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Adapting crop rotations to climate change in regional impact modelling assessments

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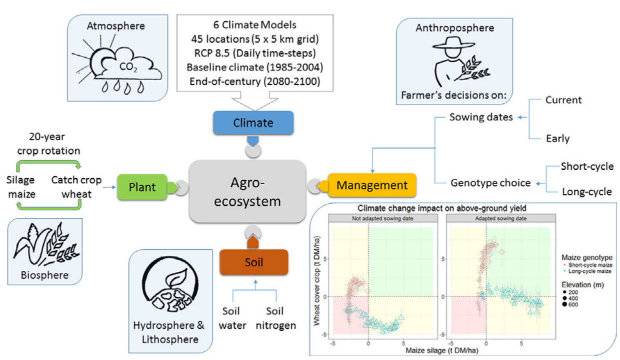
HIGHLIGHTS

- We assess spatial variability in adaptation of crop rotations to climate change.
- Climate change impacts differed depending on how adaptation was represented.
- Adaptation of one crop had carryover effects on following crops of the rotation.
- Rotation responses to climate change and adaptation were spatially variable.
- Results illustrate methodological aspects to adapt rotations in spatial assessments.

GRAPHICAL ABSTRACT



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ABSTRACT

The environmental and economic sustainability of future cropping systems depends on adaptation to climate change. Adaptation studies commonly rely on agricultural systems models to integrate multiple components of production systems such as crops, weather, soil and farmers' management decisions. Previous adaptation studies have mostly focused on isolated monocultures. However, in many agricultural regions worldwide, multi-crop rotations better represent local production systems. It is unclear how adaptation interventions influence crops grown in sequences. We develop a catchment-scale assessment to investigate the effects of tactical adaptations (choice of genotype and sowing date) on yield and underlying crop-soil factors of rotations. Based on locally surveyed data, a silage-maize followed by catch-crop-wheat rotation was simulated with the APSIM model for the RCP 8.5 emission scenario, two time periods (1985–2004 and 2080–2100) and six climate models across the Kaituna catchment in New Zealand. Results showed that direction and magnitude of climate change impacts, and the response to adaptation, varied spatially and were affected by rotation carryover effects due to agronomical (e.g. timing of sowing and harvesting) and soil (e.g. residual nitrogen, N) aspects. For example, by adapting maize to early-sowing dates under a warmer climate, there was an advance in catch crop establishment which enhanced residual soil N uptake. This dynamics, however, differed with local environment and choice of short- or long-cycle maize genotypes. Adaptation was insufficient to neutralize rotation yield losses in lowlands

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but consistently enhanced yield gains in highlands, where other constraints limited arable cropping. The positive responses to adaptation were mainly due to increases in solar radiation interception across the entire growth season. These results provide deeper insights on the dynamics of climate change impacts for crop rotation systems. Such knowledge can be used to develop improved regional impact assessments for situations where multi-crop rotations better represent predominant agricultural systems.

1. Introduction

Agriculture is one of the most sensitive economic sectors to climate change (Godfray et al., 2010). Historically, agronomic practices have developed and evolved under relatively stable climatic conditions. Therefore, with the fast pace of climatic changes observed in the past decades (Smith et al., 2015) and projected for the next century (IPCC, 2007a) current agronomic practices will be challenged and will require refinement. In climate change impact assessments for agricultural systems, changes to agronomic management are often formulated as farm-level reactive interventions to manage risks and/or enhance productivity (IPCC, 2007b). The inherent capacity that individual farmers have to adapt agricultural practices to changing conditions is a valuable knowledge-asset that influences regional and global food security. For example, risks due to weather variability between years are often managed by shifting sowing dates, genotype choices or the combination of crop species in a rotation (Porter et al., 2014). It is, therefore, critical to develop methods to include farmers' tactical adaptation into climate change impact assessments to assess their effect on the direction and magnitude of estimated climate change impacts (Ewert et al., 2015). Biophysical process-based models are one of the most commonly applied tools for assessing crop responses to climate change impacts and adaptation (Rosenzweig et al., 2013). For example, biophysical models often show large yield losses due to climate change when adaptation is not considered for maize crops (Bassu et al., 2014; Liu et al., 2016), the cereal with the largest global production (FAOSTAT, 2017). In contrast, when adaptations are considered, negative impacts of climate change are often minimized or reverted, although results vary across and within studies (Butler and Huybers, 2013; Challinor et al., 2014). Tactical management adjustments by maize growers, particularly the use of long-cycle genotypes, were estimated to increase maize yields from 7% to 57% in Northeast China, depending on the sub-region assessed (Zhao et al., 2015b). Additional gains from adaptation were projected when the widening of the growth season due to a warmer climate was considered, as the analysis of entire season provides a more comprehensive quantification of trade-offs with previous and following crops in multi-crop sequences (Fletcher et al., 2011). A literature review by White et al. (2011) has shown that ~60% of the assessed climate change impact studies included for some representation of adaptation, and a mere 5% considered crop rotation sequences specifically. This is an important gap because in many agricultural regions worldwide, including New Zealand, multi-crop rotation sequences to improve productivity and minimize environmental impacts are commonplace. It is unclear the extent of the carryover effects of one crop to the next, e.g. through the timings of crop transitions (Fletcher et al., 2011) and residual soil water and nitrogen conditions (Teixeira et al., 2015) that can influence adaptation assessment results. This understanding is particularly important for regional assessments that require aggregation of model inputs and/or results spatially, because adaptation may have contrasting effects on the different crops in the rotation, depending on local environmental conditions. In this study we designed a biophysical modelling case study to assess the effects of farmers' tactical adaptations on crop rotations, across an exemplar catchment in New Zealand where sequences with maize crops are historically practiced. Our aim is to understand how tactical adaptation options influence spatial patterns of climate change impacts across the entire length of a crop rotation. Insights from this analysis are expected to inform large-area impact assessments where complex agricultural systems, such as crop rotations, more accurately represent production systems in practice.

2. Materials and methods

2.1. Study location and agronomic scenario

The modelling experiment was performed across approximately 115,000 ha of the Kaituna catchment, Bay of Plenty, New Zealand (Fig. 1). The catchment represents a typical lowland environment in New Zealand which is occupied by a diverse mix of primary production activities (cropping, horticulture, forestry, dairy, sheep and beef farming) and natural ecosystems (freshwater wetlands and native forests) areas (Ausseil et al., 2016). There is a progressive increase in elevation from the north-eastern coastal areas (near sea level) to the most south-eastern areas at ~800 m above sea level (Fig. 1).

To quantify differences between current and future climate projections, a continuous crop rotation (i.e. without re-setting of soil carbon, nitrogen or water conditions) was simulated across the entire catchment area. The main crop in the rotation was spring-sown maize (*Zea mays*) for silage. An autumn catch crop of forage wheat (*Triticum aestivum*) was sown after the harvest of maize at silage maturity. The selection of this specific rotation aimed solely to represent a plausible crop sequence, without any intent to depict either current or future land uses across the catchment, which are largely driven by factors beyond the scope of our investigation (e.g. market forces, infrastructure, local culture and land use regulations). Silage maize followed by a winter cereal was found to be one of the most productive, i.e. >30 t (t; 1000 kg) of dry matter (DM) per ha/year, crop rotations across New Zealand (de Ruiter

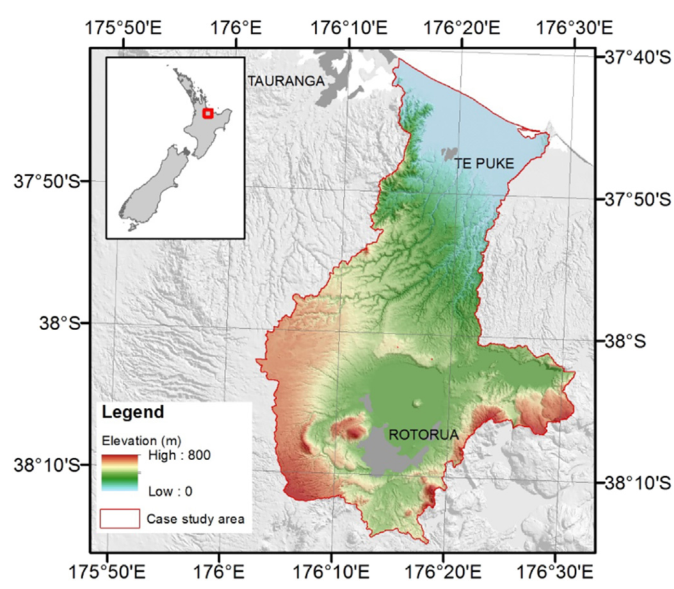

Fig. 1. Case-study area in the Kaituna catchment, Bay of Plenty, New Zealand. The map shows contrasts in elevation across the catchment area, meters above sea level.