acquired resistance or resilience require further investigation.

Vaccination is an alternative method to induce adaptive immunity (Claerebout and Geldhof, 2020; Matthews et al., 2016). Research into vaccines for GIN and *F. hepatica* has been ongoing for decades (Claerebout and Geldhof, 2020; Pal et al., 2024; Zwanenburg et al., 2023). One of the complicating factors hindering vaccine effectiveness

are the immunomodulatory effects of infecting parasites on the host (Freire and Capozzo, 2025). Especially chronic infections are reported to have stronger immunomodulatory effects. An integrated approach that detects infections early and intervenes when necessary to improve vaccine efficacy is suggested by Freire and Capozzo (2025). Vaccines for GIN and *F. hepatica* would be invaluable in an AHS approach. Although an effective vaccine for *D. viviparus* exists, it is not available in all countries where *D. viviparus* causes disease. The development of this vaccine requires infecting live calves with *D. viviparus* and harvesting the excreted larvae. These larvae are irradiated and dosed orally. Because effective vaccination requires modified live larvae the shelf-life of this vaccine is limited (Claerebout and Geldhof, 2020; McKeand, 2000). Infection of donor calves also raises ethical questions. An alternative with equal efficacy, without the need for donor calves is obviously preferable. The development of recombinant vaccines would therefore be of great value but is a major challenge in helminth disease (Claerebout and Geldhof, 2020). Research in this area continues to evolve (Golden et al., 2010; Sweers et al., 2026; Zwanenburg et al., 2023). These issues merit the development of alternative vaccines for *D. viviparus*, alongside vaccines for GIN and *F. hepatica*.

Breeding more resilient animals is another way to decrease the risk of disease. This approach has been successfully adopted for GIN in sheep (McManus et al., 2014). Evidence towards genetic or breed resilience to *F. hepatica* in cattle has also been reported (Hayward et al., 2021a; May et al., 2017; McClure et al., 2014). Hayward et al. (2021b) used slaughterhouse data to evaluate the effect of breed on the consequences of *F. hepatica* infections. They found that liver fibrosis scores, as a measure of high fluke burden, are not always correlated with age at slaughter. They hypothesize that either breed or environment play a role in the discrepancy between fibrosis scores and age at slaughter. If more knowledge on breed and/or genetic resistance or resilience would be available, selective breeding of dairy cattle could potentially be an effective tool to prevent disease (Hayward et al., 2021b; Kloosterman et al., 1992; Molento et al., 2009). As farmers will have to choose between many parameters influenced by genetic selection, more detailed knowledge on the potential benefits of selecting for genetic resistance/resilience to helminth infections is needed.

Nutrition can influence the host's resilience to helminth infections (Claerebout and Vercruysse, 2000). Supplemental feeding has been suggested to improve cattle immunity, resulting in a reduction in losses caused by nematodes (Coop and Holmes, 1996; Mansour et al., 1992; Van Houtert and Sykes, 1996). Trials comparing growth and production of grazing cattle exposed to natural infections show mixed results. Several experiments report poor protection in cattle fed additional roughage and/or concentrate (Dermauw et al., 2017; Larsson et al., 2006; Larsson et al., 2011). In sheep, nutritional supplementation has been researched extensively as a method to control helminth infections (Coop and Holmes, 1996; Sayers and Sweeney, 2005; Van Houtert and Sykes, 1996; Yoshihara et al., 2023). Protein supplementation is suggested to aid in immune development and resilience in sheep (López-Leyva et al., 2022; Louvandini et al., 2006). Research in cattle is more limited. Louvandini et al. (2002) found that a higher crude protein diet resulted in an increased resilience against disease caused by controlled *Haemonchus placei* exposure in calves. Infections with *O. ostertagi* have been demonstrated to significantly alter cattle nitrogen metabolism, suggesting a potential link of infection to protein supplementation (Randall and Gibbs, 1981). This has been researched in a smallholder setting, with clear benefit from protein supplementation (Garg et al., 2013). Urea-molasses blocks did improve the weight gain of calves compared to negative controls, but did not result in a reduced FEC of a field infection with multiple GIN species (Waruiru, 2004). Although the effects in sheep may be suggestive of a potential benefit for cattle, the addition of protein or sources of nitrogen to the diet of cattle to reduce the effects of helminth disease is debatable. In order to increase nutritional efficiency and reduce greenhouse gas emission a reduction in dietary protein is often discussed instead (Sinclair et al., 2014). Further

research into the effects of protein supplementation is needed to recommend it in an AHS approach, requiring additional balancing of the (environmental) benefits and costs. If evidence indicates it is beneficial towards development of immunity or resilience, selective usage for certain subherds might be the most effective application. This could for instance be using protein supplementation in subherds that are exposed to helminths to develop natural immunity, or in preparation for vaccination.

4.5. Integrating risk assessment and prevention

Information acquired from risk assessment can be used in preventive management to minimize negative consequences of helminth infections. Dependent on the risk found, this implementation differs. If pastures are found to pose high risk for infection, these pastures can be used for silage, instead of grazing. If a subherd has grazed on a pasture that turned out to have a high infection pressure, these animals should be monitored more closely and possibly selected for diagnostic follow-up (see step 3).

5. Step 3: diagnostics

The diagnostic tools available for GIN, lungworm and liver fluke have been summarized and reviewed by [Charlier et al. \(2023\)](#). Herd-level diagnostics have been discussed in step 1. This section will discuss diagnostics on the subherd- (groups of animals) and individual animal-level. Diagnostics on both the subherd- and the animal-level can be used to determine which animals would benefit from treatment. Diagnostic tools at all levels can be used to provide input in risk assessment and to evaluate preventive measures. Finally, diagnostic tools can be used to determine and monitor anthelmintic resistance, which asks for specific attention from the perspective of AHS.

This paragraph aims to describe practical considerations with the implementation of diagnostics. The inherent sensitivity and specificity of diagnostics cannot be changed. By using diagnostics on a subherd level, the prevalence of disease in that subherd can be estimated. Likewise, if risk assessment indicated that certain subherds have a high risk of disease (e.g., by grazing youngstock on high-risk pastures), the expected prevalence is higher. This influences the accuracy of diagnostics and can be used to optimize efficient diagnostic use.

To determine which animals benefit from treatment, both diagnostics of infection and diagnostics of disease are important. Diagnostics can be based on pathophysiology, immunology, parasitology, milk production, growth and behavior ([Charlier et al., 2023](#)). Pathophysiological or production parameters seem promising to diagnose subtle disease symptoms and subclinical disease. Pathophysiological and behavioral parameters are intricately linked to disease. Immunological or parasitological parameters are linked to infection, but if animals are resilient to infection, this might result in positive diagnostic results without disease being present. Diagnostics such as those based on weight gain or diarrhea score offer immediate results. However, as weight gain reduction or diarrhea can be caused by multiple factors, diagnosis is not always related to helminth disease. Furthermore, disease caused by helminth infections is mostly subclinical, using clinical diagnostics exclusively is currently not feasible ([Charlier et al., 2023](#)). By combining parasitological and/or immunological diagnostics with pathophysiological diagnostics, both disease and the potential helminth cause can be diagnosed.

5.1. Subherd-level diagnostics

Based on risk assessment, specific diagnostics can be applied at the subherd-level, to diagnose the occurrence of disease. Certain subherds are more susceptible to disease from specific helminths than others. For example, an age-linked resistance was found after nine months for *C. oncophora* in ([Kloosterman et al., 1991](#)). Although this might not be

the case in every grazing condition, diagnosing *C. oncophora* in cattle where this age-linked resistance is likely to develop is of limited added value. For *O. ostertagi*, resistance is built up by exposure during the first grazing season which can result in immune or highly tolerant adult animals ([Taylor, 2012](#)). Measuring resistance or resilience to helminths would be of great value in the creation of subherds with a similar risk of disease and is discussed further in paragraph 2.4.

Diagnostics at the subherd level can be used to identify subherds that contain animals that are likely to benefit from treatment. Direct detection of current helminth infections can be done through parasitological diagnostics such as FEC, *F. hepatica* coproantigens or larval counts on a representative selection of animals in a subherd ([Charlier et al., 2023](#); [Kenyon and Jackson, 2012](#)). For FEC, a sample of 10 animals or 10% of the subherd is suggested ([Sabatini et al., 2023](#)). Subherd-level diagnostics are inherently subject to uncertainty, as diagnostic outcomes may vary between individuals. If using a sample of 10% of the herd is used to determine treatment for the entire herd, 90% of animals will have an unknown diagnostic outcome. Depending on the prevalence within the subherd and the diagnostic test used, this will result in a proportion of animals being misclassified. Following subherd-level diagnostics with subsequent animal-level diagnostics in subherds where a benefit of treatment was found will likely reduce the number misclassifications. This approach also reduces the number of diagnostics needed compared to a farm-wide TST approach. For example, using pepsinogen on a sample of FSG calves in a subherd gives insight in the severity of disease caused by *O. ostertagi* of that subherd ([Charlier et al., 2014b](#); [Charlier et al., 2023](#); [Kenyon and Jackson, 2012](#); [Sabatini et al., 2023](#)). Subsequent weight-gain measurements when disease or infection is present can then be used to diagnose which animals within the subherd are affected. If the severity of disease is very low or absent, further steps might not be necessary.

5.2. Animal-level diagnostics

Animal-level diagnostics serve the purpose of diagnosing disease and selecting animals that benefit from treatment. If diagnostics are applied at the animal level, the number of unjustified treatments will be minimized. Diagnosing disease instead of merely the presence of infection also helps in creating a refugium of helminths. Animals without clinical or subclinical signs of helminth infections are either not infected or resilient to disease, and therefore do not require treatment ([Kenyon and Jackson, 2012](#)). Resilient animals may still excrete infective helminth stages; preventive measures should therefore still be considered for pastures grazed by these animals.

Following subherd- by animal-level diagnosis obviously requires two separate animal handling events for sampling, followed by lab processing. If animal-level sampling does not give direct results, a third handling event is needed for treatment. This complexity could be reduced by using animal-level diagnostic with immediate results on farm. Clinical diagnostic techniques or cow-side tests are suitable to reduce this complexity because of their direct results.

Although clinical diagnosis of helminth disease is difficult, evidence for effective use of clinical diagnosis in TST programs exists. FEC on a sample of FSG dairy calves, followed by weight-gain based diagnosis can be used to select animals for TST for GIN ([Höglund et al., 2013](#); [Jackson et al., 2017](#); [Merlin et al., 2017](#); [Merlin et al., 2018](#); [O'Shaughnessy et al., 2014](#)). As helminths cause a reduction in weight gain, this approach can detect weight gain reduction when FSG calves are infected by multiple parasites ([Charlier et al., 2023](#)). This method allows for direct selection of animals to be treated. However, many other diseases cause reduced weight gain in growing animals, and therefore this method is not very specific. This can be partly alleviated by using the staged approach described above: where subherd-level diagnostics are used to select subherds that are subsequently further investigated using animal-level diagnostics.

Development of additional animal-level diagnostic tools can improve

the possibility and feasibility of TST. On-farm or cow-side diagnostics are rare in the diagnosis of helminth disease, even though they could reduce the labor involved by requiring one handling event for both diagnosis and treatment. The FECPAK is the only GIN FEC tool currently widely available (Sabatini et al., 2023). The FAMACHA® has been suggested as a tool for diagnosing *F. hepatica* (Olah et al., 2015) in sheep but has not been studied for cattle. The use of ultrasound to diagnose *F. hepatica* and associated findings has been described (Arsenopoulos et al., 2017; Corda et al., 2022; El Damaty et al., 2018; Richter et al., 1999). The test characteristics in field conditions on farms with a varying prevalence are currently unknown. More research is needed to correlate this to parameters of disease. Although clinical signs of helminth infections are subtle, further development of clinical diagnostics in helminth disease could be a useful approach because they provide direct results and are (usually) quick and easy to perform. The FAMACHA provides an excellent example of a practical clinical diagnostic in sheep. Similar practical clinical diagnostics would be invaluable for individual and direct treatment of cattle.

5.3. Anthelmintic resistance diagnostics

Monitoring resistance is an essential part of AHS, as it gives information that is helpful to prevent further development of anthelmintic resistance. Information obtained from anthelmintic resistance diagnostics can be used to adapt treatment strategies and may also contribute to prevent the introduction of resistance alleles into a herd, for example by screening purchased cattle before introduction in a herd (Fissiha and Kinde, 2021). Diagnosing anthelmintic resistance, however, is not straightforward. Several methods of diagnosing resistance have been developed and will be discussed here.

A first impression of effects of treatment can be gained by using fecal diagnostics (FEC or FLC) before and after treatment using FECRT. If treatment failure is found in this way, it could be due to anthelmintic resistance, but also improper storage of anthelmintic, improper dosing, inaccurate weight estimations or measurements, or improper timing of diagnostics (Antonopoulos et al., 2024; Kaplan et al., 2023). When treatment failure is found, the cause should be determined by reviewing these treatment conditions again.

Diagnosing anthelmintic resistance is complex as it is species- and drug-specific. Currently there are no methods available to propagate (the full life cycle) of helminths *in vitro*, which hinders a straightforward diagnosis of anthelmintic resistance by measuring inhibition of this life cycle (Šlapeta et al., 2024). The currently recommended *in vivo* method to measure anthelmintic resistance in ruminants is the FEC Reduction Test (FECRT) (Kaplan et al., 2023). This method uses a reduction in FEC at a standardized time after a standardized anthelmintic treatment to determine treatment effect and thus anthelmintic efficacy or the lack thereof, and possibly resistance.

Further development of next-generation sequencing (NGS) could result in a method to diagnose and monitor anthelmintic resistance in specific cases. The use of genetic markers of specific resistance alleles from eggs or larvae has recently been reviewed by Antonopoulos et al. (2024). It requires the development of genetic markers for the relevant alleles, which is still incomplete. Genetic markers for resistance against benzimidazoles have been described and used in large scale screening (Melville et al., 2020; Von Samson-Himmelstjerna et al., 2007). Development of markers for resistance of macrocyclic lactones is currently underway (Doyle et al., 2022). NGS could use these markers in the diagnosis and monitoring of resistance. This would provide great benefit in the advising of the anthelmintic to be used in an AHS approach. Although costly for individual sampling, scaling might make this more accessible for practical applications (Antonopoulos et al., 2024; Francis et al., 2024).

5.4. Deciding on treatment

Ideally, the decision to treat should be guided by a clear balance between the benefits of treatment from the perspective of health, welfare and production and the associated impact on resistance development, environmental hazard and financial costs. With every treatment, the benefits should outweigh the drawbacks. This balance cannot be clearly quantified, however. We argue that when treating diseased animals, this benefit of treatment is always present. In subclinical cases, AHS can be achieved by reducing the number of treatments needed and maximizing the accuracy of treatment. In many situations, individual diagnostics have added value to maximize this accuracy. However, compared to TT, TST has disadvantages such as financial costs and required labor. A TST protocol also bears the risk of disease development due to false negative diagnostic results. For example: O'Shaughnessy et al. (2015) applied a TST protocol for deciding on treatment against GIN and *D. viviparus*. They compared blanket treatment with TST based on Baermann, FEC and pepsinogen. Calves in the TST group developed clinical signs of *D. viviparus* infection. They concluded their TST protocol is not suitable to prevent disease in animals with a high burden of lungworm. This shows improper TST protocols can increase the risk of disease. If individual diagnostics results in delayed treatment, causing more clinical disease as exemplified by O'Shaughnessy et al. (2015), TT is preferred. We think that in cases where the prevalence within subherds is low or unknown, the benefits of an approach where subherd diagnostics are followed by individual diagnostics outweigh the drawbacks. If, however, the prevalence within subherds is high, the benefits of treatment decisions on a subherd level may outweigh the drawbacks.

6. Step 4: treatment

Anthelmintics are an effective way to treat helminth infections. However, anthelmintic use is a risk for the selection of anthelmintic resistance and potential hazard to the environment (Charlier et al., 2024; Kaplan et al., 2023; Vercruyse et al., 2018; Vokrál et al., 2023). The choice of an anthelmintic product influences the expected efficacy, resistance development and environmental hazard. This paragraph describes and discusses factors related to selection of an anthelmintic which are relevant for AHS.

When selecting anthelmintic drugs for treatment the following factors need to be considered:

- Indication and working spectrum
- Resistance status
- Treatment method
- Environmental burden
- Availability
- Price

Of these six factors, we will not discuss availability and price. Availability varies greatly per country and is influenced by commercial, strategic, and regulatory considerations of the producing companies, which fall outside the scope of this paper. Cost of anthelmintics used is obviously considered important in farm management decisions. However, these costs are not discussed in this paper as it requires a quantitative modelled comparison, which cannot yet be made. We will also discuss the use of natural products as possible alternatives to standard anthelmintics. Table 3 summarizes available information on the indication, working spectrum and treatment method for several anthelmintic classes registered in Europe in the veterinary medicine database (European Medicines Agency, 2026).

6.1. Indication and spectrum of activity

The indication and working spectrum of a product can be derived from package inserts accompanying the product. These leaflets have

Table 3

Anthelmintics registered for cattle in the European Union. Source: Union Product Database (European Medicines Agency, 2026).

Substance	Substance class	Indication	Spectrum	Treatment method
Abamectin	Macrocyclic lactone	GIN, lungworm, various ectoparasites	Broad	Feed ^a , Pour-on ^b
Albendazole	Benzimidazole	GIN, lungworm, liver fluke (adult) ^c , tapeworm	Broad	Drench
Clorsulon ^d	Aminobenzene sulfonamides	Liver fluke (adult)	Narrow	Injection
Closantel	Salicylanilides	Liver fluke (>7 weeks)	Narrow	Drench, injection, pour-on
Doramectin	Macrocyclic lactone	GIN, lungworm, various ectoparasites	Broad	Injection, Pour-on
Eprinomectin	Macrocyclic lactones	GIN, lungworm, various ectoparasites	Broad	Injection, Pour-on
Febantel ^e	Benzimidazole	GIN, lungworm	Broad	In-feed
Fenbendazole	Benzimidazole	GIN, lungworm	Broad	Drench, In-Feed, bolus
Ivermectin	Macrocyclic lactone	GIN, lungworm, various ectoparasites	Broad	Injection, Pour-on
Levamisole	Imidazothiazole	GIN, lungworm	Broad	Drench, injection, Pour-on
Moxidectin	Macrocyclic lactone	GIN, lungworm, various ectoparasites	Broad	Injection, Pour-on
Nitroxinil	Phenol	Liver fluke (adult)	Narrow	Injection
Oxfendazole	Benzimidazole	GIN, lungworm	Broad	Drench, in-feed, bolus
Oxyclozanide	Salicylanilides	Liver fluke (adult), tapeworm	Narrow	Drench
Rafoxanide	Salicylanilides	Liver fluke (>8 weeks)	Narrow	Drench
Thiabendazole ^f	Benzimidazoles	GIN, lungworm	Broad	Drench
Triclabendazole	Benzimidazoles	Liver fluke (all stages)	Narrow	Drench ^g , Pour-on ^h

^a Registered only in Romania and Bulgaria

^b Registered only in Ireland

^c A higher dose is commonly recommended by manufacturers to achieve efficacy for adult liver flukes.

^d All registered products containing clorsulon also contain ivermectin.

^e Converted to fenbendazole after absorption.

^f Registered only in Greece.

^g Drench formulation not for use within 45 days or 6 weeks before calving, or during lactation.

^h Pour-on formulation only in combination with moxidectin. Only for use in animals not intended for dairy production.

different names and requirements by the respective legislative body in a country or region. As an example, in the EU, the European Medicines Agency (EMA) produces Summaries of Product Characteristics (SPC) for veterinary medicinal products. Information on the efficacy of products can be derived from these SPC's, as sufficient evidence of efficacy must be provided for EMA registration. Intercontinentally, the International Cooperation on Harmonization of Technical Requirements for Registration of Veterinary Medicinal Products (VICH) offers guidelines for

veterinary pharmaceuticals that are recognized by the EU, the USA and Japan, among other nations. The VICH has provided guidelines regarding the label claims for veterinary products in general (VICH, 2024a) and specific guidelines for determining efficacy of anthelmintics in cattle (VICH, 2024b).

6.1.1. Conventional anthelmintics

Most anthelmintics with efficacy against GIN and lungworm are broad spectrum. Narrow spectrum anthelmintics are mostly aimed towards mature liver flukes. Only one active substance is available for liver flukes of all stages of the definitive host: triclabendazole. Macrocyclic lactones are effective against ectoparasites as well as against GIN and lungworm.

It stands to reason that a broader working spectrum of anthelmintic causes resistance in a broader population of helminths. In antimicrobial stewardship, a narrow working spectrum is advocated to reduce potential resistance development in healthy bacteriological flora in animals (Lloyd and Page, 2018). Helminths, however, differ significantly from bacteria because there is no commensal helminth flora in animals. Some arguments for antimicrobial stewardship therefore seem not to apply to AHS. Effective treatment, however, should include only the targeted helminth, because a broader working spectrum is neither necessary nor desirable. Residues of products with a broader working spectrum are likely a hazard to more non-target organisms in the environment. Because most anthelmintic products registered for cattle are considered broad-spectrum (Fissiha and Kinde, 2021; Sutherland and Leathwick, 2011), the distinction between broad- and narrow-spectrum does not appear useful to guide product selection. As endectocides, macrocyclic lactones stand out with an even broader working spectrum and persistence (see paragraph 4.4). They are therefore likely a higher hazard and risk to non-target species. An AHS approach requires that these compounds are only used when no other suitable alternative compounds are available. Although the environmental hazards of many anthelmintic products have been researched, practical guidance towards selecting a product to use is not available. A practical decision support tool comparing the environmental impact and including a weighing of resistance development of products with the same indication would be valuable for veterinarians and farmers.

Combined anthelmintic products with two or more compounds with a different mode of action but an overlap in spectrum have been suggested as a method to reduce anthelmintic resistance development (Baiak et al., 2018; Bartram et al., 2012; Fissiha and Kinde, 2021; Šlapeta et al., 2024; Sutherland and Leathwick, 2011). The rationale behind combination products is that helminths surviving the effect of one compound are killed by the exposure to the other compound. Effective reduction of resistance development does depend on several criteria of the combination used (Bartram et al., 2012; Leathwick, 2012; Leathwick and Besier, 2014; Leathwick and Luo, 2017; Leathwick et al., 2012). Criteria have been derived from protective measures to reduce pesticide resistance development in crops and adjusted to resistance development in helminths in sheep (Bartram et al., 2012). These criteria should be considered when developing a combination product for cattle, but also when applying a product on farm.

For appropriate use of combination products on farms, knowledge on the presence of resistance alleles is necessary, as well as insight in coinfections. As the dose of each individual compound should be high enough to reach high individual efficacy (Bartram et al., 2012; Leathwick and Besier, 2014), the total amount of anthelmintics used is higher than with a single compound, with likely a higher environmental risk. The EMA considers the risk of two compounds as additive, while the acceptable threshold of risk remains the same (European Medicines Agency, 2009). Published reports on the actual environmental effects of combination products are rare. Although combination products are potentially an effective method to delay resistance development, using this method in an AHS approach requires careful balancing of the benefits and costs. Due to the lack of data on the protective effects on

resistance development, resistance status on farms and environmental effects of combination products, this balance cannot currently be made.

Registration of combination products combining two or more anthelmintics with the same working spectrum is rare. In the US and Australia, a combination product containing doramectin and levamisole is registered for use in cattle younger than 20 months (Valcor® (Website) and Dectomax-V® (Website), respectively). Currently, all combination products registered for use in the EU are combinations between a narrow spectrum flukicide and a broad-spectrum anthelmintic against GIN and lungworm (European Medicines Agency, 2026). Unless the aim of treatment is to treat both adult liver flukes and GIN or lungworm, these combinations should not be used. Combinations of anthelmintics should not be used unless registered as a combination product, as the environmental risks and benefits to treatment have not been approved.

6.1.2. Natural products with anthelmintic properties

Although anthelmintics are an understandable and effective choice for most indications, other options are available. Some examples: A recent review by Ramdani et al. (2023) summarized the research into essential oils, polyphenols (such as tannins) and their anthelmintic effects. Tannins from legumes have been studied in sheep and goats for their anthelmintic properties (Hoste et al., 2012). Research in calves performed by Desrues et al. (2017; 2016) on the infection burden of GIN suggests a strong effect of pelleted sainfoin (*Onobrychis vicifolia*) on the reduction of the eggs of *O. ostertagi*. Forage chicory (*Cichorium intybus*) has similarly been demonstrated to reduce the burden of *O. ostertagi* in calves when added to the diet (Peña-Espinoza et al., 2016).

Using natural products instead of anthelmintics for treating diseased animals requires careful consideration. Registration of natural products for a treatment indication requires the same standards of evidence as conventional anthelmintics. If a natural product has attained a registration with indication for helminth disease, efficacy can be assumed. In this case, natural products are preferred if there is no evidence of resistance development or environmental burden. If natural products are not registered, treatment with natural products cannot be assumed to cure disease and curative use does not fit in an AHS approach. The VICH guidelines indicate that a product can be labeled as an “anthelmintic” with an efficacy of at least 90% (VICH, 2024a). Given the often lower efficacy of natural products, it is unlikely that these products can attain this labeling status.

6.2. Resistance status

Using information on resistance status and resistance development in the selection of anthelmintics to be used on farm is essential for an AHS approach. Information on resistance parameters is mostly available from scientific studies. Baiak et al. (2018) reviewed the lack of efficacy of anthelmintics in beef and dairy cattle worldwide. They reported prevalences of reviewed number of treatments with reduced efficacy due to anthelmintic resistance on a continent-level. They did not separate results from dairy and beef cattle, which hinders a straightforward conclusion for either one farming method. Rose Vineer et al. (2020) created an open database on anthelmintic resistance in ruminants in Europe and systematically reviewed this database. In their analysis, they demonstrate the difficulty of estimating an actual prevalence of anthelmintic resistance due to the scarcity of data. Their database includes the possibility to record farming method, but not all entries for cattle the farming method on record. Their weighted prevalences for anthelmintic resistance in cattle in European countries are necessarily based on very few reports in decades, over wide areas. In many cases, the prevalence of resistance for specific anthelmintic groups for cattle cannot be estimated because no reports are available. Incidental scientific reports on anthelmintic resistance are likely to be of high quality. If they follow the guidelines of the WAAVP (Kaplan et al., 2023), these reports yield reliable, internationally comparable results. However,

relying on scientific publications results in a bias towards cases where resistance has been found (Rose Vineer et al., 2020). Furthermore, it results in a fragmented and infrequently updated overview of resistance status. Care should be taken when interpreting data from cattle in general, without the recorded farming method.

Translating these overviews to farm-level guidance is difficult. It requires assuming that the reported AR prevalence is accurate for the AR status on farm. If the AR prevalence is estimated infrequently on a small number of farms, this may not be the case. This emphasizes the need for routine recording of anthelmintic resistance, including information on farming methods. Even if the standards required for scientific publication are not met by a system recording treatment failure, the applicability for on-farm guidance can be vastly improved (Holzhauer et al., 2017).

Although specific guidance is hardly attainable using reviews, trends and patterns can provide guidance for general management practices. For instance, Baiak et al. (2018) found that oral applications have a higher efficacy than injection or pour-on methods. They also found a higher efficacy for combination treatments compared to single-compound treatments.

6.3. Treatment method

The method of treatment, including the route of administration, determines the efficacy and the ease of treatment, but also the speed of resistance development and the extent of the environmental burden. Anthelmintic treatment methods consist of injectable formulations, orally administered tablets or boluses, pour-on formulations, orally administered fluids (drench) or in-feed products.

Several intra-ruminal pulsatile release bolus products with oxfendazole are registered in Europe. These devices release five equal treatments at timed intervals and offer a protective cover of anthelmintics for approximately 130 days. Although this is very convenient when grazing cattle are out of reach for prolonged periods of time, repeated dosing means repeated treatment without diagnosis, with the associated effects on anthelmintic resistance and environmental risk. Thus, pulsatile release boluses are not to be advocated from the perspective of AHS and should only be used in exceptional cases.

Pour-on formulations are easy to use but pose a higher risk of contaminating the environment than oral or parenteral formulations (Finch et al., 2020; Laffont et al., 2001; Laffont et al., 2003). Pour-on formulations for ivermectin have been demonstrated to largely rely on grooming behavior of calves and subsequent oral absorption to reach effective blood plasma levels (Laffont et al., 2001; Laffont et al., 2003; Sutherland and Leathwick, 2011). A lower efficacy of pour-on products compared to oral products has been found by Baiak et al. (2018). In a controlled study, allowing or disallowing allo- and self-grooming resulted in a high variability in systemic availability of pour-on ivermectin between calves and when repeated within the same calf (Laffont et al., 2003). This indicates that controlled delivery of a dose is less accurate when using pour-on formulations. Treatment methods that allow for a higher availability of active substances need a lower dose, improving accuracy and reducing spillover effects (Baiak et al., 2018; Leathwick and Luo, 2017). Pour-on formulations therefore do not fit into an AHS approach.

AHS requires responsible administration of the chosen anthelmintics. This requires strict adherence to the method of administration as described in the SPC. Correctly estimating weight is essential for accurate dosing. Underdosing is often linked to anthelmintic resistance development (Edwards et al., 1986; Fissiha and Kinde, 2021; Kellerová et al., 2020), while overdosing results in an unnecessarily high anthelmintic use. Visually estimating weights has been seen to lead to underdosing in cattle (Van Dijk et al., 2015). Weighing methods such as weight tapes also carry a risk of misjudging the weight of cattle (Wangchuk et al., 2018). Weight bridges can be assumed to have the highest accuracy and can also be used to diagnose reduced weight gain

(see paragraph 3.2: Animal-level diagnostics).

6.4. Environmental hazards & risks of treatment

After treatment, residues pose a risk for the ecosystem either through excretions, or by spillover when using pour-on formulations (Lumaret and Errouissi, 2002; Madsen et al., 1988; McKellar, 1997). Many authors have investigated the hazards of anthelmintic residues on arthropods and free-living nematodes (Finch et al., 2020; Madsen et al., 1988; Madsen et al., 1990; McKellar, 1997), plants (Iglesias et al., 2018; Navrátilová et al., 2020; Navrátilová et al., 2023) and symbiotic fungi (Gkimprizi et al., 2023; Parniske, 2008). A single treatment can have a prolonged effect on the environment (Navrátilová et al., 2021; Navrátilová et al., 2023). Ivermectin, for example, has a high persistence in soil, potentially causing a prolonged burden (Lewis et al., 2016; Sands and Noll, 2022; Shija, 2025).

Registration of an anthelmintic as a veterinary product most often requires an environmental risk assessment. The specific assessment method used varies between countries and continents. The VICH offers guidelines for an Environmental Impact Assessment (VICH, 2000, 2004). The EU has adopted these guidelines (EU, 2018), and EMA assesses the dossiers of applicant products according to these guidelines (European Medicines Agency (n.d.)). If the risk is deemed unacceptable, the applicant can provide specific risk mitigation measures. This is the case for ivermectin pour-on formulations in the EMA database, for example: The SPCs for these products mention that cattle should not be allowed in the rain for two hours after treatment (European Medicines Agency, 2026). Not following the SPC guidelines will lead to an increase in the environmental risk and does not fit in an AHS approach. The registration procedure described above uses predicted environmental concentrations and a no effect concentration. Whether up-to-date scientific ecotoxicological standards are used is unknown. Observed environmental concentrations from field studies are rare in scientific literature. These might be part of an application dossier, but in most cases, this is not publicly available. This could potentially introduce an uncertainty on the actual effects of anthelmintics, especially if products have held a registration for a long time. Studies investigating field concentrations of anthelmintics and their effects could alleviate this uncertainty. Meanwhile, an AHS approach should consider preferring anthelmintics with a lower risk. Practically, this means avoiding pour-on formulations and macrocyclic lactones whenever feasible and strictly following the mitigation procedures mentioned in the SPC.

7. Discussion

The aim of this paper was twofold: to develop a stepwise approach for farmers and veterinarians to practice AHS on dairy farms; and to identify gaps in the practical implementation and scientific knowledge of the different steps within AHS. In this paper we propose an integrated four-step approach aimed at describing the theoretical goals of AHS as a feasible reality and transferring them into practically implementable guidelines. Similar guidelines have been developed and reviewed for helminth management in horses (Nielsen et al., 2025). Helminth infections and their consequences, the apparent current reliance on anthelmintics, and the wider system-level consequences of anthelmintic use constitute what can be described as a wicked problem: complex, interdependent dilemmas that cannot be addressed by a single discipline, intervention, or technical fix. Instead, they require an integrated and multidisciplinary approach that acknowledges the innate biological complexity, environmental sustainability and the interests of animals, farmers and society.

Reviewing the current knowledge gaps towards implementation revealed there are gaps in every step in the four-step approach, both in research and in implementation. Nevertheless, with the currently available tools, implementation of the four-step approach is feasible for farmers and veterinarians, adding to a more sustainable approach of the

management of helminth infections through AHS.

Although a substantial portion of literature and examples cited in this review reflect the European situation, the aim of this review is to discuss the principles of AHS in a global setting. One of the foundational aspects of the AHS approach is the adaptability to different situations. The variation of farming methods requires a flexible and adaptable system. Applying the four steps of AHS might require significant adaptation in different settings of farming, but the basics and the rationale remain the same.

7.1. Developing a four-step approach

The goals of AHS as described in our definition are hardly novel. Science has long advocated the prudent use of anthelmintics, especially regarding resistance development. Although excellent diagnostic and preventive tools have been developed, helminth management and anthelmintic use in practice is often not sustainable. A shift in helminth management towards strategies that align with AHS is required, supporting optimal decision-making by farmers and veterinarians. The four-step approach described in this paper attempts to do exactly that: making the complexity of helminth infections more manageable and offer a stepwise plan to realize AHS.

The four-step approach shows the possible use of many different tools in each of the steps. This offers farmers and veterinarians flexibility to use tools that are available and feasible in their specific farm situation. The “Basket of options” as described by Charlier et al. (2024) is an excellent initiative summarizing and sharing the tools available for both veterinarians and farmers. These tools can be implemented along the lines of the four-step approach.

As described, many tools are imperfect, with clear drawbacks and negative consequences. Using imperfect tools synergistically in the integrated four step approach, however, may allow for compensation of the shortcomings of these tools in the other steps in the process. The low sensitivity of weight gain measures on an individual level can for instance be compensated by using them in a subherd where the prevalence of disease is higher. If disease has been positively diagnosed in a subherd, the prevalence is likely higher than if disease was negatively diagnosed in the subherd. By combining weight gain measures with a parasitological sample test on subherd level, the attribution of the found growth loss to a helminth infection becomes much more likely. Combining imperfect methods within and between the four steps increases the overall benefit of each of them to AHS and supports its practical applicability.

7.2. Gaps in scientific knowledge

In the first step of AHS there is a clear need for practical assessment tools for the risk of GIN and *D. viviparus*. Risk assessment for *F. hepatica* is much more developed, although the developed tools are not always available in practice. Further development of BTM-analysis can improve its value (Nijhuis et al., 2026). More quantitative details of a *F. hepatica* BTM-ELISA would for instance increase its value as a quantitative measure of infection (Byrne et al., 2018; Sekiya et al., 2013; Takeuchi-Storm et al., 2021).

Knowledge on prevention of helminth disease can be improved by researching pasture management- and grazing strategies. Controlled studies on the efficacy of preventive management measures are desirable but very complex. Preventive treatment with natural products with anthelmintic properties may have an added value in reducing infection pressure. Because they rarely result in complete eradication, immunity development is likely maintained. This should be studied and implemented further. Development of vaccines for *F. hepatica* and GIN is considered invaluable (Ahumada et al., 2026; Chansap et al., 2025; Sweers et al., 2026), but vaccines for helminths are notoriously complex to develop. Although the effects of a field infection with *D. viviparus* can be effectively controlled through vaccination with live-attenuated

lungworm larvae, this approach still relies on the production and use of live parasites. Therefore, there is a strong need for alternative vaccines that do not have this dependency (Claerebout and Geldhof, 2020).

Also in the third step, diagnostics, several gaps exist. Previous authors have discussed the need for thresholds for subclinical disease in all helminth diagnostics (Charlier et al., 2023). Additionally, there is a need for diagnostics – preferably quantitatively – correlated to disease, to select animals for treatment based on expected benefit. Pathophysiological tests are promising in this regard. Cow-side tests would also be beneficial to diagnose affected individual animals, in order to be able to treat them in the same handling event. Interpretation of currently available tests could be improved by researching correlations with disease. Further development of BTM-ELISA interpretation could be a great aid in selecting subherds for preventive management or further diagnostics. Finally, there is a clear need for methods of diagnosing anthelmintic resistance, such as is being developed with NGS.

The knowledge on anthelmintic treatment as described in the fourth step also contains gaps. More information is needed on the consequences of specific anthelmintic treatments on the environment. Practical guidance for selecting anthelmintics would be greatly beneficial to optimize anthelmintic choices. A decision support tool based on the six factors we described would be of added value to select an optimal product for anthelmintic treatment. More information on the effects of different anthelmintics on resistance development and environmental burden is needed to allow for a responsible selection of anthelmintics.

As farmers advised by veterinarians are making the actual decisions on farm management, their perception towards helminth management is a crucial factor in the application of AHS. Perception towards implementing diagnostics (Vande Velde et al., 2015, 2023) and other sustainable control approaches (Vande Velde et al., 2018) has been researched. Research into the drivers and barriers underlying the decision to treat should be investigated to further implement AHS and can be used for more effective communication towards farmers and veterinarians.

7.3. Gaps in practical implementation

In the first AHS step, risk assessment, clear implementation gaps are demonstrated by the limited reported use of prediction models. The Ollerenshaw index is the only method reported to be implemented at this time. For other prediction models, it is unknown whether the actual gap lies in scientific knowledge or in practical usability and implementation. Regardless, there is potential in the currently unused models.

In scientific literature little is reported on the implementation of prevention methods for helminths in practice. It would be valuable to publish descriptive inventory studies on helminth management in different regions, to compare common preventive strategies and their effects.

Several gaps in the implementation of diagnostics aligned with AHS are present. Based on a risk-based approach, the value of each diagnostic method can be optimized (Ravinet et al., 2017). AHS requires diagnostics to detect the potential benefit of treatment. This requires critical interpretation of diagnostic results, especially when diagnosing at the herd- or subherd-level. For example, in BTM-ELISA, a correlation between *O. ostertagi* antibody Optical Density Rate (ODR) and low milk yield has been described (Charlier et al., 2014b; Forbes et al., 2008), leading to the development of a guide chart (Sabatini et al., 2023). In this example, however, the treatment effect remained ambiguous, even when all lactating animals were treated (Charlier et al., 2010b). This exemplifies the discrepancy between diagnosing a benefit of treatment and (a history of) an infection.

Currently, dairy cattle weighing is not done routinely on most farms. Routine weight measuring would greatly improve the insight into growth of youngstock on farms, which is one of the most relevant parameters causing economic loss due to helminth disease (Charlier et al., 2020). More importantly, routine weight measuring in youngstock

would allow earlier detection of chronic diseases other than helminth infections, improving animal welfare as well as future production. Finally, weight measurements would allow for accurate dosing, as estimates, even performed with measuring tapes, demonstrate inaccuracy (Wangchuk et al., 2018).

Guidelines for (field) studies into anthelmintic efficacy using FECRT are published by the WAAVP (Kaplan et al., 2023). Despite the availability of these guidelines, it remains unclear to what extent routine diagnostics for anthelmintic resistance are performed and/or reported internationally. Consequently, the implementation and systematic recording of FECRT results represent an important gap in resistance surveillance that could be addressed. Although meeting all WAAVP criteria may be challenging in routine veterinary practice, FECRT can still provide valuable information on treatment efficacy. Even when not all guideline criteria are fulfilled, recording FECRT results and documenting suspected treatment failure is both feasible and valuable for improving resistance monitoring.

Finally, a successful implementation of AHS would, in our opinion, be greatly helped by a benchmarking system for anthelmintic usage. Without a baseline and benchmarking, a change in anthelmintic usage cannot be monitored, and the effect of any change in management on a farm level cannot be evaluated.

7.4. From theory to practice

Applied research, as described in this paper, should focus on supplying farmers and veterinarians with practical tools to improve management in each of the steps of AHS. While developing improvements to existing tools and novel tools for each step, imperfect but available tools can be used. The AHS approach along the four steps can, in our opinion, be implemented to improve helminth management on every dairy farm. Each of the four steps allows for a tailor-made approach using the tools available and feasible on each specific dairy farm. The idea is to give specific attention to all four steps of AHS, integrate them, and make informed, evidence-based decisions in helminth management. A farmer should ideally work with their veterinarian and draw up such an approach, consisting of check- and action-lists developed for the local situation.

Ultimately, every management decision is up to the farmer and veterinarian. Deciding to use any tool in the four steps requires a balance of the perceived drawbacks and advantages of the tool in question. Evidence-based veterinary medicine should guide this perception. The risk of disease or subclinical losses accepted by farmers and veterinarians determines the level of investment a farmer makes in all four steps. This level of investment influences the balance of decisions made. If a farmer doesn't want to accept a high risk on helminth disease, they should apply more risk assessment methods, more preventive measures and more diagnostics with a higher sensitivity (Merlin et al., 2017; Merlin et al., 2018). Simply treating animals without diagnosis to reduce the risk of helminth disease or treating whole subherds with a low prevalence seem easy solutions, but do not fit with an AHS approach and will ultimately lead to problems that are hard to solve.

8. Concluding remarks

The four-step AHS approach provides a structured and flexible framework to translate theoretical principles into practical implementation on dairy farms. Although significant knowledge and implementation gaps exist at each of the steps described these gaps do not have to delay practical implementation of AHS.

Future research should focus on optimizing practical tools, developing more and alternative interventions (e.g., vaccines, natural products), and improving diagnostic accuracy. With that, the four-step approach will ultimately provide a practical approach to guide more sustainable and evidence-based decision-making in helminth control within dairy production.

CRediT authorship contribution statement

Hannes J.C. Bijkerk: Writing – review & editing, Writing – original draft, Visualization, Investigation, Conceptualization. **Adriaan F.G. Antonis:** Writing – review & editing, Supervision, Project administration, Funding acquisition, Conceptualization. **Jaap A. Wagenaar:** Writing – review & editing, Supervision, Conceptualization. **Theo J.G. M. Lam:** Writing – review & editing, Supervision, Conceptualization. **Deborah C.K. van Doorn:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

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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Glossary

- Anthelmintic:** A veterinary medical product containing one or more active ingredients which, when applied to an animal, results in the killing or stunning of helminths. Several classes of substances are available for cattle in the European Union (EU).
- Anthelmintic resistance (AR):** A heritable loss of sensitivity to an anthelmintic in a parasite population that was in the past susceptible to the same anthelmintic.
- Asymptomatic infection:** Infection that does not lead to noticeable negative effects on production or clinical disease.
- Disease:** An infection with helminths with either subclinical or clinical consequences.
- Hazard:** The potential of a chemical agent to do harm (WOAH, 2024).
- Risk:** The likelihood of the occurrence and the likely magnitude of the biological and economic consequences of an adverse event or effect (WOAH, 2024).
- Herd:** All dairy cattle on a farm.
- Host resilience:** The ability of an animal to control the consequences of a helminth infection, i.e. to maintain health and production.
- Host resistance:** The ability of an animal to prevent or limit a helminth infection through immunity.
- Natural product:** A product that is not synthetically produced with one or more active ingredients with anthelmintic properties.
- Preventive measures:** Management measures that prevent infection and/or disease.
- Refugia:** A proportion of a population of helminths that is not exposed to anthelmintics and is able to complete their life cycle, passing on their anthelmintic susceptibility or resistance traits. Refugia comprises the untreated population within a host as well as the free-living stages in the environment (feces and pasture).
- Subclinical disease:** An infection with helminths that leads to negative effects on production parameters without clinically visible symptoms such as diarrhea or coughing.
- Subherd:** A selection of a group of cattle on a farm based on e.g. age or lactation stage, generally with similar risk factors and exposure to helminth infections.
- Targeted selective treatment (TST):** Anthelmintic treatment of selected individual animals, based on animal-level information.
- Targeted Treatment (TT):** Anthelmintic treatment of a herd or subherd, based on information on infection at herd or subherd level.