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PROGRESS IN UNDERSTANDING CHALLENGES AND OPPORTUNITIES FOR AGRICULTURE UNDER CLIMATE CHANGE

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Abstract
Future climate is likely to have a major impact on the primary sector, and has the potential to drive major shifts in land use as previously suitable climatic conditions change. A team funded by the Deep South and Our Land & Water National Science Challenges is researching the potential impacts on the primary sector. Impacts can be due to chronic effects (long-term changes in climate conditions) or acute effects (extreme events).

Introduction

Representative concentration pathways (RCPs) from the IPCC's 5th Assessment Report facilitate comparative exploration of the potential impacts and implications of climate change across the wide range of plausible future global greenhouse gas emissions and resulting radiative forcing. Although called 'concentration pathways', the naming convention actually refers to the resulting additional radiative forcing in 2100 in watts per metre squared (W/m^2) relative to pre-industrial (1850–1900) levels. The effects of each RCP on future climate in New Zealand were modelled by NIWA using six different global climate models (GCMs) coupled with the New Zealand Regional Climate Model. The temperature and precipitation climate variables were bias corrected and semi-empirically further downscaled from 30 km to 5 km horizontal resolution using a physics-based approach (Sood 2014).

The trends identified by these downscaled projections have been summarised in a report for the Ministry for the Environment (2018). In general, it was found that warmer temperatures are likely to lead to an increase in the number of hot days, a decrease in the number of frost days, and an increase in growing degree days. The rainfall pattern is predicted to change, leading in many cases to more extreme drought and rainfall events, depending on the region.

A previous study investigated the implications of these changes in climate on agriculture (Rutledge et al. 2017). This work focused on a two sectors (pastoral, forestry) and long-term effects. More recently, the Deep South and Our Land & Water National Science Challenges partnered to expand the research to include acute impacts and environmental effects (Beare et al. 2017; Ausseil et al. 2019). The current project (in tranche 2) is reviewing and extending this earlier work and filling some knowledge gaps. This paper reports on some of the earlier findings and progress with the new work.

Methods

A range of impacts on agriculture that can be explored through modelling have been identified. These models require daily times series of future climate data. Time series reflecting four RCPs are used in our research: RCP2.6 (mitigation pathway), RCP4.5 and RCP6.0 (both stabilisation pathways), and RCP8.5 (business as usual pathway).

The climate change impacts being studied in the previous and current projects that are discussed in this paper include effects on:

- crop suitability and timing of phenological stages
- drought risk for different crops
- environmental risk of nitrate leaching and erosion
- prevalence of facial eczema.

Some of the various modelling approaches being used in our work are now described in more detail. Information on the other models that underpin the earlier climate change impact assessment work can be found in Ausseil et al. (2019).

1) Crop suitability

The Grapevine Flowering Véraison model (Parker et al. (2011)) was used to simulate the time of key phenological stages of flowering and véraison, and the Grapevine Sugar Ripeness model (Parker et al. (2020)) identifies the time to target sugar ripeness. Running the four RCPs through these models enables changes in key phenological events and the time to target sugar concentrations in berries to be determined (Ausseil et al. 2021).

A biophysical model (APSIM; Holzworth et al. (2014)) was used to explore the spatial impact of climate change on silage maize crops (chronic risk). This allowed an assessment of whether changing the sowing date and the maize genotype might counteract the impacts (Teixeira et al. 2018). APSIM was also used at three locations to determine the seasonal impact of climate change on pasture production and nitrogen leaching (Ausseil et al. 2019).

Through a simpler land suitability assessment approach, critical climate factors can be identified for specific crops (acute risks). Onions, for example, are sensitive to heat stress, while potatoes are susceptible to frost. Thus, change in suitability can be mapped by examining the number of days of heat stress (>31°C at harvest) and frost (<0°C) under the various RCP scenarios.

2) Impact of drought

The NZ drought index is a water balance model designed to monitor national drought conditions (NIWA 2022) and it is being run on the four climate projection time series. This model, currently set up for pasture, is being adapted to include a crop coefficient that varies with crop phenological stages, thus capturing changing demand for water as an annual plant establishes canopy, reaches reproductive stage, and then matures. If successful, this modification will enable drought risk assessments to be assessed for a range of crops.

3) Impact on erosion

The NZeem® model, which represents the total average annual suspended sediment load from all erosion sources (Dymond et al. 2010), was combined with the RUSLE model of surface erosion adapted by Donovan and Monaghan (2021) to assess grazing impacts in New Zealand. Spatial rules based on terrain classes and knowledge of erosion process contributions to sediment loads were used to partition modelled total suspended sediment loads into estimated contributions from mass movement, surface, and channel bank erosion. Mass-movement erosion processes are dominant in soft-rock hill country (e.g., Trustrum et al. 1999; Basher 2013; Spiekermann et al. 2017), while surface and channel bank erosion tend to dominate loads from lowlands (Basher et al. 2020). For those terrain classes where there is insufficient information to partition sediment loads into erosion process contributions, we use total loads from NZeem®. Modelled changes in mean annual rainfall and changes in the magnitude and frequency of landslide-triggering storm events were used to represent climate-induced changes in surface and mass movement erosion, respectively. Modelled changes in mean annual flood were used to drive changes in bank erosion (Smith et al. 2019). Land cover was assumed to remain constant.

4) Impact on facial eczema

A more empirical approach is being used to assess the potential risk of facial eczema in sheep. This is a metabolic disease caused by toxic spores of the fungus *Pithomyces chartarum*. Spores grow on dead litter at the base of pasture. Warm, wet conditions exacerbate this long-running animal health challenge, currently limited to the upper part of the North Island. A statistical model relating spore counts to climatic variables will be developed and used to predict the likely risk of high spore counts under the climate change projections.

Results

Some examples of completed and preliminary modelling results from the new work are presented here. Due to space constraints, map results mostly show just RCP8.5. Further results can be found in Beare et al. (2017), Rutledge et al. (2017), Teixeira et al. (2018), Ausseil et al. (2019) and Keller et al. (2021).

1) Crop suitability

Modelling of silage maize crops indicated that yields in the South Island might increase under RCP8.5 by the end of the century, but decrease in the North Island in the absence of adaptation (Figure 1). This decrease could be partially mitigated by changing the sowing date and the maize genotype.

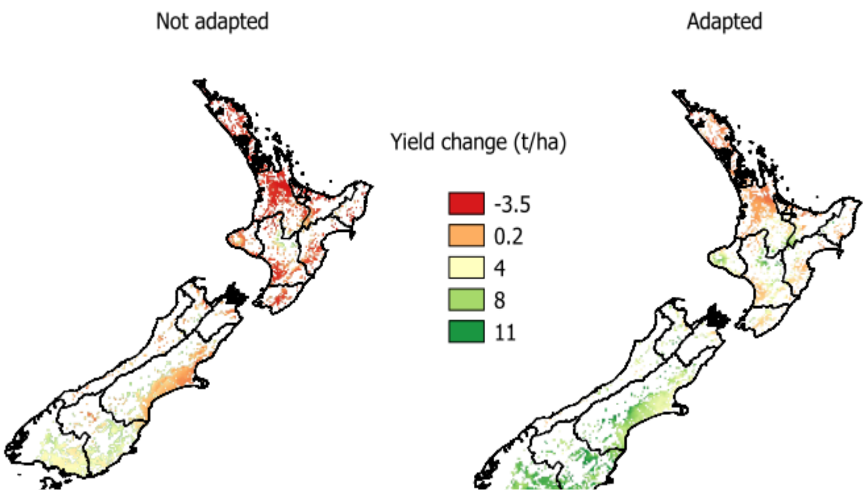

Figure 1. The change in maize production at the end of the century under RCP8.5 with and without adaptation (sowing date and genotype selection).

Modelling pasture under RCP8.5 at three case study locations suggests that by 2090 there might be a higher peak in production in the spring and lower production in the summer at the Waikato (Figure 2) and Hawke's Bay locations, and an increase from spring through to autumn in Southland (Ausseil et al. 2019). The same modelling work suggests that nitrogen leaching might not vary much in the North Island sites but might increase in Southland, probably due to the higher rainfall (Figure 3).

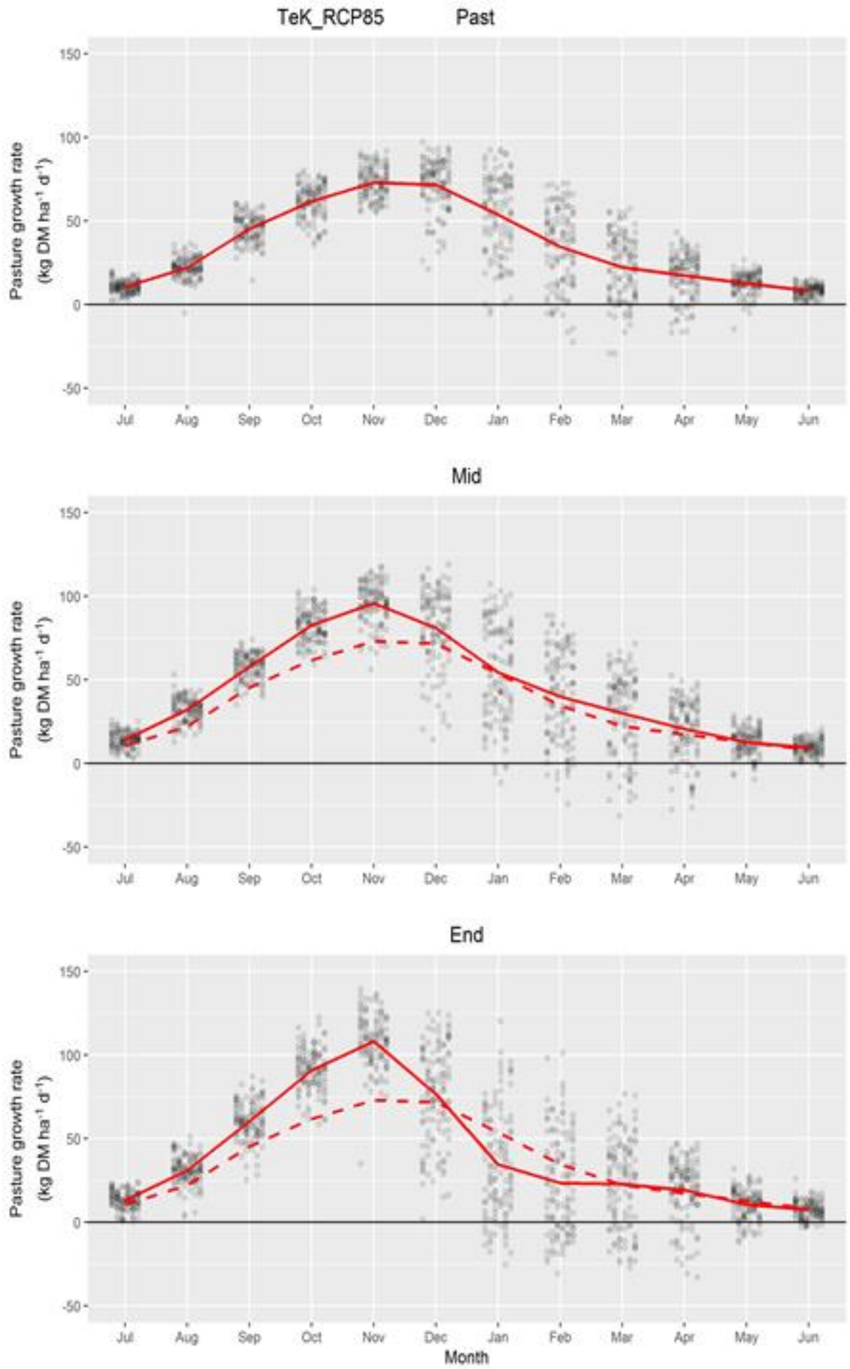

Figure 2 . Representative current (Past), mid-century (Mid) and end of the century (End) monthly pasture growth curve changes in one of the locations/soils (Waikato / Te Kowhai soil) under RCP8.5. Dots represent the six GCMs (columns) and 20 years (rows) with no colour coding. Dashed lines in the Mid and End panels are the current growth curves.

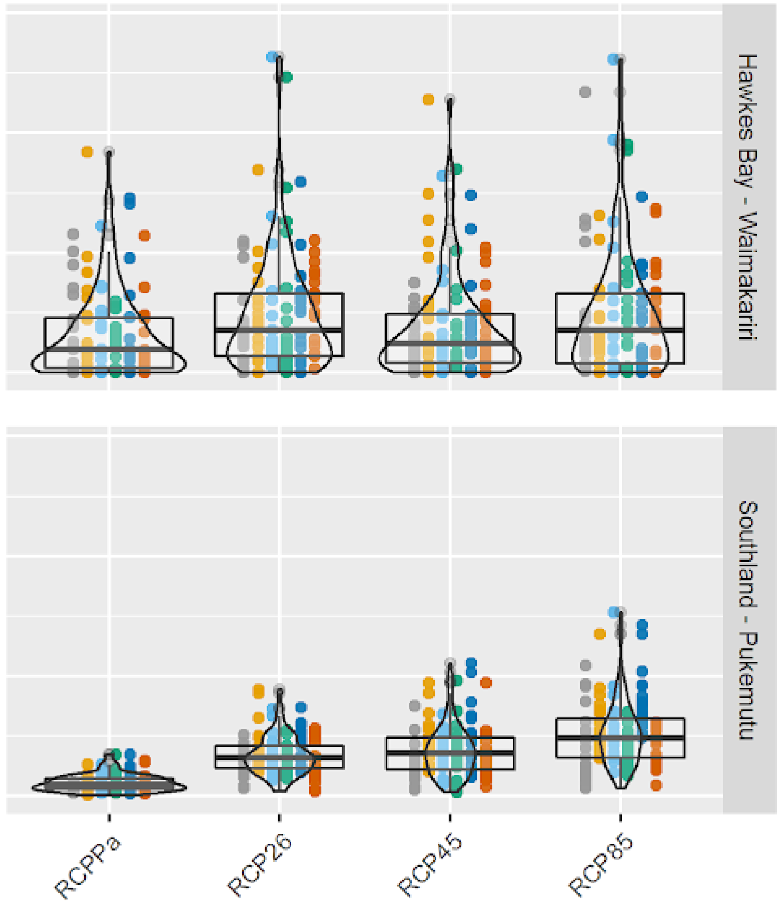

Figure 3. Annual nitrogen leaching for two locations (Hawke's Bay and Southland) and soils (Waimakariri and Pukemutu) under current conditions (RCPPa) and the three RCPs at the middle and end of the century. Dots represent the six GCMs (columns) and 20 years.

Viticulture simulations show an overall advance in flowering, véraison, and sugar ripeness by mid-century, with a more pronounced advance by the end of the century (Ausseil et al. 2021). The results show that the magnitude of changes depends on the combination of greenhouse gas emission pathway, grape cultivar, and region.

The potential change in suitability for onions and potatoes considering specific stress metrics is shown in Figures 4 and 5. Without comprehensively considering other stress metrics that might also be relevant under climate change, these results suggest that it might be harder to grow onions in Canterbury due to greater heat stress risk, but there might be more opportunities to grow potatoes in Otago due to less frost risk.

Figure 4. Change in the suitability of growing onions in Canterbury when considering heat stress risk by the end of the century.

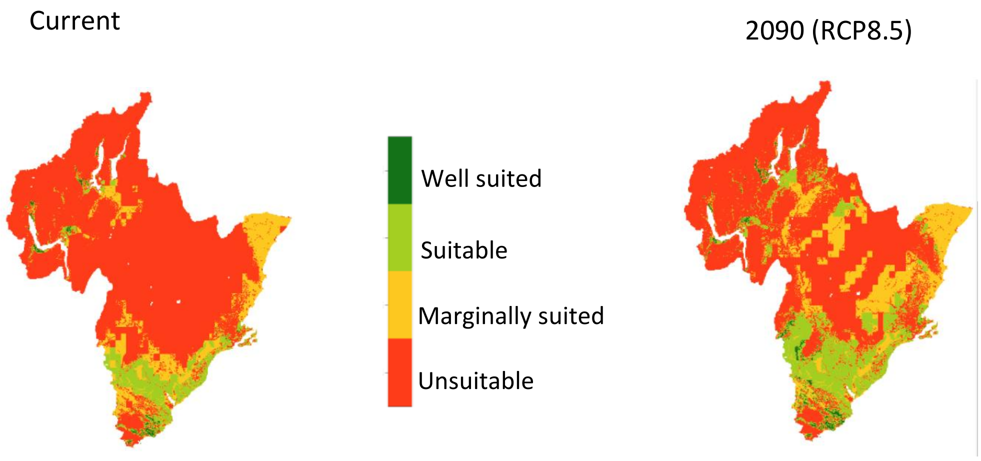

Figure 5. Change in the suitability of growing potatoes in Otago when considering frost risk by the end of the century.

2) Impact on erosion

Projected percentage changes in sediment yields are largest in the North Island (Figure 6), particularly in the soft-rock hill-country areas of the central and lower North Island and Northland, which increase in yield by >100% by 2090 under RCP8.5. By contrast, areas around Mt Taranaki, north-eastern Waikato, and the axial ranges between Hawke's Bay and Bay of Plenty see a decrease in sediment yields. This spatial pattern of change in sediment yields is similar in the North Island across the four RCPs for both mid and late century. This differs from the South Island, where some regions have opposing directions of change by 2090 between RCP2.6 and RCP8.5.

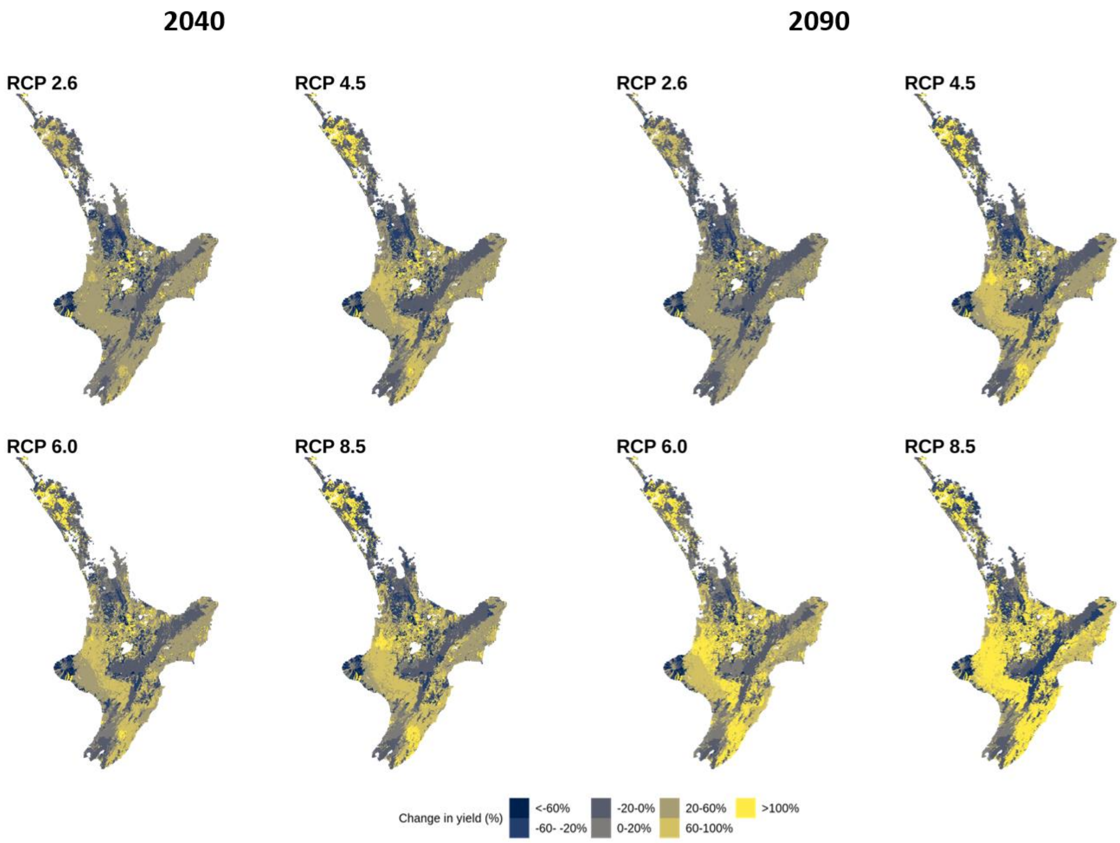

Figure 6. Projected median percentage change in suspended sediment yield for each segment watershed in the digital stream network for each RCP across the North Island, based on the six GCMs.

There is less variation in percentage changes in erosion across the four RCPs in the South Island (Figure 7). This result may reflect limitations in the application of the model framework to the

South Island, where areas of hard-rock geology and alpine terrain dominate, and are represented by NZeem® with no erosion process differentiation, so changes in yield are driven by changes in mean annual rainfall only. Potential changes in the alpine environment under climate change – such as reduced snow cover duration and extent, glacier recession, warming of perennially frozen ground, and thawing of ground ice (Barry 2005) – are not represented in the model, but may alter the dynamics of sediment load generation from mountain terrain in the South Island.

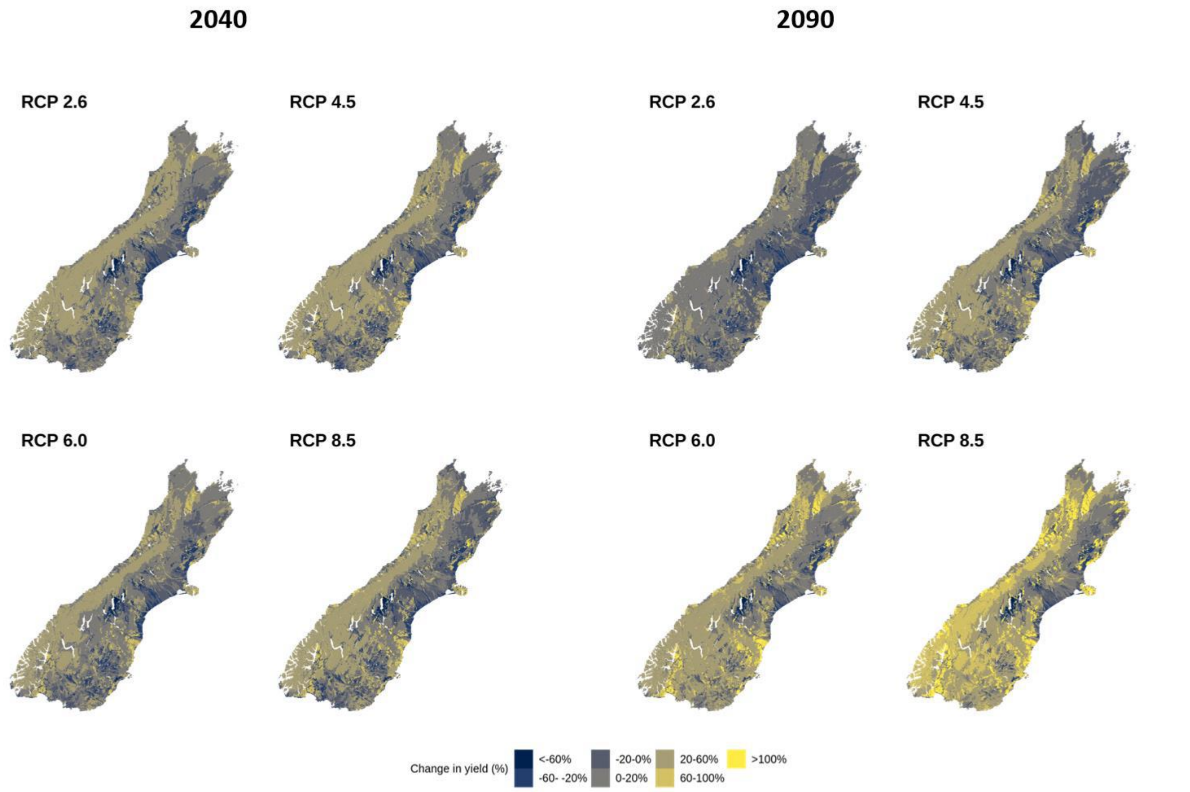

Figure 7. Projected median percentage change in suspended sediment yield for each segment watershed in the digital stream network for each RCP across the South Island, based on the six GCMs.

3) Other work

In other progress, an approach that includes a dynamic crop coefficient has been developed (for use in assessing drought conditions) and is currently being tested. This will allow the assessment of drought on a range of annual crops to be explored. Work is underway to collect the data to develop the statistical model of facial eczema.

Discussion

1) Risks and opportunities

For chronic effects, the various climate change projection scenarios showed a general pasture increase in the spring but declines in the summer. The seasonality and spatial suitability of some crops will change. For example, maize crops could be planted earlier to minimise negative climate change impacts (Teixeira et al. 2018). Under the highest emission scenario, grapes could flower up to 2 weeks earlier for the Sauvignon Blanc variety in Marlborough, and 4 weeks earlier for Pinot Noir in Central Otago by mid-century. New areas could become suitable for grapes as the frost risk decreases (Ausseil et al. 2021).

Keller et al (2021) showed that even though annual pasture yields in New Zealand are projected to increase, the seasonal pattern will probably change, with more favourable conditions in winter and spring, and less growth projected in summer due to an increase in water demand. The regional differences mean that some regions will also require more adaptation than others.

From an environmental perspective, the model results suggest that nitrate leaching could be higher and more variable, with increasing variability in the timing and intensity of rainfall events. Erosion rates are also likely to increase in parts of the North Island due to an increase in storminess.

For acute effects, drought was shown to be an increasing issue in regions that are already drought-prone (Ausseil et al. 2019). The sensitivity of the crop or pasture depends on the water demand profiles. Heat stress could increase, affecting animal welfare and milk production from dairy cows (Bryant et al. 2007; Ausseil et al. 2019).

2) Adaptation strategies for agriculture in New Zealand

The level of adaptation needed will depend on the global warming trajectory and future climate change projections. These measures can range from tactical, to strategic or transformational changes. For example, tactical changes in the short term could involve changes in sowing dates and genotypes in annual crops (Teixeira et al. 2018), and bringing in feed, or changing the mix of pasture and crops or pasture species (Keller et al. 2021). Strategic changes involve changing a current system, such as changing the ratio of sheep to cattle, increasing lambing percentage or installing irrigation. These changes can take many years. Transformational changes may involve considering a change in land use if the activity becomes unviable.

3) Future directions: the way forward

Given the complexity and uncertainty of climate change projections, a risk approach combining hazard, sensitivity, and adaptive capacity has been used by the IPCC to help communicate the adverse impacts of climate change and response options. We plan to adopt this risk-assessment approach, combining hazard, susceptibility, and adaptive capacity for each major risk. The biophysical models can help to assess the susceptibility of crops to future climate, with the hazard described by the likelihood of extreme events occurring in different parts of the country.

References

Ausseil A-G, van der Weerden T, Beare M, Teixeira E, Baisden W, Lieffering M, Guo J, Keller E, Law R, Noble A 2019. Climate change impacts on land use suitability Manaaki Whenua-Landcare Research Contract Report LC3573. 78 p. https://deepsouthchallenge.co.nz/wp-content/uploads/2021/01/Climate-change-impacts-on-land-use-suitability.pdf.

Ausseil A-GE, Law RM, Parker AK, Teixeira EI, Sood A 2021. Projected Wine Grape Cultivar Shifts Due to Climate Change in New Zealand. Frontiers in Plant Science 12(679), https://doi.org/10.3389/fpls.2021.618039.

Barry R 2005. Alpine climate change and cryospheric responses: an introduction. In: De Jong C, Collins D, Ranzi R eds. Climate and hydrology of mountain areas. Chichester, John Wiley and Sons. Pp. 1-3.

Basher L 2013. Erosion processes and their control in New Zealand. In: Dymond J ed. Ecosystem services in New Zealand – conditions and trends. Lincoln, New Zealand, Manaaki Whenua Press. Pp. 363–374.

Basher L, Spiekermann R, Dymond J, Herzig A, Hayman E, Ausseil A-G 2020. Modelling the effect of land management interventions and climate change on sediment loads in the Manawatū–Whanganui region. New Zealand Journal of Marine and Freshwater Research 54: 490–511.

Beare M, van der Weerden T, Ausseil A-G, Baisden W, Teixeira E, Vogeler I, Keller E, de Klein C 2017. Identifying climate attributes that impact on land use suitability, PFR Contract Report 34484, SPTS No. 15283. 32 p.

Bryant JR, López-Villalobos N, Pryce JE, Holmes CW, Johnson DL 2007. Quantifying the effect of thermal environment on production traits in three breeds of dairy cattle in New Zealand. New Zealand Journal of Agricultural Research 50: 327-338.

Donovan M, Monaghan R 2021. Impacts of grazing on ground cover, soil physical properties and soil loss via surface erosion: A novel geospatial modelling approach. Journal of Environmental Management 287: 112206, https://doi.org/10.1016/j.jenvman.2021.112206.

Dymond JR, Betts HD, Schierlitz CS 2010. An erosion model for evaluating regional land-use scenarios. Environmental Modelling & Software 25(3): 289-298, https://doi.org/10.1016/j.envsoft.2009.09.011.

Holzworth DP, Huth NI, deVoil PG, Zurcher EJ, Herrmann NI, McLean G, Chenu K, van Oosterom EJ, Snow V, Murphy C and others 2014. APSIM – Evolution towards a new generation of agricultural systems simulation. Environmental Modelling & Software 62: 327-350, https://doi.org/10.1016/j.envsoft.2014.07.009.

Keller E, Lieffering M, Guo J, Baisden W, Ausseil A-G 2021. Climatic factors influencing New Zealand pasture resilience under scenarios of future climate change. NZGA: Research and Practice Series: Resilient Pastures Symposium 17, https://doi.og/10.33584/rps.17.2021.3458.

Ministry for the Environment 2018. Climate Change Projections for New Zealand: Atmospheric projections based on simulations undertaken for the IPCC 5th Assessment, MFE 1385. https://environment.govt.nz/publications/climate-change-projections-for-new-zealand/.

NIWA 2022. New Zealand Drought Index and Drought Monitor Framework29 March 2022, from https://niwa.co.nz/sites/niwa.co.nz/files/NZDI_more_info.pdf

Parker AK, de Cortázar-Atauri IG, van Leeuwen C, Chuine I 2011. General phenological model to characterise the timing of flowering and veraison of Vitis vinifera L. Australian Journal of Grape and Wine Research 17(2): 206-216, https://doi.org/10.1111/j.1755-0238.2011.00140.x.

Parker AK, García de Cortázar-Atauri I, Gény L, Spring J-L, Destrac A, Schultz H, Molitor D, Lacombe T, Graça A, Monamy C and others 2020. Temperature-based grapevine sugar ripeness modelling for a wide range of Vitis vinifera L. cultivars. Agricultural and Forest Meteorology 285-286: 107902, https://doi.org/10.1016/j.agrformet.2020.107902.

Rutledge D, Ausseil A-G, Baisden T, Bodeker G, Booker D, Cameron M, Collins D, Daigneault A, Fernandez M, Frame B and others 2017. Climate change impacts and implications for New Zealand to 2100: Identifying feedbacks , understanding cumulative impacts and recognising limits: a national integrated assessment. https://niwa.co.nz/sites/niwa.co.nz/files/RA3-Synthesis-report.pdf.

Smith HG, Spiekermann R, Dymond J, Basher L 2019. Predicting spatial patterns in riverbank erosion for catchment sediment budgets. New Zealand Journal of Marine and Freshwater Research 53(3): 338-362, https://doi.org/10.1080/00288330.2018.1561475.

Sood A 2014. Improved bias corrected and downscaled regional climate model data for climate impact studies: validation and assessment for New Zealand. https://www.researchgate.net/publication/265510643_Improved_Bias_Corrected_and_Downscaled_Regional_Climate_Model_Data_for_Climate_Impact_Studies_Validation_and_Assessment_for_New_Zealand.

Spiekermann R, Dymond J, Betts H, Marden M 2017. SedNetNZ modelling of sediment sources and loads in the Northern Hawke's Bay Region, Manaaki Whenua – Landcare Research Contract Report LC2815

Teixeira EI, de Ruiter J, Ausseil A-G, Daigneault A, Johnstone P, Holmes A, Tait A, Ewert F 2018. Adapting crop rotations to climate change in regional impact modelling assessments. Sci. Total Environ. 616–617: 785–795, https://doi.org/10.1016/j.scitotenv.2017.10.247.

Trustrum N, Gomez B, Page M, Reid L, Hicks D 1999. Sediment production, storage and output: the relative role of large magnitude events in steepland catchments. Zeitschrift für Geomorphologie N.F. Supplement 115: 71-86.