INTEGRATED LAND USE MODELLING TO ANALYSE CLIMATE CHANGE ADAPTATION IN AUSTRIAN AGRICULTURE

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Abstract

We present an integrated modelling framework (IMF) to analyse climate change impacts on biophysical processes and farm management responses at the spatial resolution of 1km². The IMF is applied to the Austrian agricultural sector for the period 2025-2040. The model results show that national agricultural producer surplus changes only marginally between -1% and +1% depending on the climate scenario. The regional results reveal that eastern cropland regions are more negatively affected than alpine grassland regions, which intensify production. This leads to changes in opportunity costs for agri-environmental programs, which calls for more targeted measures to increase efficiency and adaptation potential.

Keywords: Climate Change, Agriculture, Integrated Modelling, Adaptation, Spatial Analysis

1 Introduction

Agriculture is sensitive to climate change such that higher temperatures and CO_2 concentrations as well as changes in precipitation patterns and frequencies of extreme weather events have direct impacts on crop yields and agro-biophysical processes, which trigger farm management responses and alter environmental outcomes (Alexandrov et al., 2002; Olesen et al., 2011; BMLFUW, 2012; Mitter et al., 2014). Hence, agricultural systems are highly dependent on the adaptation potential of farmers to mitigate negative or amplify positive impacts of climate change (Leclère et al., 2013; Schönhart et al., in press).

Integrated assessments (IA) can quantify the magnitudes and heterogeneities of impacts in agriculture as well as the adaptation potential of different farming systems. These assessments shall support the development of targeted farm adaptation strategies as well as the coordination of autonomous and policy induced adaptation of land use systems and are thus widely applied (Audsley et al., 2006; van Meijl et al., 2006; Schneider et al., 2007, 2011; Henseler et al., 2009; Schönhart et al., in press; Briner et al., 2012; Strauss et al., 2012). They mirror impact chains by linking disciplinary data and models, such as from climatology, soil sciences, agronomy, animal husbandry, and economics. They are characterized by quantifying agricultural development aspects under economic, technical, biophysical and legal constraints (Schneider et al., 2011). Different studies agree that IAs are helpful in disentangling the complex interactions between the human system and the environment (Falloon and Betts, 2010; Laniak et al., 2013), and thus in quantifying climate change impacts and deriving recommendations for suitable adaptation measures (Rounsevell et al., 2012; Schönhart et al., in press). Despite the advances in IAs and numerous applications (Laniak et al., 2013), multi-regional climate change IAs at high spatial resolution are still rare but heavily required to derive robust and sufficiently stratified spatial results acknowledging a broader range of heterogeneities and uncertainties.

Several integrated agronomic studies have already assessed the vulnerability of croplands to climate change in Austria (Alexandrov et al., 2002; Klik and Eitzinger, 2010; Thaler et al., 2012; Strauss et al., 2013b). Although these studies analyse and suggest alternative agronomic adaptation measures to reduce adverse impacts on crop yields and environment (e.g. soil conservation to reduce soil erosion and retain soil water content), they do not include any economic and policy aspects. Schönhart et al. (in press), however, show in a first national agricultural impact and adaptation study that autonomous adaptation by profit-maximizing farmers can lead to mostly positive economic outputs at regional to sector scale until the mid of the 21st century. They also reveal that economic and environmental impacts as well as the choice of adaptation measures differ substantially across NUTS3 regions in Austria. Given these regional differences, it is important to further analyse agricultural impact chains at high spatial resolution as well as to evaluate trade-offs and synergies between economic and environmental effects from autonomous farm adaptation.

We therefore present an impact and evaluation assessment on Austrian agriculture and the regional environment for the period 2025-2040. An integrated modelling framework (IMF) has been developed and applied which merges disciplinary data, models and indicators coping with impact chains in agricultural ecosystem management at spatial (1km²) to national scales. In addition, trade-offs and synergies between economic and environmental effects from autonomous farm adaptation are evaluated by a rich set of land use development indicators including agricultural production (t/ha), producer surplus (€), changes in agricultural land use management (%), nitrogen fertilization (kg/ha), water use for irrigation (1000 m³), sequestration of soil organic carbon (t/ha), and soil sediment losses (t/ha). Therefore, the assessment should help to support the development of cost-effective farm adaptation strategies as well as agri-environmental schemes in securing supply of public goods under climate change.

The remainder of the paper is structured as follows: Section 2 introduces our IMF and is followed by a scenario description (section 3). Results from country to local levels are presented in section 4 and discussed in section 5. Finally, we provide some concluding remarks and policy recommendations in section 6.

2 Data and Method

2.1 Integrated Modeling Framework (IMF)

Our IMF is depicted in Figure 1 and follows similar frameworks developed by Schönhart et al. (2011a, in press), Schmidt et al. (2012) and Stürmer et al. (2013). It builds on the idea that it is essential to explore the heterogeneity of drivers (e.g. climate change or policies) and pressures (e.g. water withdrawals or fertilization) of land use change and crop management choices.

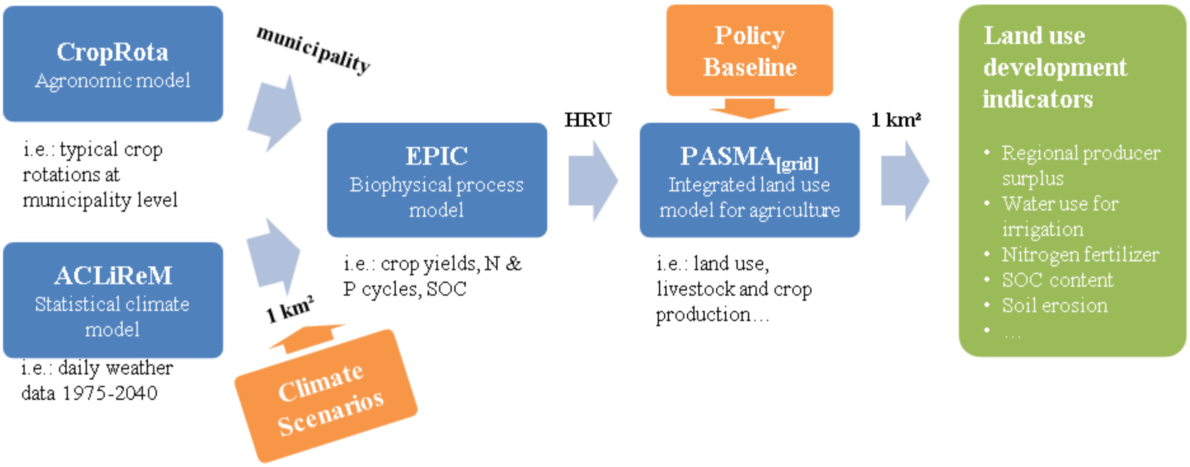

Figure 1. The IMF for climate change impact and adaptation analysis in Austrian agriculture (own illustration).

In the framework, the CropRota model derives typical crop rotations at municipality level, taking into account observed land use and agronomic constraints (Schönhart et al., 2011b). The statistical climate model ACLiReM uses regressions and bootstrapping methods in order to forecast temperature trends and project precipitation patterns in Austria until 2040 (Strauss et al., 2013a). It provides daily weather data at a spatial resolution of 1km². Both models provide input to the biophysical process model EPIC (Williams, 1995; Izaurralde et al., 2006). EPIC simulates crop yields and environmental outcomes (e.g. nitrogen and phosphorus emissions, SOC content, sediment losses) of alternative crop production systems for different climate-site-soil-crop regimes at a spatial resolution of 1km^2. Hence, outputs are differentiated by topographical, soil, and climate characteristics as well as by agronomic measures (e.g. crop rotations, fertilization intensity, and irrigation). Finally, the bottom-up economic land use optimization model PASMA$_{[grid]}$ integrates the biophysical simulation data in order to derive optimal geo-referenced production portfolios of profit maximizing farmers.

2.2 The EPIC and PASMA$_{[grid]}$ Interface

The interface between the spatially stratified biophysical simulation data from EPIC and PASMA$_{[grid]}$ utilizes the concept of homogeneous response units (HRUs) (Schmid, 2007; Stürmer et al., 2013). An HRU shares same natural characteristics such as elevation, slope and soil type and allows proper aggregation of impacts in bottom-up economic land use optimization models. Thus, PASMA$_{[grid]}$ integrates heterogeneous biophysical impact and endowment data (i.e. land qualities with different crop yields and environmental outcomes) at the intersection of HRU and municipality boundaries leading to unique geo-referenced spatial units of 1km^2. Optimal land use and management choices are thus derived for each spatial unit considering the opportunity costs of agricultural land use and livestock production. Hence, information on land endowments, biophysical impacts, and opportunity costs is available at higher spatial resolution than in many other studies at regional to national scale (e.g. Schönhart et al., 2013). This allows better representation of heterogeneities in farming responses and localisation of hot-spots.

2.3 PASMA$_{[grid]}$

PASMA$_{[grid]}$ is a linear programming model. It builds on the Austrian agricultural sector model PASMA (Schmid and Sinabell, 2007; Schmid et al., 2007), but represents in more detail the structural and environmental heterogeneity of the agricultural sector. Agricultural land use includes all cropland, grassland, alpine meadows and permanent crops (i.e. wine, fruit orchards and short rotation coppice) at 1km^2 resolution. Livestock production is modeled at NUTS3 level including feed and fertilizer balances. PASMA$_{[grid]}$ has already been applied in a regional case study application on the supply of biomass to support regional energy autarky concepts (Schmidt et al., 2012), as well as in a large scale IMF to assess ecosystem services trade-offs and synergies for different policy and climate change scenarios (Kirchner et al., submitted). This paper provides a first thorough introduction of PASMA$_{[grid]}$ with focus on its potential to elicit important spatial aspects of autonomous adaptation by farmers.

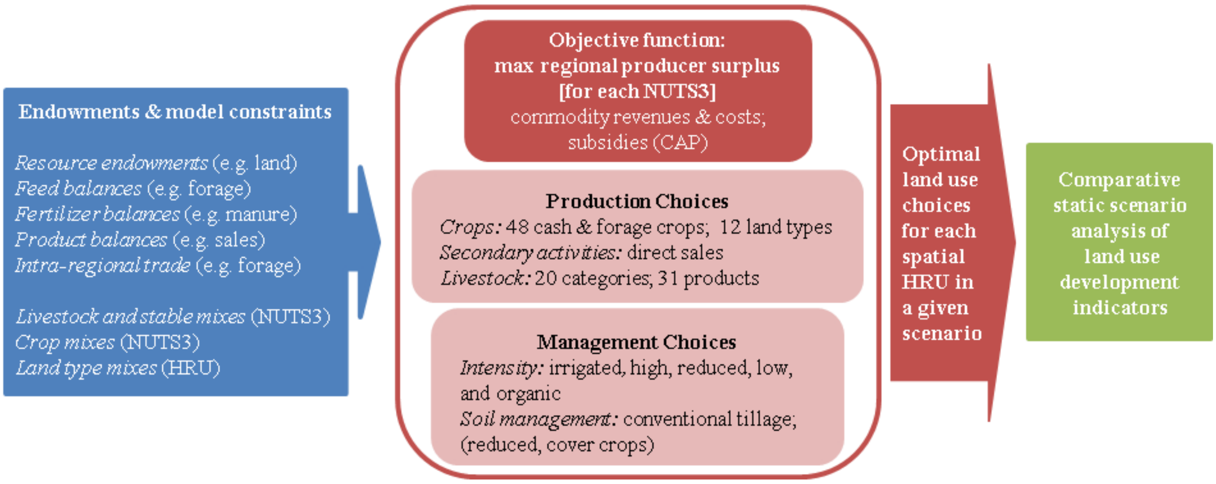

Figure 2. The structure of PASMA$_{[grid]}$ (adjusted from Schmid and Sinabell, 2007).

Figure 2 gives an overview of the model by displaying endowments and constraints, objective function, and production and management choices. The regional producer surpluses (RPS) is maximized for each NUTS3 region subject to natural, structural and regional resource endowments (e.g. amount of cropland or stables available in a region) as well as technical restrictions (e.g. feed and fertilizer balances). Observed land use and livestock activities provide boundaries and compositions which the model chooses from in building optimal convex combinations to avoid over-specialization (McCarl, 1982). $\text{PASMA}_{[\text{grid}]}$ is a bottom-up supply model, i.e. commodity prices are exogenously given and market feedbacks are not accounted for endogenously. $\text{PASMA}_{[\text{grid}]}$ optimizes at independent points in time typical to comparative static approaches.

Choices on agrarian land uses and crop management variants depend on factors such as commodity prices, production costs, subsidies, yields and nutritional value for livestock activities. In this study, the model can chose among four mutual exclusive fertilizer management variants: rainfed agriculture with (1) high, (2) moderate, and (3) low fertilization intensities on cropland and grassland, and (4) irrigated agriculture with high fertilization intensity on cropland. On cropland these fertilizer variants can be combined with three mutual exclusive soil management variants: (a) conventional tillage (i.e. mouldboard plough with 15 % crop residue on soil surface before planting); (b) reduced tillage (i.e. light disc or chisel plough with 15–30 % crop residue on soil surface before planting), and (c) winter cover crops are considered.

2.4 Major Data Sources

Data on resource endowments and observed land use are obtained from the Integrated Administration and Control System (IACS), the digital soil map of Austria (Federal Research and Training Centre for Forests, Natural Hazards and Landscape, BFW), the digital elevation map (Federal Office of Metrology and Surveying, BEV), the farm structure survey, and the Austrian Farm Accountancy Data Network (FADN). Data on production costs are estimated from standardized gross margin tables for Austrian agriculture (BMLFUW, 2008) and standardized farm labour estimates. Product prices are taken from Statistics Austria and price forecasts from the OECD-FAO agricultural outlook (OECD/FAO, 2013). Policy scenarios including assumptions on the CAP reform result from a stakeholder process and a literature review (see section 3).

3 Scenarios

In Austria, mean annual temperatures have increased by 1.65°C between 1975 and 2007 and are likely to increase by another 1.5°C until 2040 (Gobiet et al., 2013; Strauss et al., 2013a). With respect to precipitation changes, Strauss et al. (2013a) could not reveal a statistically significant trend. Precipitation rates may decline in summer and increase in winter (Trnka et al., 2011; Gobiet et al., 2013). However, they will depend on location and season (Gobiet et al., 2013). Therefore, we apply four climate change scenarios with varying assumptions on precipitation (Strauss et al., 2013a) to provide a plausible range of possible future climates until 2040 (see Table 1). The uncertainty in precipitation changes is represented by increases (*High*), decreases (*Low*) and seasonal shifts (*Shift*) in precipitation. Bio-physical impacts from climate change are averaged for the period 2025-2040.

Policy and economic assumptions are kept constant across the climate change scenarios in order to single out the climate impact. A business as usual policy baseline (BAU 2040) has been developed for the period 2025-2040 that depicts the most likely outcome of the current CAP post-2013 reform and assumes price developments according to the OECD-FAO forecast until 2022. The most important CAP assumptions are the abolition of dairy quotas and premiums for suckler cows, a shift from historical to regional decoupled direct payments, and reductions in agri-environmental payments. The scenario development has been facilitated by stakeholders from the Austrian Ministry of Agriculture, Forestry, Environment and Water management (BMLFUW), the Austrian Environmental Agency (UBA) and the Austrian Agency for Health and Food Safety (AGES).

Table 1. Climate change scenarios.

Scenario	**Period**	**Temp.**	**Precipitation**	**Policy**
REF	1990-2005	observed	observed	BAU 2040
High	2025-2040	+1.5°C	+20% annual precipitation sums	BAU 2040
Similar	2025-2040	+1.5°C	assuming similar distributions of precipitation sums compared to the past	BAU 2040
Shift	2025-2040	+1.5°C	20% decrease in summer precipitation sums and respective increase in winter	BAU 2040
Low	2025-2040	+1.5°C	-20% annual precipitation sums	BAU 2040

4 Results

In order to separate climate change impacts from market and policy effects we compare the model results of PASMA$_{[grid]}$ in the *REF* scenario (BAU 2040, current climate; see Table 1) to results from the four climate change scenarios, *High*, *Similar*, *Shift* and *Low* (see section 3). The economic effects are presented first, followed by the environmental effects to reveal trade-offs and synergies. The implications of autonomous farm adaptation and a comparison of the results with other studies are presented in section 5.

4.1 Economic Effects

Table 2 shows PASMA$_{[grid]}$ results by climate change scenarios for Austria. RPS, defined as production revenues plus subsidies minus production costs, increases in *High*, *Similar* and *Shift* slightly between 0.3 and 1.4%, and decreases by ca. 1% in *Low*. Relative changes in production revenues and costs are all positive, ranging between 0% and 3% for revenues and between 1% and 3% for costs. The level of agri-environmental payments (AEPs) decreases between 4% and 5% which indicates intensification of agricultural production. The decrease in land eligible for AEPs is even higher and ranges from -4% (*Low*) to -13% (*High*). It results from more favorable production conditions under climate change in the modelled period.

Table 2. Economic impacts by climate change scenarios for Austria (% changes compared to *REF*).

	High	***Similar***	***Shift***	***Low***
Agricultural regional producer surplus (RPS)	1.4	0.8	0.3	-0.9
Agricultural production revenues	2.7	2.0	1.5	0.0
Agricultural production costs	2.7	2.1	1.7	0.7
Agri-environmental payments (AEPs)	-5.3	-4.7	-4.5	-3.7

Notably, results at regional levels can deviate considerably from the national averages. Figure 3 depicts the impacts of climate change on RPS in the Austrian NUTS3 regions. One can detect differences both in magnitude as well as in sign with regions in the West benefiting from climate change and regions in the East being negatively affected in some climate change scenarios, especially in *Low*. Western regions are dominated by cool and humid climates. The alpine grasslands benefit from increased temperatures even if annual precipitation sums decrease. The cropland regions in the eastern flatlands are more vulnerable to changes in temperatures and precipitation, as annual precipitation sums are already low at 500 mm. Water will likely become a more limiting factor during the summer months. In the model, it results in RPS losses of up to -17% even if autonomous adaptation such as changes in irrigation, fertilizer intensity levels or soil management variants is accounted for.

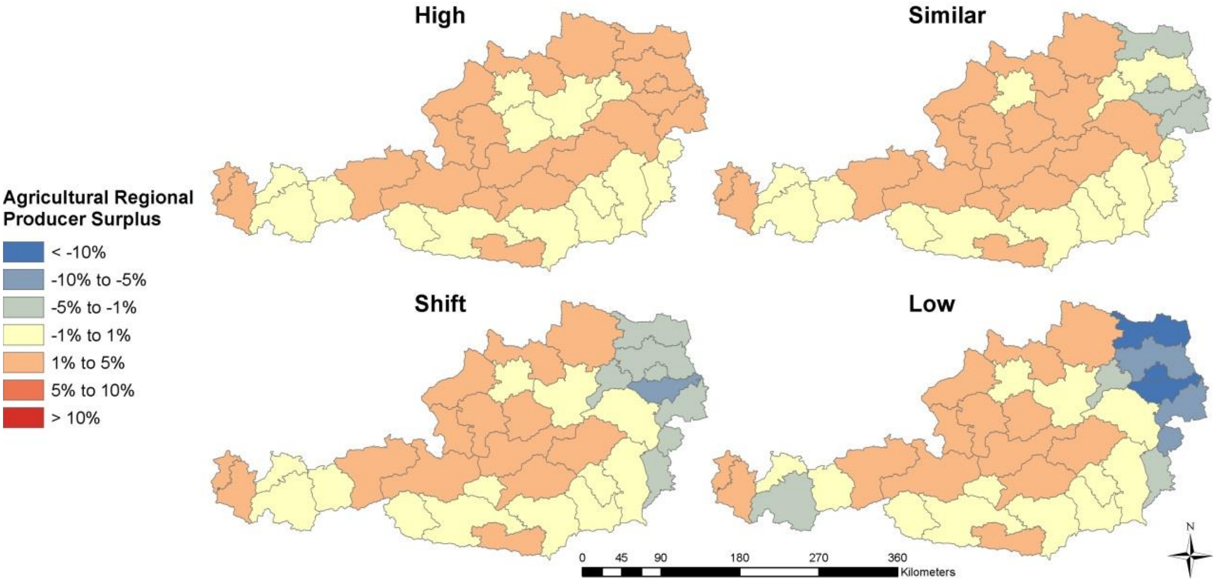

Figure 3. Changes in agricultural regional producer surplus (RPS) of NUTS3 regions by climate change scenarios (*High*, *Low*, *Similar*, and *Shift*) with respect to the reference scenario (*REF*) (own source).

4.2 Environmental Effects

Climate change impacts on environmental effects of agricultural production at the national level are displayed in Table 3. Plant production and the use of nitrogen fertilizer increase considerably, notably in *High* with +9% and +8%, respectively. It is mainly the result of production intensifications. However, impacts differ between grassland and cropland (see Table 4), as well as alpine meadows and short rotation coppice. Crop production and fertilizer use decrease in all but the *High* scenario. On grasslands, forage production and fertilizer inputs increase by more than 20%. At aggregate levels the increase in dry matter yields in plant production on grassland outweighs decreases on cropland.

Figure 4 further illustrates the spatial heterogeneity of environmental impacts with the example of nitrogen fertilizer use on agricultural land. It shows substantial increases in the South and along major valleys in the Mid-Alps, moderate increases along the alpine foreland and in Tyrol as well as decreases in the relatively dry areas in the East, especially in the *Low* scenario (see also Figure 6 in the appendix for information on elevation and land endowments). These changes correspond with the changes in forage production on grassland (not shown). Changes on cropland are more diverse, due to the different sensitivities of crops and their nutrient and water requirements.

Table 3. Environmental effects of climate change for Austria (% changes compared to *REF*).

	High	***Similar***	***Shift***	***Low***
Plant biomass production	9	8	6	3
Nitrogen fertilizer use	8	6	5	1
Soil organic carbon (SOC)	-3	1	1	4
Sediment loss	31	-13	-16	-48
Water use for irrigation	206	1274	845	4420

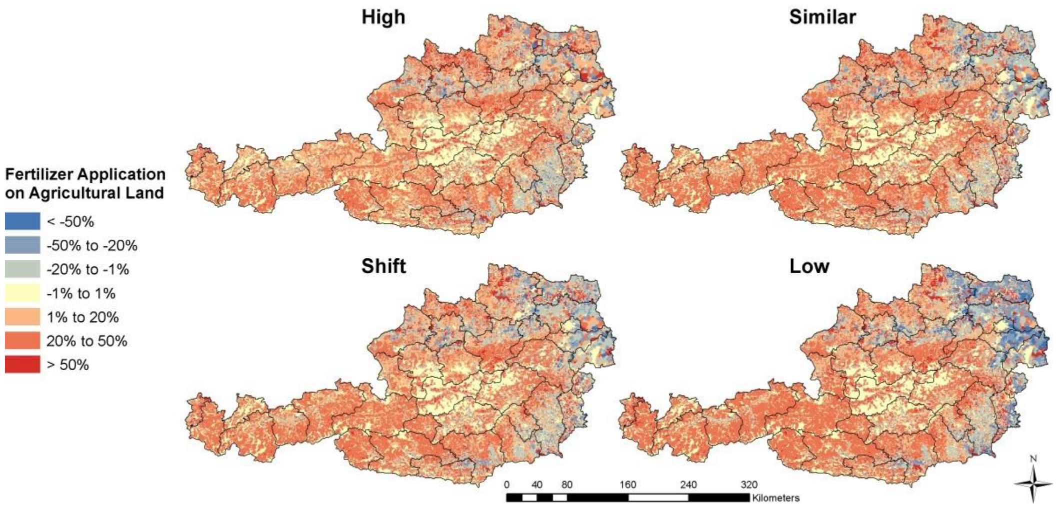

Figure 4. Change in nitrogen fertilizer use by climate change scenarios (*High, Low, Similar*, and *Shift*) with respect to the reference scenario (*REF*) (own source).

Substantial differences are modelled for SOC stocks between cropland and grassland (see Table 4 and Figure 5). On cropland, higher temperatures can stimulate mineralization, which can decrease SOC stocks. The strong yield increases on grassland outweigh this effect, as they provide additional carbon input to soils (Smith et al., 2005). At country level this means that SOC stocks increases in *Similar, Shift* and *Low*. In the *High* scenario, additional negative effects on SOC stocks due to higher soil moisture (Álvaro-Fuentes et al., 2012) and higher sediment losses, especially at higher altitudes and steeper slopes (see Figure 5 and Figure 6 in the appendix), result in net losses at the national level. In the scenarios *Similar*, *Shift* and *Low*, sediment losses decline mainly due to more plant growth and thus better soil protection. Water use for irrigation is very sensitive to our climate change scenarios. Irrigation increases in all but the *High* scenario but is only located in the East of Austria.

Table 4. Environmental effects of climate change in Austria (% changes compared to *REF*).

	Cropland				**Grassland**			
	High	***Similar***	***Shift***	***Low***	***High***	***Similar***	***Shift***	***Low***
Plant biomass production	1	-2	-3	-8	28	27	25	23
Nitrogen fertilizer use	0	-1	-4	-10	26	21	23	22
Soil organic carbon (SOC)	-3	-3	-2	-3	1	6	6	10
Sediment loss	33	-9	-9	-44	18	-28	-29	-60

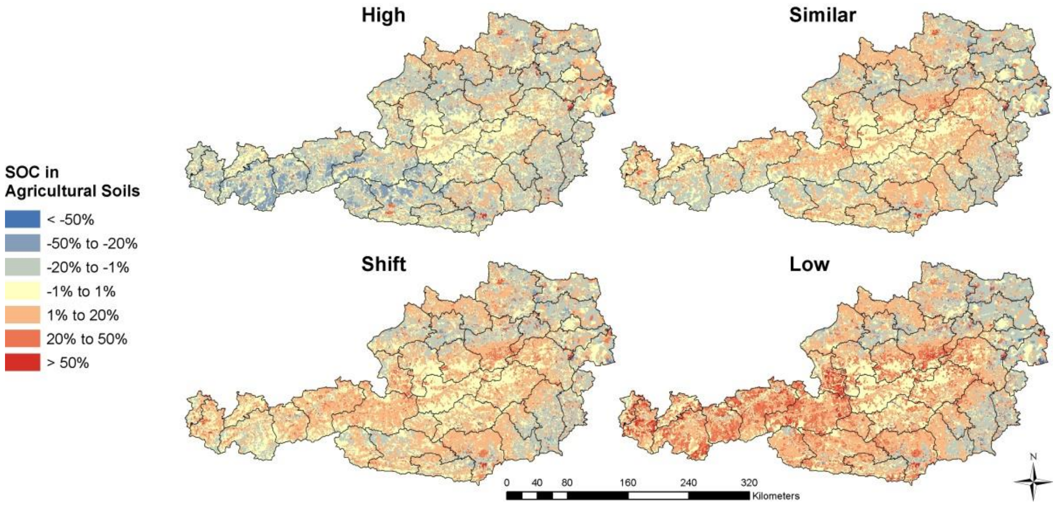

Figure 5. Change in SOC stocks by climate change scenarios (*High*, *Low*, *Similar*, and *Shift*) with respect to the reference scenario (*REF*) (own source).

5 Discussion

5.1 Agri-environmental Effects of Autonomous Adaptation

An integrated modelling framework has been developed to analyse climate change biophysical impacts (e.g. crop and forage yields, water use, sediment loss) and farm management responses. Furthermore, the potential of autonomous adaptation by profit-maximizing farmers has been assessed as well as environmental outcomes, which shall guide policy-induced adaptation. For example, increasing fertilizer use is usually associated with declining biodiversity (Schmitzberger et al., 2005; Niedrist et al., 2009) and may result in higher nitrogen emissions. The model results suggest that climate change may stimulate intensification of agrarian land use, i.e. increasing fertilizer rates, irrigation, or mowing frequency on grasslands in the next decades. While cropland production, aggregated at the national level, becomes more extensive (except in *High*), grassland is intensified in all four scenarios. The geo-referenced outputs of $\text{PASMA}_{[grid]}$ show that increases in high fertilizer intensity take place mainly in regions with favorable conditions for grassland production (e.g. medium elevation, alpine foreland, major alpine valleys) and in western and southern cropland regions. Model results suggest that most of the increase in fertilizer use at higher altitudes follows from increased nutrient requirements due to higher yields, whereas the increases in fertilizer use on alpine foreland and major alpine valleys (e.g. in Upper and Lower Austria as well as Carinthia) appear amplified by cost-efficient adaptation. To the contrary, fertilizer use in the East decreases substantially because of both lower yields and the adoption of low fertilizer management regimes. Irrigation is applied as a further adaptation measure in the model primarily in the East, where it is already required for high value crops such as vegetables, potatoes and maize. Although the results show substantial changes in relative terms for irrigated areas (similar to the water use indicator, see Table 3), absolute changes remain marginal (between 900 ha in *High* and 16,000 ha in *Low*), due to a very small base values (600 ha). Nonetheless, pressures on groundwater aquifers in eastern regions, such as the Marchfeld, have been high since the 1970ies. Although recent measures such as water channels have remediated past impacts, scenarios such as *Low* could again severely affect these groundwater aquifers.

Intensification is the result of higher marginal value products of inputs such as fertilizers or irrigation water. It also leads to higher opportunity costs of extensive land use and puts pressure on AEP (see Table 2). The positive effects of climate change are similar to increasing market prices and challenge the efficient design and affordability of future AEPs. The spatial results show high variation in impacts and changes in management intensities. This demonstrates the importance of considering spatial heterogeneity in land use studies and reveals the benefits of spatial targeting in AEPs.

5.2 Effects of Model Structure and Assumptions

We did not find strong responses in modelled crop choices. There seems to be a tendency towards more protein crops and less maize, but changes occur only within 2%. Lack of responsiveness with regard to crop choices may be partly the result of the model set-up. The solution space is limited to historical observed crop mixes at NUTS3 level. This approach helps to avoid typically unrealistic corner solutions of linear programming but can be quite restrictive with regard to alternative crop choices in a region. For example, it does not allow for the adoption of crops that have not been observed in the region before. This assumption could be relaxed by introducing new crops that have been observed in adjacent regions.

$\text{PASMA}_{[grid]}$ results are further limited by its availability of adaptation measures. Although important measures such as the choice of crops, fertilizer use, irrigation, and land allocation are included, some others have not been considered yet either due to the lack of knowledge (e.g. new land management techniques and crop breeds) or because they are outside of our modelling boundaries (e.g. changes in the infrastructure, seasonal weather forecasting, crop and weather insurance). Our results may thus underestimate the potential of farmers to adapt to climate change (for further discussion see also Schönhart et al. (in press)).

Given these constraints, our results still illustrate regions where autonomous adaptation could both amplify economic-environmental trade-offs – in case higher fertilizer intensity and/or irrigation become more profitable – and reduce economic-environmental trade-offs – in case low fertilizer intensity becomes more profitable.

5.3 Comparison to other Studies

Our results reflect to a large extent findings in previous studies, e.g. the potential negative impacts on crop yields in the eastern pannonian crop production regions (Alexandrov et al., 2002; Kirchner et al., 2012; Strauss et al., 2012; Thaler et al., 2012), SOC increases on alpine grasslands (Smith et al., 2005), as well as a high sensitivity of soil erosion and irrigation to climate change scenarios (Klik and Eitzinger, 2010; Schönhart et al., in press). Most studies also predict increases in forage yields on alpine grassland (Smith et al., 2005; Henseler et al., 2009; Briner et al., 2012; Schönhart et al., in press), except for Audsley et al. (2006).

With respect to economic impacts, $\text{PASMA}_{[\text{grid}]}$ outputs are more moderate in general but confirm the direction of results presented by Schönhart et al. (in press) at NUTS3 level and by Leclère et al. (2013) at country level. While both studies take into account similar cost-efficient adaptation measures by farmers, differences may accrue due to different climate change scenarios and models (both employ global circulation models and regional downscaling), different climate periods (2031-2050 and 2071-2100, respectively), and model resolution (NUTS3 and Austria at country level, respectively). Some studies further support our findings that adaptation to climate change in Austria may lead to (1) a general move towards more intensive production (van Meijl et al., 2006; Leclère et al., 2013; Schönhart et al., in press) as well as (2) regional differences with intensification in favourable areas and extensification in marginal areas (Audsley et al., 2006; Henseler et al., 2009). The latter impact has also been observed in a regional case study in Switzerland (Briner et al., 2012). In contrast to Briner et al. (2012) and Henseler (2009) we do not find any significant land abandonment in alpine areas. Except for Briner et al. (2012), who provide a regional case for Switzerland with a spatial resolution of 1ha, most of the studies that account for autonomous adaptation were modelled at a much coarser resolution than $\text{PASMA}_{[\text{grid}]}$ (e.g. NUTS3 or country level).

6 Concluding Remarks and Policy Recommendations

Our spatially explicit IMF demonstrates the importance in considering spatial heterogeneities with regard to climate change impacts, opportunity costs in production and AEP participation, and the choice of cost-efficient farm adaptation measures. The results show that regional differences are prevalent and that regional impacts and adaptation can be quite different from national level results. In Austria, grassland dominated alpine areas experience higher forage yields whereas crop yields decline more likely in eastern cropland areas.

Climate change and farm adaptation measures can amplify economic-environmental trade-offs. In the absence of targeted policies, environmental impacts of autonomous adaptation such as intensification of agricultural production likely fail to deliver socially optimal outcomes. Consequently, intensification by increasing fertilizer and water inputs should be limited by policies, if environmental costs are expected to increase. In contrast, higher crop yield potentials through climate change should be realized if environmental impacts are low. The spatially explicit results allow identification of potential climate and environmental hot-spots and can thus support the design of regionally targeted policy responses. It may include the support of sustainable water policies in the East, targeted AEPs in regions with high intensification pressures (e.g. alpine foreland), or policies on conservation tillage in regions with high soil sediment losses from changing precipitation patterns. Future studies should focus on analyzing the impact of such regionally targeted policies and include a broader range of land use development indicators (e.g. GHG emissions, biodiversity, landscape amenities) to comprehensively evaluate trade-offs and synergies between autonomous and policy-induced adaptation. Furthermore, studies are required that analyze adaptation prerequisites (e.g. availability and accessibility of technology and information) as well as the behavior of land managers towards the adoption of adaptation measures outside the historical solution space.

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Appendix

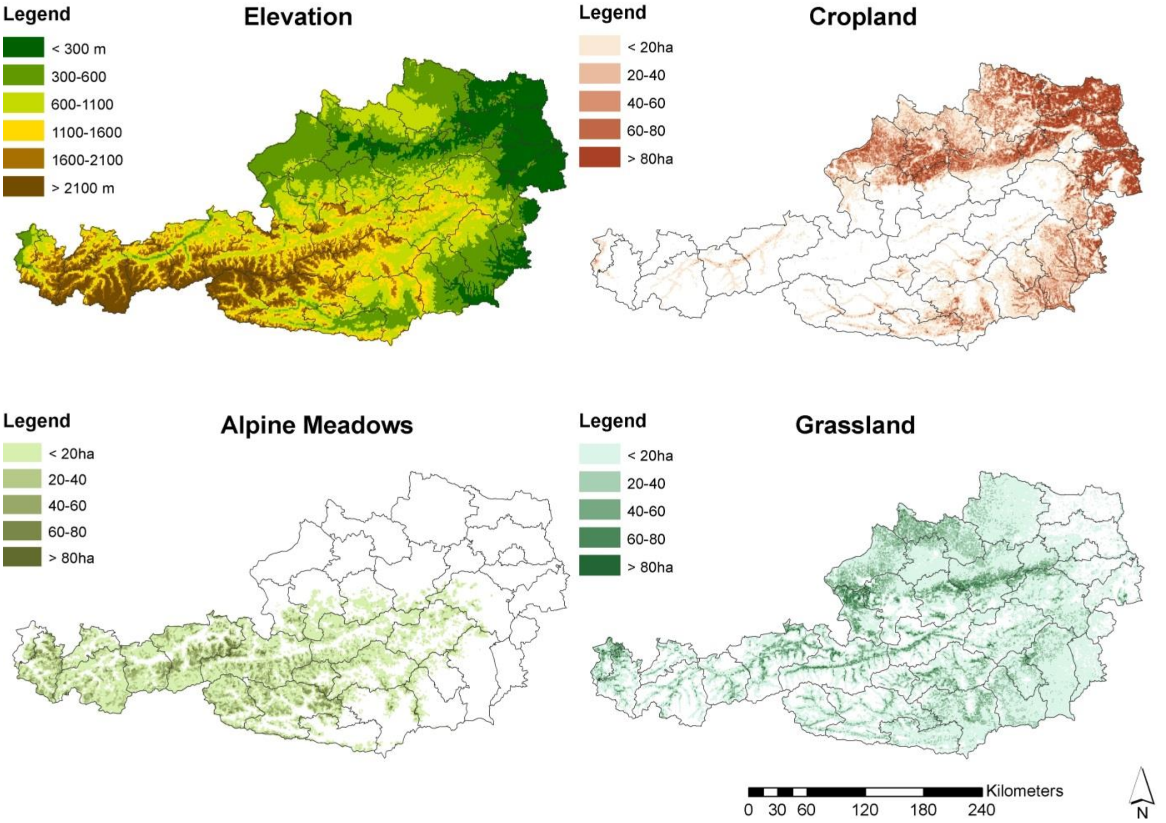

Figure 6. Elevation and land endowments of the 1km grids (own illustration)