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673. Simulating technical, economic and environmental performance of a dairy herd under selection in future climate conditions

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Abstract

Climate change will have direct effects on performance of livestock. Simulations that mimic livestock systems risk misrepresenting performance if these effects are not accounted for. Here, the technical, economic and environmental performance of a Scottish dairy herd under genetic selection (for 7-correlated traits) was investigated using an original simulation model. There were two scenarios: in the control scenario, the technical performance of individuals was not affected by daily weather; in the treatment scenario, technical performance was dynamic to daily weather conditions. Herds were simulated for 20-years. By the final year of the simulation, for herds in the treatment scenario relative to the control scenario, annual gains in gross margin were reduced by 2.1% and gains in greenhouse gas emissions intensity were reduced by 1.7%. Failure to account for weather effects in models that simulate herds into the future will likely cause over-estimation of technical, economic and environmental performance, even in temperate regions such as southwest Scotland.

Introduction

It is likely that global temperatures will continue to rise. This, together with increasing magnitude and frequency of extreme weather events, will present major challenges to livestock production in the coming years (IPCC, 2021). The production of ruminant livestock, such as dairy cows, is under particular pressure given that some negative externalities of the system (e.g. greenhouse gas – GHG – emissions, which not only include enteric emissions but also emissions from manure management and managed soils – for details, see Gavrilova *et al.*, 2019) will exacerbate existing environmental challenges. In the face of such challenges, dairy production must remain efficient, which means the system and its components must be resilient (Friggens *et al.*, 2017). This resilience may be improved with artificial selection (e.g. Poppe *et al.*, 2020), however, the value of resilience at the animal-level is not well established, and is likely to be proportionate to the degree of challenge expected for a given system. Against this back-drop, we present the application of an individual-based model (IBM) under different scenarios of future climate, where the objective is to demonstrate the value of herds if individuals are resilient – or not – to variable daily weather conditions.

Methods

Using an original, daily time-step, IBM, we mimic the daily biological performance and management of a herd of individuals, where individuals are represented according to a set of underlying genetic characteristics, covering production and functional traits. As in real life, individuals differ in their genetic ability, and, over time, the genetics of the herd improves, driven by breeding dams to genetically improved sires and subsequent selection of genetically superior replacements. This, together with stochastic functions in the model, generates variability in the performance of individuals, resulting in realistic variation in the performance of the herd. The performance of individuals can also be dynamic to key weather variables, based on scenarios of future climate change. In terms of model outputs, individual performance data were collected daily and used to calculate raw technical performance, economic outcomes and GHG emissions at the herd level.

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The model was parameterised to be representative of a specialist dairy herd in southwest Scotland. Therefore, the simulated herd consisted of approximately 200 lactating cows; they were housed for 6 months per year (October – March, inclusive), and housed part of the day for the remainder, as is common in the United Kingdom (March *et al.*, 2014). The herd was simulated for 20-years into the future (2021-2040).

The daily performance of herd-members was affected by 7-traits of economic importance, these were: milk yield, fat yield and protein yield (production), dry matter intake (maintenance), probability of mastitis infection (health), number of inseminations to conception (fertility), and days of life (longevity). The daily phenotypic performance of each individual across these traits was a function of their genetic ability and environmental factors (including daily weather). According to these phenotypic functions, each day individuals would yield a given quantity and quality of milk, would consume a given quantity of dry matter, may succumb to mastitis infection, may conceive, and/or may be culled, respectively. Main interactions of productivity, reproduction and health occurring during the productive lifetime were integrated. However, the simulation was not an optimisation model, therefore, herd management rules remained static between climate scenarios and across time. In addition to this, we assume no adoption of climate mitigation technologies or practices by the farmer.

In one scenario of the simulation (herein, the treatment scenario), the explicit weather-dependence of daily phenotypes enabled prediction of the degree and extent of weather effects on herd performance. Here, weather affected daily yields, feed intake, and rates of mastitis, conception and mortality. This allowed us to capture the cumulative impact of seasonal and long-term weather variations on herd performance. As well as simulation runs that accounted for climate change in this way, the simulation was also run with static weather variables that did not reflect climate change, which acted as a baseline where animals were resilient and therefore unperturbed by variable weather (herein, the control scenario). Weather variables came from UK Climate Projections 2018 (UKCP18), downscaled for the target area.

The technical output and production characteristics of the herd were used to calculate economic and environmental performance. Gross margin was calculated as income (e.g. from milk sales) minus variable costs (e.g. pregnancy testing). For the environmental performance, we calculated enteric and manure methane, and direct, volatilised and leached nitrous oxide from manure; these emissions were calculated according to the IPCC 2019 refinement to the IPCC 2006 national GHG inventory (Gavrilova *et al.*, 2019). We did not directly calculate emissions from spreading manure on managed soils, as we assumed these emissions are captured by feed component emissions factors (EFs). Dietary assumption and associated EFs were provided by consultants at SRUC as representative for the modelled system. Emissions intensity is reported as total emissions of the lactating herd per unit of energy-corrected milk (kg CO_2-eq/kg ECM). Total emissions of the herd were calculated as kg CO_2-eq, using the IPCC AR5 GWP100 conversion. ECM accounts for yield, fat and protein content of milk (Sjaunja *et al.*, 1990).

Results

Results show that estimates of technical, economic and environmental performance were significantly different between simulation runs for control and treatment scenarios (statistical model outputs not shown). Accounting for the effects of climate change on the technical performance of individuals led to unfavourable changes in several key herd parameters: for example, an overall decrease in productive lifespan and increased incidence of mastitis (see Figures 1a-c). In addition, we found similarly unfavourable results for age at first calving, calving index, conception rate and ECM.

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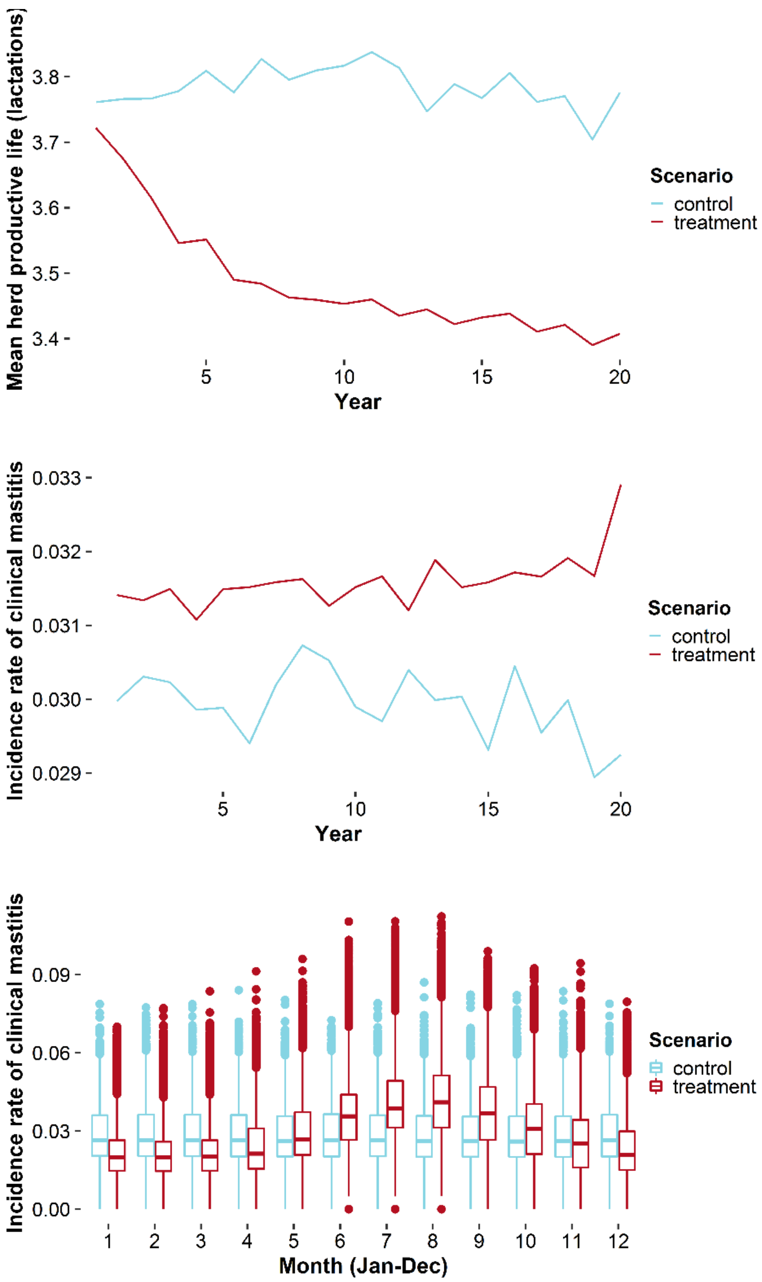

Figure 1 Plots to demonstrate the impacts of key weather variables on (a) productive lifespan across years, (b) incidence rate of clinical mastitis across years, and (c) incidence rate of clinical mastitis within years. Treatment scenario refers to simulation runs that account for climate change, and control scenario refers to simulations run with static weather variables. Please carefully note the y-axis scales when interpreting these plots.

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Accordingly, relative to the control scenario, where individuals were robust to variation in daily weather conditions, gains in gross margin were reduced by 2.1%, and gains in GHG emissions intensity were reduced by 1.7% in the treatment scenario. With 900 herds in the Scottish dairy system, this reduction in gross margin could amount to £15m for the industry – and the difference in emissions intensity could lead to an extra 25,000 tonnes CO_2-eq– resulting from less efficient production over the next 20-years, even in the temperate climate of southwest Scotland.

Discussion

Without cattle who are resilience to the impacts of projected weather over the coming decades, we can expect negative impacts on the technical, economic and environmental performance of dairy herds, even in temperate regions. Resilience to these direct effects may be introduced through selection for traits that promote individuals who are able to maintain production in the face of environmental perturbations by, for example, accounting for genetic-by-environment interactions in breeding decisions. Animals who are resilient will not only be more profitable but also produce better quality milk in greater quantities at a lower emissions intensity. As research into breeding for resilient animals continues (e.g. www.GenTORE.eu), a critical question is what value should be placed on these novel traits. Towards this question, the current paper is an important contribution.

However, also important are the methodological implications, which suggest that failing to account for the effects of climate at the animal-level in such models will cause the misrepresentation of key performance indicators, especially as this type of model becomes increasingly popular and simulated scenarios can run for many years into the future. Therefore, if researchers aim to mimic the biological performance of a herd, it is increasingly difficult to overlook relationships between climate and herd functioning, even in temperate regions.

Conclusions

This paper presents the results of a novel approach to estimating the value of resilience at the animal-level in a way that can be tailored to specific regions within production systems. We report substantial differences in individual and herd performance between production scenarios.

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