Discrepancies between observed and predicted climate-driven net herbage accumulation

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Abstract. The decline in net herbage accumulation (NHA) on the high phosphorus (P) fertilizer farmlet (HF) of a long-term P fertilizer and associated sheep grazing experiment in the last 25 years, aligns with the necessity to reduce the on-site nominal sheep stocking rates over the same period on this farmlet. This finding appears at odds with projected climate change driven modelling that forecast a largely positive outcome on pasture growth in summer moist environments. In this paper we explore the apparent discrepancies between the observed and predicted climate-driven NHA by using a climate-driven pasture growth module within a larger process-based model (AgPasture in APSIM) to simulate NHA, legume growth, nitrogen fixation and water balance across three slopes [Low (LS; 0°-12°), Medium (MS; 13°-25°) and High slope (HS;>25°)] from 1980-2021. To assess the ability of the model to capture the influence of spatiotemporal climate variables on pasture growth, the model output for 1972-1981 was compared with NHA measurements collected across the three slope classes for that same period. A good relationship was found between modelled and measured NHA across the three slopes classes giving confidence in the model's ability to capture the influence of both spatial and temporal climate variation on plant growth. A comparison of the modelled NHA for the three slope classes during 1982-88 with 2012-2018 indicates a significant ($p<0.01$) decline in NHA over time. There has been no clear trend in annual rainfall since 1982, however, mean daily maximum temperature has increased 1.5°C. The average modelled summer soil moisture deficit (January to March) has increased from -41mm between 1982-1988 to -55 mm between 2012-2018. Our modelling work suggests that the summer soil moisture deficit and temperature stress are having a greater effect on NHA than the predicted benefits of higher [CO_2] and winter and early spring temperatures, leading to long-term reductions in NHA, rather than an overall increase.

Introduction

New Zealand, a primary industry-based economy, trades on its combination of rich natural capital stocks and mild climate, with pastoral agriculture still the biggest single land use. However, pastoralism is under pressure (Chapman et al. 2022) from factors such as competition for land from urban, peri-urban and other primary industries, forest planting for GHG offsetting, native forest restoration, changing consumer demands with increasing interest in plant-based products. The potential direct impacts of climate change on pastoral productivity also loom large, in predicting the future trajectory of the pastoral industry. Multiple studies (Lieffering et al. 2016; Ausseil et al. 2019, Keller et al. 2021, Newton et al. 2022) have been conducted in New Zealand exploring the potential impacts of long-term average changes in climate on the future on the countries primary industries. The current consensus using climate driven modelling (Lieffering et al. 2016; Keller et al. 2021, Newton et al. 2022) is that future climates will likely show generally positive or neutral outcomes for NHA in wetter and cooler environments and a neutral to small negative outcome in summer dry environments.

An examination of actual pasture and animal production data from both dairy and sheep/beef systems collected over the last 20-40 years, suggests that NHA has not increased, but has been either static (Glassey et al. 2021) or in decline (Gobilik et al. 2021). In a comparison of historic long-term modelling and measurement of forage production in Waikato dairy systems, Glassey et al. (2021) pointed to a divergence between a modelled reduction in climate-driven pasture production and relatively stable actual measured NHA. Most recently, Mackay et al., (2022) reported that measured NHA on the Ballantrae hill country high phosphorus (P) fertility farmlet (HF) was only 87% of that observed on the same summer moist sites between 1982 and 1988. We explore the apparent discrepancies between observed and predicted climate-driven NHA at Ballantrae by using a climate-driven multi-species pasture growth module within the Agricultural Production Systems sIMulator (APSIM) to model NHA, legume growth and the summer (January-March) soil moisture deficit across three slopes over the last five decades.

Methods

Study site

The long-term P fertilizer and associated sheep grazing experiment (1975-2022) is located at the Ballantrae Hill Country Research Station in Southern Hawke's Bay, New Zealand (408180S 1758500E). It is typical of much of the North Island's hill country which covers 3.0 million ha (28% of the total farmland area). The soils include Brown (43% of NZ soils) and some Pallic (13% of NZ soils), formed under forest which was cleared and sown to grassland about 100 years ago. The characteristics of the self-contained experimental farmlets that form part of the long-term P fertiliser and sheep grazing experiment established in 1975, are described in detail in Mackay et al. (2021). Since 1980 the HF farmlet has received 375 kg single superphosphate ha^{-1} $year^{-1}$. Breeding ewes have been grazing the HF farmlet in a rotational fashion since 1975.

Modelling pasture growth (1972-2020)

The AgPasture module (Li et al. 2011) of APSIM Next Gen (Holzworth et al. 2018) was used to explore the influence of climate alone on pasture growth between 1980-2021. AgPasture is a process-based multi-species pasture growth model that can explore the influence of climate, topography, soil profile properties and some management practices on a range of soil-plant system attributes, including pasture growth and biological nitrogen (N_2) fixation. For the modelling, daily weather files for the period 1972-2021 were obtained from the National Institute of Water and Atmospheric Research (NIWA) Virtual Climate Station network node (Tait et al. 2006) within 5 km of the AgResearch Ballantrae Research Station. Soil profile physical and chemical characteristics to parameterise the model were obtained from the National Soils Database (NSD) and Gradwell (1976). The soil bulk density was 0.92 Mg m^{-3}, field capacity 45% v/v, and permanent wilting point 17% v/v in the topsoil (0-50 mm). Root depth was 450 mm, 300 mm and 200 mm on LS, MS and HS, respectively, with associated profile water holding capacities of 110, 75 and 50 mm, respectively, for the three slopes.

Model simulations for the three slope classes involved: for LS a perennial ryegrass/white clover pasture with excreta N return of 105% and a grazing residual of 1500 kg DM ha^{-1}; for MS a perennial ryegrass/white clover/browntop pasture with excreta N return of 95% and a grazing residual of 1600 kg DM ha^{-1}; for MS a browntop/white clover pasture with excreta N return of 80% and a grazing residual of 1700 kg DM ha^{-1}. With the soil P fertility (Olsen P values) of the HF farmlet at or above optimum (Olsen P >25 µg ml^{-1}) required for maximum growth since the mid 1980's (Mackay et al. 2021), P availability was not a factor in the modelling. To assess the ability of the model to capture the influence of spatiotemporal climate variables on pasture growth, the model output for 1972-1981 was compared with NHA measurements across the three slope classes for the same period by Lambert et al. (1983).

Statistical analysis

For model simulations, a four-year running average was calculated from the annual NHA data. Modelled NHA for each of the three slope classes from 1972 to 1981 was compared with measured NHA across the same slope classes and timeframe. Analysis of variance was used to examine the effect of slope and the two 10-year periods (1982-1991 and 2012-2021) on NHA.

Results and Discussion

Comparing modelled and measured net herbage accumulation

In the study of Lambert et al. (1983), NHA was measured using exclusion cages across three slope and aspect classes and under two P fertiliser levels and three grazing regimes (rotational grazing with sheep, set stock with sheep, rotational grazing with cattle). A good relationship was found between measured (average for the P fertiliser levels, grazing regimes and aspect) and modelled NHA across the three slope classes where NHA varied from 4000 kg DM ha^{-1} on the HS class to >15,000 kg DM ha^{-1} on LS class (Fig.1).

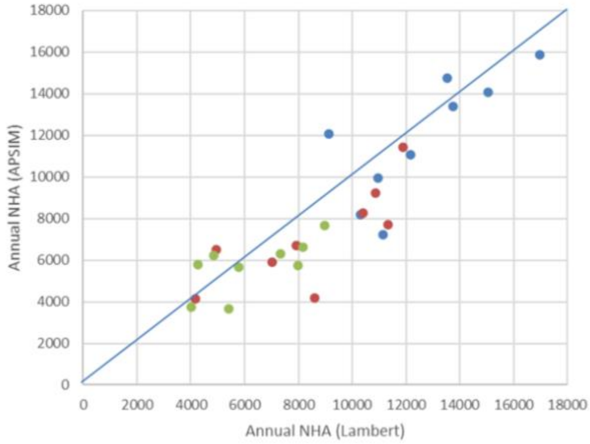

Figure 1. Comparison of simulated net annual herbage accumulation (NHA; kg DM ha^{-1}) across three slope classes (high slope (green), medium slope (red), low slope (blue) from 1972-1981 using the AgPasture module of APSIM, with measured using exclusion cages across three slope classes (average for the P fertiliser levels, grazing regimes and aspect) for the same period (Lambert et al. 1983).

Modelling of net herbage accumulation

The decline in the annual NHA on all three slope classes appears to have started prior to 2000 (Fig. 2). This finding aligns with some earlier modelling work using just an average slope (Mackay et al., 2022). Analysis of the modelled NHA for the three slope classes during 1982-88 compared with 2012-2018 indicates a significant ($p<0.01$) decline in NHA. Mean annual NHA in 1982-88 and in 2012-2018 were 12340 kg DM ha^{-1} and 10500 kg DM ha^{-1}, respectively; LSD = 890 kg DM ha^{-1}) in addition to the effect of slope (mean LS, MS and HS class annual NHA were 16970,10350 and 6930 kg DM ha^{-1}, respectively, LSD = 1090 kg DM ha^{-1}).

While there was no interaction ($p=0.6$) between the two variables (time and slope), the decline in NHA tended to increase with increasing slope (88, 84 and 77% on the LS, MS, and HS, respectively). The decline in the modelled NHA is consistent with the lower NHA measured in 2015-16 and in 2020-21 compared with the 1980’s (Mackay et al. 2022) and with the fact the sheep stocking rate has declined since 2000 (Mackay et al. 2021)

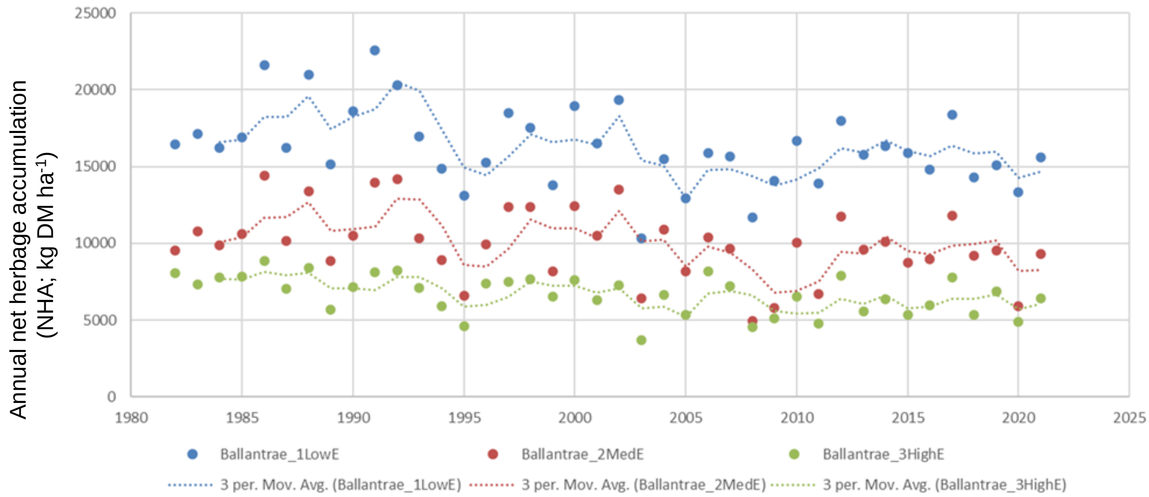

Figure 2. Simulated annual net herbage accumulation (NHA; kg DM ha^{-1}) from 1980-2021 for a perennial ryegrass/white clover pasture on three slope classes using the AgPasture module of APSIM. Dotted lines represent four-year running averages from the annual data.

Simulated annual NHA of the clover component and biological N_2 fixation showed the same declining trends as total NHA, but the percent decline in clover NHA from 1982-88 through to 2012-2018 was similar across all three slope classes. The simulated decline in clover growth and N fixation aligns with the small, measured decline in total soil N and increases of the soil C:N ratio in the HF farmlet in 2020 (Mackay et al. 2022) compared with earlier reports (Lambert et al. 2020). While there has been no clear trend in annual rainfall since 1982, mean daily maximum temperatures have increased by 1.5°C (Mackay et al. 2022). The increase in mean daily temperature contributed to the significant ($p<0.01$) increase in the mean summer soil moisture deficit (January to March), which increased from -41mm between 1982-88 to -55 mm between 2012-2018. The modelling suggests that the summer soil moisture deficit and temperature stress drivers of pasture growth are over-compensating for the predicted benefits of higher [CO_2] and warmer winter-early spring temperatures, leading to long-term reductions in NHA, rather than an overall increase. We postulate that these net effects will vary across topographically diverse hill country landscapes, where slope and aspect strongly influence moisture and temperature drivers of NHA.

Conclusions and/or Implications

Current strategies by industry and government policy are working on the basis that the impact of future climates on forage supply in our pastoral systems will see small reductions in pasture growth in drier environments and some increases in wetter environments into the future. Evidence is accumulating to suggest that this may not be the case, and a major rethinking of our response to future climates will be required.

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