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Climate change impacts on farm production, landscape appearance, and the environment: Policy scenario results from an integrated field-farm-landscape model in Austria

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ABSTRACT

Climate change is among the major drivers of agricultural land use change and demands autonomous farm adaptation as well as public mitigation and adaptation policies. In this article, we present an integrated land use model (ILM) mainly combining a bio-physical model and a bio-economic farm model at field, farm and landscape levels. The ILM is applied to a cropland dominated landscape in Austria to analyze impacts of climate change and mitigation and adaptation policy scenarios on farm production as well as on the abiotic environment and biotic environment. Changes in aggregated total farm gross margins from three climate change scenarios for 2040 range between +1% and +5% without policy intervention and compared to a reference situation under the current climate. Changes in aggregated gross margins are even higher if adaptation policies are in place. However, increasing productivity from climate change leads to deteriorating environmental conditions such as declining plant species richness and landscape appearance. It has to be balanced by mitigation and adaptation policies taking into account effects from the considerable spatial heterogeneity such as revealed by the ILM.

1. Introduction

Climate change will cause major changes in agricultural land use in the upcoming decades by directly and indirectly stimulating mitigation and adaptation efforts of individual famers. Farmers autonomously adapt to direct climate change impacts, such as local changes in temperature and precipitation patterns, in order to alleviate losses, exploit gains, and protect their production resources (for recent and ancient examples see Niles et al., 2015 and Chen et al., 2015). In addition, farmers adapt to climate change affected market impacts and respond to adaptation and mitigation policies. Knowledge on farm level vulnerability, mitigation potentials, and adaptation options is crucial to understand climate change impacts and adaptation responses even at larger scales of spatial aggregation beyond the farm level (Reidsma et al., 2010). It can help to design efficient adaptation policies that alleviate negative and utilize positive climate change impacts. Potentially environmentally harmful autonomous adaptation by farmers, such as increasing land use intensity, can be anticipated by adequate policy responses. Knowledge on the mitigation potential of agricultural land use at the farm scale and its trade-offs to other environmental and socio-economic objectives supports the design of effective mitigation policies at national to EU levels.

Quantitative interdisciplinary research approaches that combine multiple scales have emerged in agricultural sciences to fulfill such knowledge demands. Among those, integrated land use modeling at the farm level – synonymous to bio-economic farm modeling (Janssen and van Ittersum, 2007) – can realistically represent land use choices under climate change to complement global (e.g. Nelson et al., 2014), regional (e.g. Henseler et al., 2009; Leclère et al., 2013), and field level studies (e.g. Lehmann et al., 2013). Some studies analyze responses of different farming systems to mainly external changes (e.g. Dono et al., 2013; Kanellopoulos et al., 2014), which shall support farm and policy decision making. Other applications focus on inter-annual farm processes and decision making such as scheduling of field work (e.g. Aurbacher et al., 2013). Land use decisions are taken at the farm scale but many land use impacts – e.g. soil sediment loads, ecological functionality, or landscape appearance – are effective at the landscape scale. Hence, another group of studies applies bio-economic farm models to analyze climate change effects on land use and the environment at the landscape to small regional level (e.g. Briner et al., 2012; Reidsma et al., 2015).

Climate change studies for Austria indicate i) heterogeneous effects with winners and losers among regions and farms, ii) uncertain climate conditions particularly concerning changes in precipitation patterns and extreme events, and iii) unclear environmental consequences

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such as on biodiversity and landscape appearance (Gobiet et al., 2014; Schönhart et al., 2014; Kirchner et al., 2015). The objective of this study is to improve our understanding on the research issues i-iii raised above utilizing the advantages of a bio-economic farm model. An existing integrated land use model (ILM) at the field-farm-landscape level – mainly combining a biophysical model with a bio-economic farm model (Schönhart et al., 2011a,b) – has been extended to analyze separated and joint impacts from climate change as well as mitigation and adaptation policies. An extensive indicator set is available in order to describe changes in farm production, the abiotic and biotic environment, and landscape appearance. The ILM is applied to a cropland dominated case study landscape and shall inform researchers, farmers, and policy makers about possible risks and opportunities from uncertain climate change – particularly with respect to precipitation patterns – and the effectiveness of agricultural mitigation and adaptation policies.

Section 2 describes the case study landscape, modelling methods, data, indicators, as well as the applied climate and policy scenarios. Section 3 presents results, which are discussed in Section 4. Section 5 concludes on the modeling results and raises emerging research questions.

2. Methods and data

2.1. Case study landscape

We apply the ILM to a landscape in the Lower Austrian Mostviertel region. This region has been chosen due to its variety in land uses, the importance of landscape elements such as orchard meadows, and its pronounced land use intensity and climate gradients. The case study landscape with a size of ca. 2000 ha and 113 farms is intensively managed, rather homogeneous with respect to landscape elements and dominated by cropland (84% cropland, 16% permanent grassland). Observed average annual precipitation is about 1.000 mm and the average annual temperature ranges between 8 to 9 °C (unpublished data from Strauss et al., 2013). Predominant arable crops in the period 2005 to 2009 have been corn (31%), winter wheat (23%), winter barley (12%) and silage maize (7%).

2.2. Integrated land use model (ILM)

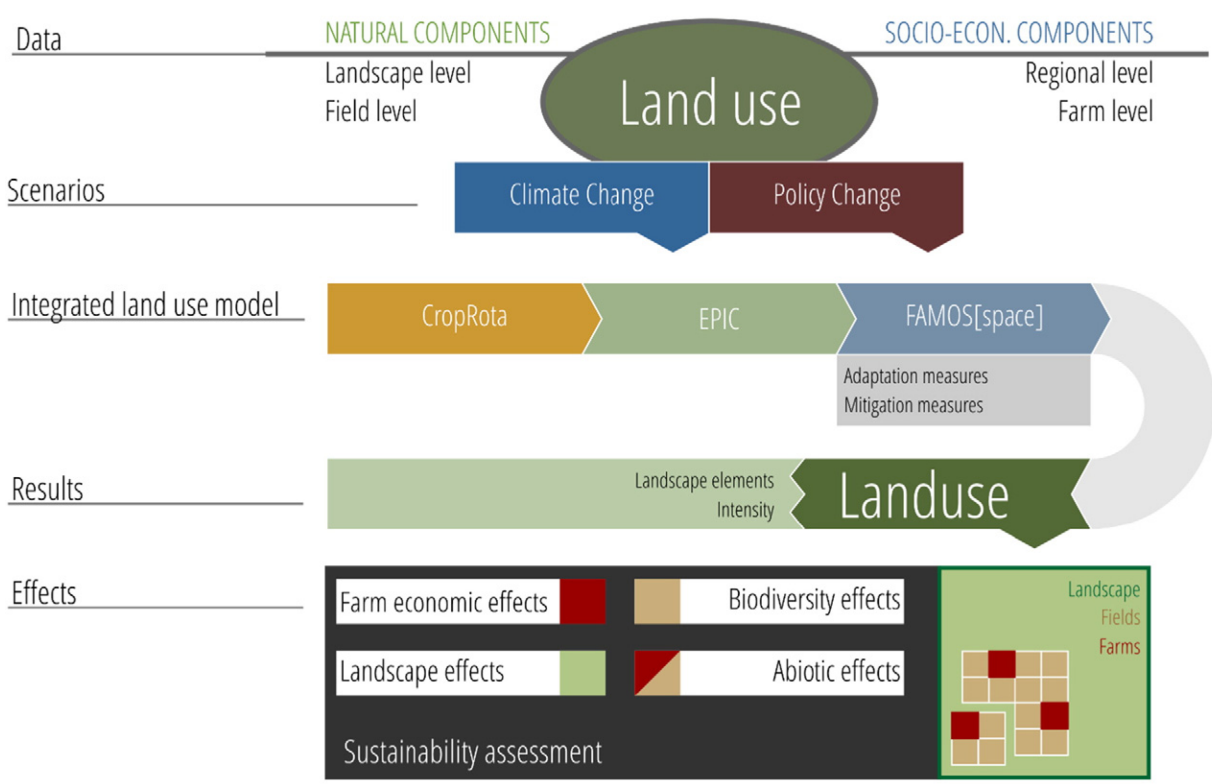
2.2.1. ILM overview

The ILM (Fig. 1) sequentially links the crop rotation model CropRota (Schönhart et al., 2011d), the bio-physical process model EPIC (Williams, 1995) and the bio-economic farm model FAMOS [space] (Schönhart et al., 2011c). The latter optimizes land use and livestock production at farm scale, which are drivers of abiotic and biotic environmental as well as landscape indicators (see Section 2.4).

2.2.2. Modeling crop rotations and bio-physical processes

The choice on crop rotations is fundamental to the economic and environmental outcomes of agricultural systems but knowledge on crop rotations applied by farmers is usually limited. In the ILM, CropRota shall fill this empirical knowledge gap. It generates crop rotations at farm level and computes their likely share in a farm's cropping plan. The share results from judgments on the agronomic value of pre-crop – main-crop sequences within a rotation and on the farm's observed land use. We select four crop rotations with the highest share on each farm – assuming those are typical – to reduce computational efforts in the ILM. However, to increase the adaptive capacity of a model farm towards impacts from markets, policies, and climate, we add three additional crop rotations with the highest shares at landscape level. Consequently, each model farm can choose among seven crop rotations. For further details on CropRota see Schönhart et al. (2011d).

Crop rotations are input to EPIC and complement a portfolio of pre-defined crop management measures (i.e. tillage, fertilization intensity, irrigation, mowing frequency), geo-referenced field data (i.e. soil, slope, elevation) and climate data (i.e. daily temperature,



Source: own illustration

Fig. 1. Overview on the research design.