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Assessing local and regional economic impacts of climatic extremes and feasibility of adaptation measures in Dutch arable farming systems

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ABSTRACT

We propose a method that combines local productivity factors, economic factors, crop-specific sensitivity to climatic extremes, and future climate change scenarios, to assess potential impacts of extreme weather events on agricultural production systems. Our assessment is spatially explicit and uses discounted time series of cash flows taking into account expected future impacts on yield and crop quality, to estimate changes in the expected net present value (NPV) of agricultural systems. We assess the economic feasibility of a portfolio of adaptation measures by considering their initial investments, annual costs, and effectiveness in reducing crop damage. We apply the method to investigate potential economic impacts of extreme weather events in arable farming systems in the Netherlands around 2050. We find that the expected increase in extreme weather events frequency can severely affect future productivity potential. Particularly, heat waves, warm winters, and high intensity rainfall are expected to substantially undermine the future economic viability of Dutch arable farming systems. The results indicate considerable differences between regions in terms of vulnerability to climatic extremes: while some regions are severely impacted by all climatic extremes, other regions consistently demonstrate high resilience to increases in extreme event frequency. The findings are robust to a wide range of scenarios and suggest that the interactions between economic factors and management practices (particularly, crop specialisation) are decisive drivers of the economic viability of agricultural systems under more frequent climatic extremes. However, the exact magnitude of the impacts remains highly uncertain, as we do not consider endogenous interactions in market conditions resulting from climate change and socio-economic developments. Nevertheless, crop adaptation measures should be regarded as no-regret strategies, since they alleviate both economic impacts and uncertainty around impact magnitude. The proposed method provides insights in region-specific threats and opportunities that are relevant for stakeholders and policy-makers. This information improves communication on main climate risks at the local and regional levels and contributes to prioritising adaptation strategies.

1. Introduction

The economic viability of agricultural production systems depends on a complex combination of economic, technological and political factors operating within particular socio-cultural contexts, and according to the opportunities and constraints set by spatial factors (e.g. biophysical features, available transport networks; for an overview of the factors driving agricultural land use, see: Geist et al., 2006; Hersperger and Bürgi, 2007; Bakker et al., 2013; Van Vliet et al., 2015). Since the biophysical environment is spatially heterogeneous, location is a key factor in describing the economic viability of agricultural systems (Van der Hilst et al., 2010; Kuhlman et al., 2013; Diogo et al., 2014; Diogo et al., 2015). In addition to conditions that are relatively stable over time (e.g. soil characteristics), temporal dynamic factors such as weather conditions have shown to particularly influence attainable crop yields (Peltonen-Sainio et al., 2010). Future climate change impacts are likely to affect crop yields and, consequently, the economic viability of current agricultural systems (Jones and Thornton, 2003; Hermans et al., 2010; EEA, 2012).

Several modelling approaches have been implemented to quantitatively assess future impacts of climatic changes on potential crop yields and their implication in agricultural production systems. Crop growth models are frequently used to assess the effects of gradual climate changes, such as increasing CO_2 levels and changes in long-term

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temperature and rainfall patterns, on agricultural yields (e.g. Reilly et al., 2003; Parry et al., 2004; Wolfe et al., 2008; Elliott et al., 2014). It is however argued that the impacts on agricultural production of more frequent extreme weather events and related emergence of pests and diseases will be greater than those resulting from gradual pattern changes (Rosenzweig et al., 2001; Gregory et al., 2009; Iglesias et al., 2012; Schaap et al., 2013; Porter et al., 2014). Therefore, special attention should be given to the economic impacts on agricultural systems resulting from the damage caused by more frequent extreme weather events.

The need for design and deployment of adaptation measures is increasingly recognised, even in the event of moderate climate change (Van Vuuren et al., 2011; EEA, 2012). Extreme weather and climate events vary from place to place, occurring first at the local level and locally affecting people, but with impacts then cascading to different extents at the national and international levels (Field et al., 2012). Appropriate adaptation measures in agricultural systems should thus be identified according to the main climate risks in a region, following comprehensive approaches looking at different levels of impact (Howden et al., 2007) and taking into account the role of decisions made at the farm level (Schaap et al., 2011; Schaap et al., 2013; Reidsma et al., 2015; Mandryk et al., 2017). Yet, there is limited understanding of the interplay between local production capabilities, regional climatic changes and more general socio-economic conditions that determine the economic viability of agricultural systems and their ability to cope and adapt to future changing conditions. Improving this understanding can help formulating strategies at different regional levels that take into account the spatial heterogeneity in both local impacts and opportunities for adaptation.

In this paper, we describe a spatially-explicit method that allows:

- assessing and mapping the local impacts of more frequent extreme weather events in the economic viability of current agricultural systems;
- assessing and mapping the economic feasibility of different local adaptation measures and to which extent they help reducing the economic impacts of more frequent extreme weather events;
- identifying the regional patterns of climate vulnerability and resilience of arable farming systems under more frequent weather extremes.

The method is illustrated with a case study on arable farming systems in the Netherlands, a country with an advanced agricultural sector and relatively large shares of global agricultural production and export of agricultural commodities. Despite not being as sensitive to climatic changes as other regions of the world, agriculture in the Netherlands is expected to be affected in various ways: while gradual pattern changes are not expected to lead to a disruption of the agricultural sector (Ewert et al., 2005; Hermans et al., 2010), the potential decline on yield and product quality resulting from more frequent extreme weather events and related occurrence of diseases might severely undermine its relatively strong market position in the future (Field et al., 2012; Van Oort et al., 2012; Schaap et al., 2013).

2. Material and methods

This paper proposes a method to assess at the local and regional levels the magnitude of the economic impacts on agricultural systems resulting from more frequent, climate change-induced extreme weather events. We combine information on local productivity factors, general economic factors, climate sensitivity of crops (agro-climate calendar) and future climate change scenarios to assess the impacts of extreme weather events and related occurrence of pests and diseases on agricultural systems. We apply the proposed method to a case study in the Netherlands, in which we assess the potential economic impacts of extreme weather events on Dutch arable farming systems, taking into account impacts resulting from both potential yield losses and loss of product quality. Our analysis is based on a mapping tool representing arable farming systems with a spatial resolution of 100 m.

Arable farming systems can be considered as economic enterprises where investments are made with a long-term perspective. We therefore apply the Net Present Value (NPV), a standard method used in capital budgeting for appraising long-term projects, to assess the long-term potential economic performance of arable farming systems in the Netherlands. According to the NPV method, an investment should have strictly non-negative NPV in order to be regarded as economically viable. Similarly to previous approaches (see e.g. Van der Hilst et al., 2010; Diogo et al., 2015), we calculate NPV of agricultural systems by measuring discounted time series of expected cash inflows and outflows in a spatially-explicit way. Local economic impacts are assessed by estimating changes in the expected NPV due to the potential losses in terms of crop yield and product quality resulting from more frequent extreme weather events. Based on this, the economic feasibility of adaptation is subsequently assessed by determining the avoided decrease in NPV resulting from adopting adaptation measures. For that purpose, we consider a portfolio of adaptation measures and their specific investment costs, annual operational costs and effectiveness in alleviating crop damage.

Our approach is schematically depicted in Fig. 1, with the main methodological steps being described in more detail in the following sections:

- assessing the local economic performance of arable farming systems (Section 2.1), by estimating their local potential NPV;
- assessing the local economic impacts of more frequent extreme weather events (Section 2.2), by estimating the losses on crop production and quality, and resulting changes in NPV;
- assessing the avoided economic impacts achieved through local adaptation (Section 2.3), by estimating the avoided decrease in NPV that can be obtained by adopting adaptation measures at the local level;
- assessing the economic viability of arable systems and feasibility of adaptation (Section 2.4), by determining the locations in which NPV is able to remain positive under more frequent extreme weather events, with and without the adoption of adaptation measures.

Finally, we perform a sensitivity analysis (Section 2.5) to evaluate how sensitive our results are to variations in key economic and productivity factors.

2.1. Potential economic performance of arable farming systems

Arable farming systems in the Netherlands are characterised by the cultivation of several annual crops, primarily potatoes, sugar beets, grains and onions, usually grown in rotation season after season. The share of different crops in the rotation can differ substantially between regions, as a result of the combined effect of spatial heterogeneity in local biophysical conditions influencing crop suitability, regional specialisation and market opportunities (e.g. existence of processing plants in the vicinity). The Basic Parcel Registration (BPR) data series (MEZLI, 2013), a collection of annual farm surveys on crops grown per plot, was used as reference map to define the locations where land is currently used by arable farming systems (Fig. 2) and to specify their crop rotation schemes. We distinguished crop rotation schemes for fourteen different agricultural regions and according to two main soil types, clay and sandy soils. The specification of regional crop rotation schemes can be found in the Supplement Material in Table A.1.

The local economic performance of arable farming systems was determined following the standard NPV method. For an extensive account on the application of the NPV method to appraise the economic performance of agricultural systems in a spatially-explicit way, we refer to Diogo et al. (2015); for previous applications of the method to case