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Chasing helminths and their economic impact on farmed ruminants

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Global agriculture will be required to intensify production from a shrinking natural resource base. Helminth infections of ruminants are a major constraint on efficient livestock production. The current challenge is to develop diagnostic methods that detect the production impact of helminth infections on farms in order to target control measures and contribute to the global challenge of preserving food security. We review here our understanding of the effects of helminth infections and control practices on productivity and the diagnostic tools that can inform on this. By combining advances in helminth laboratory diagnostics and animal health economics, sustainable management of helminth infections can be integrated into the whole-farm economic context.

Focus on food security

It has been projected that global agriculture will be required to intensify production from a shrinking natural resource base, and with reduced environmental impact, to feed an extra three billion people over the next 50 years [1]. In addition, the production of meat and dairy products will need to expand to meet the demands of an increasing and changing world population [2]. An important contribution to achieving this challenge must come from improved animal health management, which has a major impact on livestock farming efficiency. In this context, helminth infections of ruminants are a major constraint on efficient livestock production globally. Most grazing ruminants are infected by a variety of helminth parasites which negatively impact on feed intake, growth rate, carcass weight, carcass composition, wool growth, fertility, and milk yield [3]. The impact of helminths on animal productivity is well known, but farm productivity depends on multiple other factors such as scale, other diseases, management, and regional restrictions [4]. A major challenge will thus be to assess the importance of helminth infection within this farm-economic framework and prioritize the available resources to the interventions that will be the most cost-effective and have the largest impact on farm productivity.

A crucial factor in addressing this challenge will be the diagnostic tools used to detect helminth infections and their impact on the host. New and more automated laboratory diagnostic methods are emerging that are based on detection of helminth-specific eggs, antibodies, antigens, or DNA in host samples [5–7]. However, the evaluation of these tests remains very much focused on detecting the presence/absence of infection, although some more recent tests attempt to quantify the actual parasite burden [8]. What is now required is to use these diagnostic methods to understand the production and economic impact of helminth infections on a farm. This will allow targeted implementation of control measures, and the realized efficiency gains at the farm level should contribute to the global challenge of preserving food security.

In this review we first address our understanding of the effects of helminth infections and control practices on

Glossary

Coproantigens: proteins released by parasites in the gastrointestinal tract that can be detected in the feces for diagnostic purposes.
Cost-benefit analysis: measures the difference between the costs of a control strategy and the expected reduction in economic loss from the disease. These are typically carried out to compare the expected economic effects of different control strategies.
Disease cost estimate: estimates of the value of losses in the expected output and/or resources due to a specific disease, together with the expenditures associated with treatment or preventive measures.
FAMACHA© score: a score that evaluates the color of the ocular mucosa, which is used as an indication of the degree of anemia induced by *Haemonchus contortus* in sheep.
Loop-mediated isothermal amplification (LAMP): a technology that allows the amplification of target nucleic acids under isothermal conditions.
Pepsinogen: inactive precursor of the enzyme pepsin that contributes to peptic digestion in the abomasum. Infection with *Ostertagia ostertagi* in cattle results in elevation of abomasal pH, inhibition of the normal conversion of pepsinogen to pepsin, and leakage of pepsinogen into the bloodstream. Serum pepsinogen concentration in calves is used as an indicator of abomasal damage induced by *O. ostertagi* infection.
Production parameters: indicators of the level of performance of a production animal. Examples are milk production per day (kg), daily weight gain (kg), or number of inseminations per conception.
Subclinical: a term used to describe a degree of parasitism which interferes with production but is not evident by physical and visual examination of the animal. In practice, it is a state of parasitism usually diagnosed by a positive production response to the administration of an anthelmintic.

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Table 1. Common helminth infections of economic importance in ruminants

Helminth	Epidemiological situation	Economic importance	Refs
Gastrointestinal nematodes (e.g., *Ostertagia ostertagi, Cooperia oncophora, Teladorsagia circumcincta, Haemonchus contortus*)	All grazing ruminants are exposed. Chemoprophylactic treatments to reduce production losses are widely applied and clinical disease has become rare. Demonstrable production losses are present on 10–50% of farms. Over-reliance on anthelmintic drugs results in drug-resistant nematodes, and this is considered a major obstacle to reliable and sustainable control.	Reductions in weight gain, milk production, and carcass quality.	[51–54] [42,55,85]
Liver fluke (*Fasciola hepatica*)	Prevalence shows regional variation depending on suitable environmental conditions for the intermediate host snail that thrives in small water bodies on pasture. Herd-level prevalences of 30–80% are commonly encountered across Western Europe. Anthelmintic drug resistance and climatic and environmental changes are thought to lead to increased incidence of disease.	Reductions in weight gain, fertility, milk production, and carcass quality.	[56–58]
Lungworm (*Dictyocaulus viviparus*)	Responsible for sporadic outbreaks of severe respiratory symptoms in pasture-based cattle farms. Infection is widespread (70–80% herd-level prevalence) whereas clinical symptoms occur in 10–20% of the herds per year. Intensive application of anthelmintic drugs in young stock compromises the development of immunity and has led to increased incidence of clinical outbreaks in adult cattle.	Mortality, reductions in weight gain and milk production.	

productivity. Next, we discuss whether we can use diagnostic test results for helminth detection to determine their impact on production. Finally, we investigate how we can combine this diagnostic information on helminth infection with the farm-level economic situation to evaluate and prioritize different control options and achieve sustainable helminth control that is better integrated into the whole-farm economic context.

The effects of helminth infections and deworming on productivity

Helminth infections with a recognized negative impact on ruminant production in temperate climate zones and their current epidemiological situation are summarized in Table 1. The underlying mechanisms for the impact of helminths on production can be divided into three main categories: (i) direct tissue damage and decreased functioning of the affected organs [9], (ii) diversion of energy and protein resources of the host from production towards defense and immune mechanisms [10], and (iii) reduced feed intake. Reduced feed intake is a common feature of all helminth infections, is linked with hormonal changes in the host, and is thought to be the major mechanism of subclinical production impact [11,12].

The first step towards an 'impact diagnosis' of helminth infections is to understand the effect they exert on production parameters (see Glossary). Therefore, in Box 1 we summarize the available literature that describes these effects. Although average estimates are reported, it is well known that the production effects of helminths are very heterogeneous between individual animals or between different herds and flocks [13]. Variability between production impacts can be ascribed to differing levels of infection, developmental stage of the parasite, host genetic background, feeding management, and other as yet unknown factors [8,14,15]. This is also captured in the concept of 'resilience', where animals may host a significant parasite burden but not suffer from morbidity effects and production losses [16]. The complexity and multi-causal nature of production losses are considered to be major obstacles in assessing helminth-induced production losses at the farm level [17]. Nevertheless, to remain competitive in an increasingly globalized world, farmers need to work and act on farm-specific figures [2].

Detecting helminth-induced production impact

From the above, the question arises whether we have the diagnostic tools that can inform on production impact of helminths at farm level. Three main approaches have been used to address this problem: (i) correlation of helminth diagnostic test results with parasite burden, (ii) correlation of helminth diagnostic test results with measures of animal productivity, and (iii) direct use of production or morbidity parameters to decide upon anthelmintic control measures.

Several studies have attempted to correlate diagnostic test results with parasite burden, with variable success (Box 2). However, because morbidity and production losses are often not directly related to parasite burden, it makes sense to establish a direct correlation between helminth diagnostic test results and measures of productivity. We describe below examples where this association has been assessed and highlight some of the limitations encountered.

In first-season grazing cattle, serum pepsinogen concentration can be used to discriminate between different levels of *O. ostertagia* infection and morbidity, and evaluate the likely associated production losses [8,18]. However, an important constraint is that blood samples need to be taken from several animals to obtain a representative readout, and this parameter loses much of its informative value soon after housing of the animals – when there is no new exposure to incoming infective larvae [19]. More practical parameters would be the use of helminth-specific antibody levels in bulk tank milk or muscle transudate, both of which allow the collection of herd-specific information for dairy or meat animals, respectively, in a more user-friendly and less invasive way. After controlling for confounding factors, consistent negative relationships have been demonstrated between antibody levels to