Adaptation strategies to climate change for New Zealand cropping rotations

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Abstract
Projected climate change (CC) at global and regional scales will have large impacts on agricultural systems. Increasing atmospheric CO_2 concentrations, temperature and particularly altered patterns of precipitation will require adaptations to how these cropping systems are managed. In New Zealand, cropping systems are characterised by intensive and flexible multi-crop rotations. Impacts of climate change and the benefits of specific adaptation options are expected to differ among different crops within a rotation. Using the Agricultural Production Systems sIMulator (APSIM) we evaluated the likely benefits of two possible adaptations for the 2030–2049 period, assuming the SRES-IPCC A2 climate scenario. These were (i) migrating maize silage crops further south in New Zealand and (ii) decreasing allowances of irrigation water for a crop rotation in Canterbury to adapt to CC. This analysis highlighted the contrasting response of crops species. Warmer temperatures would enable an increase in maize silage yields and quality (grain fraction) in southern regions due to longer growth seasons. Limited irrigation water allocations in Canterbury would affect crop species differently. Autumn sown wheat, peas and kale responded positively up to irrigation allowances of 300 mm/year. In contrast, winter crops, such as cereal forage, reached maximum yield at an irrigation allowance of ≤200 mm. Soil water holding capacity (WHC) was an important influence when considering irrigation allocation. The greater capacity of deeper soils to store water could buffer crops from drought stress and increase yields by ~10% at high irrigation quotas to nearly twofold under rain-fed conditions.

Key Words
Adaptation, APSIM, climate-change, crop-rotation, irrigation.

Introduction

Warmer temperatures and changes in the amount and distribution of rainfall due to climate change (CC) will be key environmental factors affecting future crop yields in New Zealand. In order to minimise CC negative impacts and to explore potential opportunities of a new climate, it is important to evaluate crop responses to adaptation options. The benefits of different adaptive technologies can be quantified using crop simulation models. New Zealand arable cropping relies on intensive rotations that include a wide variety of crop species. In this paper, we explore two adaptation case studies for arable cropping systems in New Zealand. First, we quantify the benefits of a potential southwards migration of maize silage crops due to warmer temperatures. Silage maize is a key forage option used as feed supplement in intensive New Zealand dairy systems. However, cold temperatures currently constrain crop development and the economic production of maize silage in Southland. Second, we assess the benefits of providing additional irrigation water to increase yields and reduce yield variability in Canterbury. Irrigation is a key strategy to adapt to potentially drier and warmer conditions due to climate change. Pressure to share limited water resources fairly and reduce environmental impacts of intensive crop management means that water allocations may decrease in the future. We therefore assess the yield impact of decreasing allowances of irrigation water. In both case-studies, we use the Agricultural Production Systems sIMulator (APSIM) to evaluate the yield responses of crop species currently used in typical New Zealand rotations for a baseline climate (1980–1999) and a climate change scenario for the period of 2030–2049.

Methods

The APSIM model

APSIM is a modular modelling framework that has been developed in Australia to simulate the responses of biophysical processes of cropping systems to management practices and climate (McCown *et al.*, 1996). The model has been extensively described and tested for different crops and a range of environments (Keating *et al.*, 2003) including New Zealand cropping rotations (e.g. Teixeira *et al.*, 2010; Teixeira *et al.*, 2011).

Simulation experiments set-up
Simulations were used to assess crop yield responses to climate, irrigation, crop species, soil type and policies of water allocation. Both case study simulations were performed for a 20-year period baseline (1980–1999) and a future A2 climate scenario in the 2030–2049 period (IPCC, 2000). Sufficient nitrogen fertiliser was supplied to ensure yields were not N-constrained. Downscaled weather data from the National Institute of Water and Atmospheric Research (NIWA) Regional Climate Model were used in both case study simulations. For the first adaptation study, a rotation with silage maize→ winter forage was set for the Southland region (-45°59'S, 168°58'E). For the second adaptation study, a typical 3-year crop rotation (winter-sown wheat → autumn-sown cereal forage → spring-sown kale → spring-sown barley → spring-sown pea → spring-sown barley) was simulated for Canterbury (-43°45'S, 171°49'E) considering irrigation allowances from 0 to 1000 mm/year. Three replicate simulations (each offset by 1 year) were run to ensure each crop in the rotation was present in each of the 20 years. The scenarios were run for both a high water holding capacity (WHC) soil (160 mm WHC) and a low WHC soil (80 mm WHC). The irrigation rule in APSIM was set to apply water at a variable frequency to maintain soil water content above 50% water holding capacity in the top 600 mm of soil. Irrigation allowance values represent a hypothetical 100% irrigator efficiency and therefore can be interpreted as "effective" irrigation allowances.

Results and Discussion

Adaptation study 1: Maize migrating to higher latitudes
Simulation results suggest that yield of maize silage in Southland could increase from 3% under rain-fed conditions to 8% under irrigated conditions due to climate change (Figure 1a). In addition, silage quality is expected to increase due to ~5% higher grain concentration in total silage biomass (Figure 1b). Longer growth periods enabled maize crops to intercept more light and fill grains until later in the season, increasing grain yields. Therefore, a warmer climate in Southland by the middle year 2040 would enable higher yields with better quality silage (higher energy and lower moisture content) with benefits to the silage fermentation process and livestock performance. The use of maize at higher latitudes could be seen as an adaptive option to seize an opportunity created by a warmer climate.

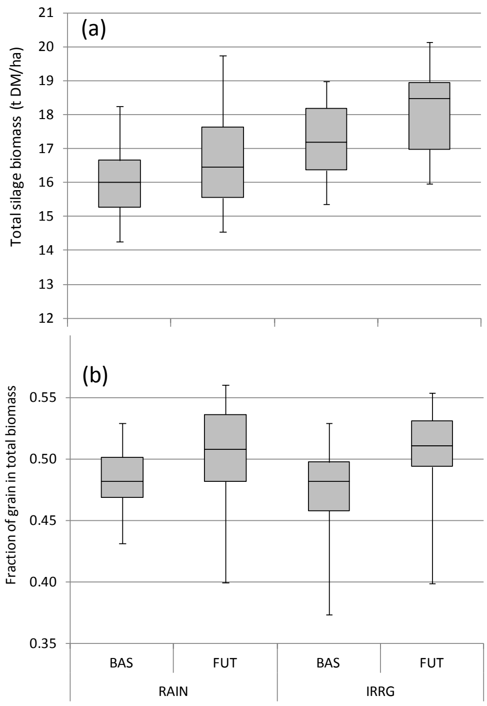

Figure 1. Simulated total biomass (a) and grain fraction in dry matter (b) of silage maize in Southland, New Zealand for a baseline climate (BAS, 1980-1999) and a future (FUT, 2030–2049) A2 climate change scenario from IPCC under rain-fed (RAIN) and irrigated (IRRG) conditions. Line is the median, boxes edges are the 25th and 95th percentile and whiskers delimit the 5th and 95th percentile of 20-year simulations.

Adaptation study 2: Using irrigation under a reduced water allocation policy scenario

Irrigation was an important adaptation option to enable high yields (Figure 2). Overall, results show that effective irrigation allowances >300 mm per year would be necessary to adapt to future 2030–49 climate. Although responses were similar for the baseline and future climates, benefits differed with crop species. Summer-sown kale was the most responsive crop to irrigation allowances (Figure 2a). Yield started to decline at allowances below 300 mm because water demand is highest during summer, when most of kale growth occurs. In contrast, wheat and barley grow mostly during the cooler periods (autumn and spring) reaching maximum yields above 100 or 200 mm of effective irrigation allowance per year. Barley was less responsive than wheat owing to its shorter growth duration and consequent lower water demand. Winter-cereal and pea crops (not shown) responded similarly to autumn sown wheat under a light soil type.

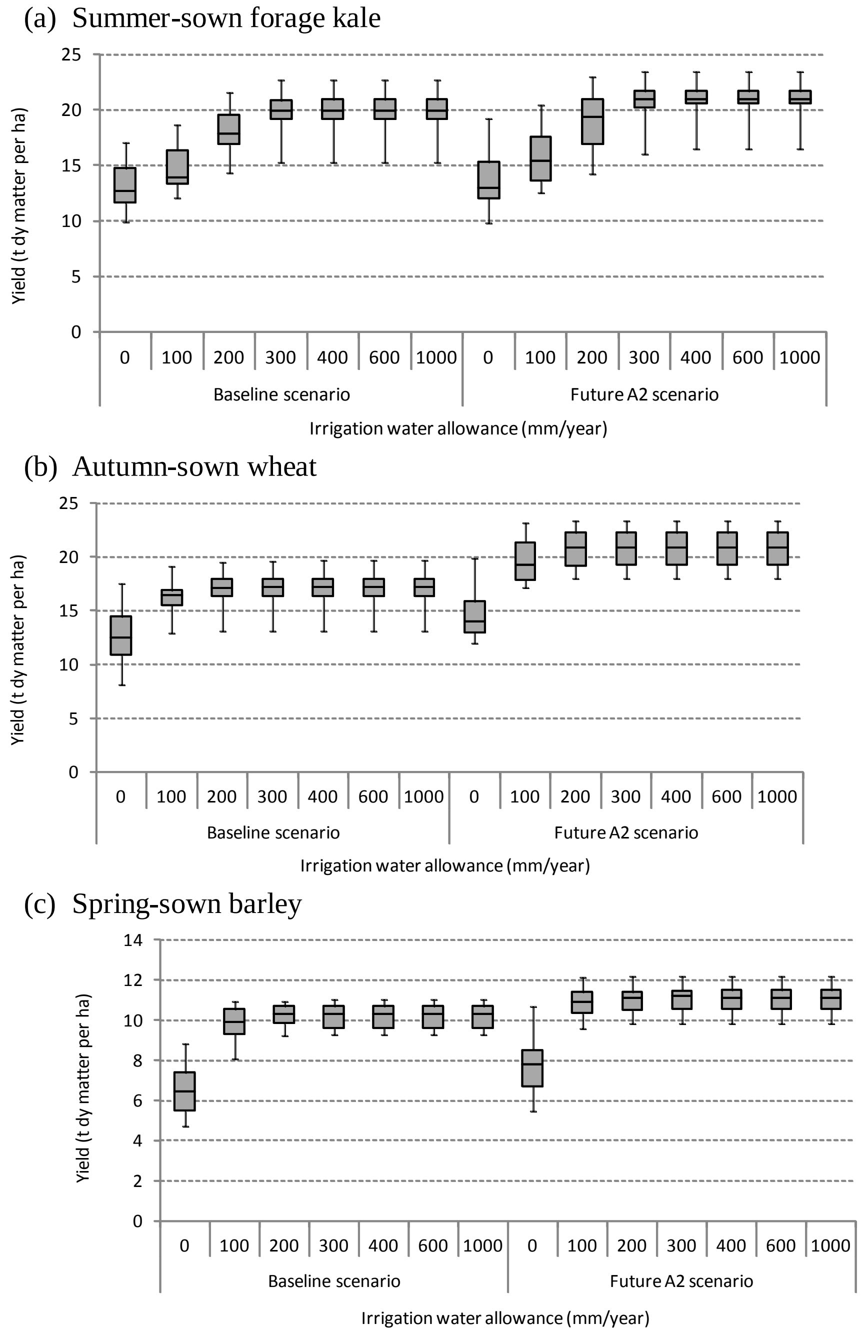

Figure 2. Simulated yield of contrasting crops in response to irrigation water allowances on a low water holding capacity soil (80 mm available water) for a baseline climate (1980-1999) and a future (2030-2049) climate change scenario A2 from IPCC. Line is the median, boxes edges are the 25th and 95th percentile and whiskers delimit the 5th and 95th percentile of 20-year simulations.

These results do not consider the risk of extreme events (e.g. severe droughts and heat waves) that may become more intense and frequent with climate change.

Impact of soil type

The strategic allocation of crops in different soils can also increase adaptive capacity of arable systems. Soils with high water holding capacity enabled higher yields, particularly under low irrigation allowances or rain-fed conditions (Figure 3). However, the net benefit of adapting soil type depends on the crop grown. For example, spring sown barley produced at least 60% more in high WHC than in low WHC soils, while autumn sown wheat crops produced only 10 to 30% more.

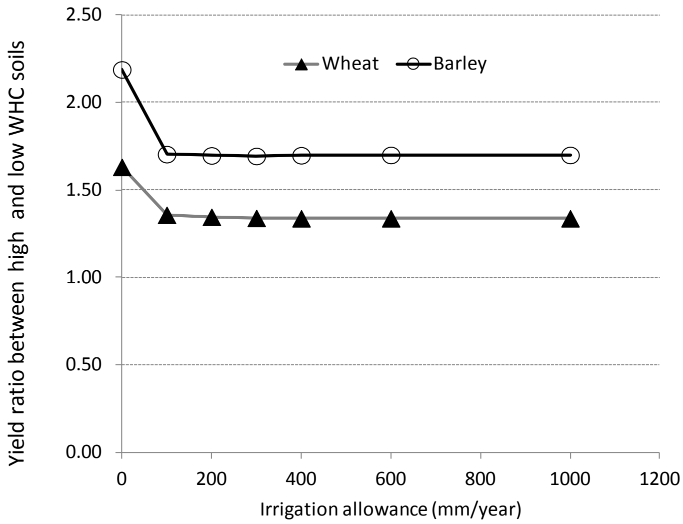

Figure 3 Yield ratio of total biomass between high and low water holding capacity (WHC) soil types (160 and 80 mm WHC, respectively) for autumn sown wheat and spring sown barley crops for irrigation allowances ranging from 0 to 1000 mm/year. Results are pooled for baseline and future climates.

Conclusions

We used a crop model to quantify potential benefits of adaptation to climate change for New Zealand arable systems. By changing species, such as using maize in southern areas of the country (adaptation study 1), farmers could harness the opportunities of warmer temperatures on crop growth and development. In adaptation study 2, the importance of irrigation application is highlighted as an adaptive option. Water allowance policies may need to take crop type and soil characteristics into consideration because these also affect net benefits of irrigation. Our results highlight the value of using crop models to quantify benefits of adaptive options when assessing complex combinations of crop species, crop management, climate scenarios, policies of resource allocation and soil types.

Acknowledgements

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