Trends in Parasitology

CellPress

Review

Cattle and Nematodes Under Global Change: Transmission Models as an Ally

Sien H. Verschave,[1] Johannes Charlier,[2] Hannah Rose,[3]
Edwin Claerebout,[1,*] and Eric R. Morgan[3]

Nematode infections are an important economic constraint to cattle farming. Future risk levels and transmission dynamics will be affected by changes in climate and farm management. The prospect of altered parasite epidemiology in combination with anthelmintic resistance requires the adaptation of current control approaches. Mathematical models that simulate disease dynamics under changing climate and farm management can help to guide the optimization of helminth control strategies. Recent efforts have increasingly employed such models to assess the impact of predicted climate scenarios on future infection pressure for gastrointestinal nematodes (GINs) in cattle, and to evaluate possible adaptive control measures. This review aims to consolidate progress in this field to facilitate further modeling and application.

Achieving Effective Nematode Control in the 21st Century

Over the past decades several aspects of livestock production, their parasites, and the host–parasite relationship have changed and arguably more drastic changes can be expected in the next half-century. GINs represent the most prevalent parasites of grazing ruminants and are an important constraint for livestock farming [1]. Infections with GINs impair the health of livestock but, owing to intensive chemoprophylaxis, clinical infections are rarely observed and nowadays the focus lies mainly on the economic impact of the disease. The future control of these parasites, however, is challenged by several factors such as the development of anthelmintic resistance [2] and changes in climate and farm management [3]. Current control programs are still based on transmission and epidemiological patterns that were mapped decades ago. They need to be re-evaluated and adapted to maintain their efficacy [4].

Because the host–parasite system is a tight network, impacting factors will often interact, resulting in a complex web of inter-related and sometimes opposing forces. Future control approaches therefore need to be holistic by taking these interactions into account, and for each adaptive change in management the consequences on the whole system need to be considered before intervening [3,5].

Mathematical transmission models that simulate disease dynamics and host responses have great potential to improve our understanding of parasite epidemiology under changing conditions and to support the implementation of integrated parasite control strategies. This review first discusses current and anticipated trends for both livestock and their GIN parasites, while focusing on the underlying drivers of these changes and their interactions, with the aim of explaining how transmission models are an asset in dealing with changing parasite epidemiology and can form the foundation of sustainable and effective control. Then, an overview of the

Trends

Mathematical and computer models are now available to simulate climate- and management-driven transmission dynamics in a range of host and gastrointestinal parasite species.

Key recent advances include the ability to formally incorporate uncertainty into parameter estimates, and into future climate and management projections, as a result of increased computer power.

The advent of high-throughput diagnostics for parasite infections in farmed ruminants brings opportunities for model validation using large datasets, which were not realistically possible when the model frameworks were originally conceived.

These models provide a useful contribution to our understanding of parasite epidemiology in alternative conditions, and should be further applied and refined.

[1]Department of Virology, Parasitology and Immunology, Faculty of Veterinary Medicine, Ghent University, Salisburylaan 133, 9820 Merelbeke, Belgium
[2]Avia-GIS, Risschotlei 33, 2980 Zoersel, Belgium
[3]School of Veterinary Sciences, University of Bristol, Langford House, Langford, Bristol BS40 5DU UK

*Correspondence:
edwin.claerebout@ugent.be
(E. Claerebout).

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currently available models for GIN infections in ruminants is given, focusing on cattle, and recent progress in the development and application of transmission models to predict future risks is discussed. Progress in modeling GIN in other host species, such as sheep, is identified where it can support similar efforts for cattle. Finally, we identify key challenges in the field and suggest ways of addressing them.

Livestock in a Changing World: The Toll of Intensified Farming

In the previous century global livestock production grew substantially, with increasing numbers of animals being reared and enhanced productivity per animal. In more-developed regions, cattle farms have disaggregated into specialized milk and beef industries that show 30% higher milk yields per animal and 30% higher carcass weights, respectively, compared to 1960s production levels [6]. However, the high levels of animal performance reached today compromise other aspects of animal production, and the resulting asynchrony between animals and their environment also affects animal welfare [7]. By contrast, modern production systems are more sustainable than historical methods in that their higher efficiency reduces environmental impact per output unit produced [8]. However, the scale of growth and intensification that the industry has experienced takes a significant environmental toll locally and globally. It is common knowledge now that human activity is one of the primary causes of climate change [9], with global livestock production representing 15% of all anthropogenic greenhouse gas (GHG) emissions [10]. The place of livestock in sustainable food production is increasingly questioned due to concerns around food safety, environmental impacts, and animal welfare [11], and these factors are likely to be key in shaping future livestock production systems (Box 1). Global demand for livestock products is expected to double by 2050 [10], and the livestock industry will thus have a continued role in securing the global food supply, while operating against a background of increased climate variability and ambitious environmental and social goals.

Box 1. Drivers of Change for the Cattle Sector: Parasites in Context

Climate Change

The vulnerability of cattle to the effects of climate change depends on geographic region and production system [43]. Climate change will affect animals directly, for example by increasing heat stress [3]. Indirect effects, such as changes in farm management practice and infectious disease dynamics, might, however, be more important. For example, under future temperature and precipitation conditions the length of grazing seasons may increase [44], and this could compromise herbage quality and nutrient concentration, constraining host physiology and immunity [5], as well as prolonging parasite transmission seasons.

Environmental Impacts and Mitigation Actions

Imposed rules and legislative measures to achieve environmental goals, and attempts by farmer to mitigate the detrimental effects of climate change, will affect future animal production. Minimizing the contribution of the industry to climate change through GHG emissions can be decreased by acting directly on emissions or by enhancing production efficiency and thus lowering the emissions per unit of food produced [45]. Intensification can enhance production efficiency and reduce land-use requirements [45], even to the point of zero-grazing systems, but the impacts of inputs into those systems such as fertilizer and fuel, and outputs such as slurry, should be integrated into assessments. While the influence of parasites on GHG emissions is likely less than that of nutrition, reducing parasite challenge can provide a tractable means of intervention to mitigate environmental impacts by supporting productivity and hence decreasing emissions per unit produced [3].

Public Awareness and Consumer Opinion

In affluent western countries, public awareness concerning food production is growing. Animal welfare is an important consideration, and for cows is often connected with outdoor access and ability to graze, which can also affect perceptions of food quality and healthfulness [46]. In many systems there are trade-offs between behavioral welfare indicators and disease control along the intensive–extensive gradient, which have been poorly quantified and could affect future societal acceptance, as could changing dietary preferences (e.g., [47]) and concerns over chemical residues. Without a doubt, public opinions will drive farming-system change in future, concurrently influencing parasite risks and the legitimate means for its management.

Glossary

Demographic stochasticity: variability in population growth arising from random differences between individuals in survival and reproduction rates.

Deterministic model: a model that assumes no variability or randomness, and describes what happens on average in the system or process modeled.

Empirical model: a model based on measurements and observations. Empirical models consider correlative relationships that are in line with the current understanding of the system of interest, but without fully describing the behavior of the system. Synonyms: statistical, correlative, or phenomenological models.

Environmental stochasticity: variability in population growth as a result of fluctuations in external factors such as climate.

Generic model: a model that provides a framework aiming to assess the general dynamics of parasite infections. Generic models consider a group of similar parasites (e.g., GIN) instead of specific parasite species. In general, they do not incorporate excessive amounts of biological detail and their structure is kept simple to avoid obscuring key processes and to ensure general applicability across a range of systems.

Individual-based model: a model that assumes a heterogeneous population in which every individual of the population has its own characteristics, and that tracks the infection process for each of these individuals. Population-level effects are explicitly emergent properties of individual-level processes. These models are therefore by definition considered to be demographically stochastic (in contrast to **population-based models**). A synonym is agent-based model.

Mechanistic model: a model based on current knowledge and understanding of a system of interest, and is therefore process-oriented. Such models consider the mechanisms that underlie the behavior of the system and explicitly describe these. For infectious disease modeling, these models are typically compartmental. Synonyms: compartmental models, process-based models.