A dynamic simulation model for an agricultural catchment driven by markets, farmers attitude and rainfall change

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Abstract

Due to the complex interactions of individual farmer's behaviour interacting with the bio-physical landscape, the large range of multiple external and internal factors and the further complication from continuous changes of variables in time and space, it is impossible with linear and single-discipline approaches to assess the potential impact of future climate change on an entire agricultural region. Therefore, a dynamic multi-agent based simulation model was developed combining simplified bio-physical processes of paddock cover, dryland salinity changes and rainfall with farm profitability and farmer decisions on land use in an agricultural catchment. Individual farmers (agents) in the model make individual land use decisions based on the performance of their past land cover productivity and market returns. The modelled willingness to adapt to market drivers and the ability to maximise returns varies across farmers. In addition, farmers in the model can have various attitudes towards salinity mitigation as a consequence of salinity being on their farm, in the neighbourhood or region and can adopt land use changes with less salinity impact. The simulation with this model for a case study with historical rainfall records indicated similar trends of crop-pasture ratios, salinity change and farm decline observed in the last 20 years in the Katanning catchment of Western Australia. Using the model for future scenarios highlighted the importance of rainfall changes and wide-spread willingness of farmers to combat dry land salinity. Rainfall changes as a consequence of climate change, in particularly changes in the sequence of dry and wet seasons and the adaptation to these sequences by farmers seems to be critical for farm survival in this catchment.

Introduction

The potential impact of future climate change on an entire agricultural region is often not clear (IPCC Report 2007) due to the complex interactions of individual farmer's behaviour interacting with the bio-physical landscape, the large range of multiple external and internal factors and the further complication from continuous changes of variables in time and space. To study likely impact scenarios of future rainfall changes and potential adaptation strategies and its consequences on socio-economic and environmental indicators of an entire agricultural region including individual farmers behaviour, a dynamic multi-agent based simulation model was developed to simulate the complex interactions of bio-physical processes of paddock cover, dryland salinity changes, rainfall changes, market signals, farm profitability and individual farmer decisions on lands use in an agricultural catchment.

Methodology

A dynamic multi-agent based simulation model was developed in CORMAS (Bousquet et al. 1998) as a research tool. The model combines simplified bio-physical processes of paddock cover, dry-land salinity changes and rainfall with farm profitability and individual farmer decisions on lands use in an agricultural catchment parameterised for the Katanning region (a sub-catchment of the Blackwood River) in the south-west of Western Australia. The region consists of 300,000 ha with about 280 crop/sheep or mixed farms, 84% arable land, 10% native vegetation and 6% salinity. In the model the catchment is divided into individual 100-ha units. Average farm size is about 1100 ha, with individual farms ranging between 50 and 9,000 ha. In the model, simulated individual farmers (agents) make individual land use decisions on individual 100-ha units belonging to their farm, based on the performance of their past land cover productivity and market returns. Individual 100-ha units contribute to changes of catchment salinity as a result of rainfall and land cover. While all units contribute to salinity in the catchment, only parts of the catchment will be affected by salinity. The modelled willingness to adapt to market drivers and the ability to maximise returns varies across farmers. In addition, farmers in the model can have various attitudes (not profit driven) towards salinity mitigation as a consequence of salinity being on their farm, in the neighbourhood or region, and can adopt land use changes with less salinity impact.

Results

The simulation with this model for a case study with historical rainfall records indicated similar trends of crop-pasture ratios, salinity area changes and farm number declines observed in the last 20 years in the Katanning catchment of Western Australia (data not shown). This gave some confidence in that the model is capable to reproduce spatial and temporal dynamics of the catchment.

Using the model for future scenarios highlighted the importance of rainfall changes and wide-spread willingness of farmers to combat dryland secondary salinity (caused by excess water in annual cropping and pasture systems, draining this excess water below the potential root zone with consequently increasing saline water table rises in parts of a catchment). Figure 1 show results from a 100-years simulation experiment with a randomly created rainfall data based on the rainfall of the last 20 years in the Katanning region. Current input costs and market returns were assumed for this experiment, which of course are likely to change in the future. Of particular interest in this hypothetical experiment are the different periods of high and low rainfall years. In periods of high rainfall, e.g. 2005-2020 or 2040-2050 (Fig. 1a), cropping would be favoured over pastures due to higher returns from wheat in wetter seasons (Fig.1b), farm numbers would decline less (Fig1c most obvious during the wet period 2070-2080), but salinity would continue to increase (Fig. 1d), while regional income would be relatively high compared to other drier periods (Fig. 1e). In contrast, during dry periods (Fig. 1a: e.g. 2020-2025 or 2080-2090), the cropping area would decline in favour of pastures which are less profitable (Fig. 1b), farm number decline would be accelerated due to increased bankruptcy (Fig. 1c), salinity spread would hold (e.g. 2020-2025) or even decline (e.g. 2080-2090) (Fig. 1d) and the regional income would be relative low (Fig. 1e). The adaptation to these different periods of rainfall in the model are temporally and spatially uneven, depending on farming history and rate of adaptation of individual farmers (data not shown). In other simulation experiments not shown here, but can be also derived from the results in Figure 1, future rainfall changes as a consequence of climate change are likely to have a large impact on reducing dryland salinity. And, continuous reductions in future rainfall might have more impact on salinity reductions than local or even wide-spread approaches of farmers in land-use changes (by introducing perennial pastures and trees for higher water use and less ground water recharge) trying to mediate salinity.

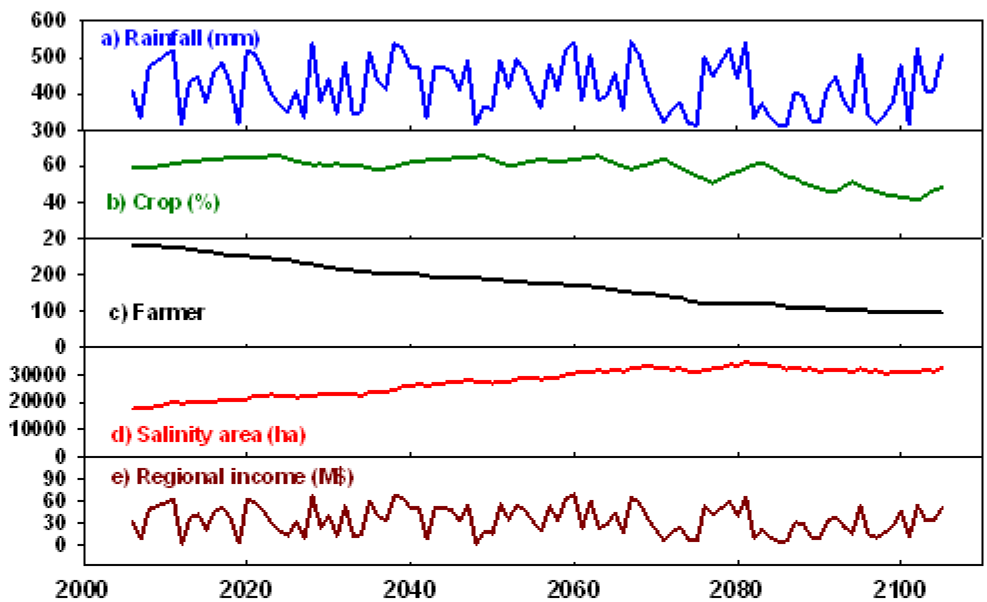

Figure 1: Simulation experiment using randomly created rainfall data based on the rainfall of the last 20 years of the Katanning region (300,000 ha) assuming current input costs and market returns.

Conclusions

A dynamic multi-agent based simulation model was developed to investigate the complex interactions of individual farmer's behaviour in a landscape with bio-physical processes of paddock cover, dry-land salinity changes, rainfall changes, market signals and farm profitability. The model could reproduce some historical dynamics of an agricultural landscape and was used to explore the sensitivity of socio-economic and environmental indicators of an agricultural region to rainfall change scenarios. Rainfall changes and in particularly changes in the sequence of dry and wet seasons and the adaptation to these sequences by farmers appeared to be critical for crop/pasture adaptation, salinity spread and farm survival in this catchment. As rainfall will not be the only future climate change, an extension of this model to include land cover responses to elevated atmospheric CO_2 and changes in air temperature will be necessary before using the model for full climate change impact and adaptation scenarios.

References

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