Integrated Assessment of Climate Change Impacts on a Grassland Dominated Austrian Landscape

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Abstract

Climate change poses fundamental challenges on agricultural production and the environment. Case studies at different spatial scales indicate heterogeneous climate change impacts and adaptation responses. Consequently, spatial heterogeneity has to be taken into account in order to derive efficient mitigation and adaptation strategies for private land users and public authorities. We apply an integrated modelling framework IMF at the farm level in a grassland region in Austria to analyze climate change impacts on land use management and its economic, abiotic, and biotic effects. Three climate change scenarios cover a range of future precipitation patterns but a unique temperature trend of +1.5°C up to 2040. Policy scenarios are modelled to prove the effectiveness of mitigation and adaptation measures. Our results show that the direct impacts of climate change and the impacts of modelled adaptation responses on farm gross margins as well as abiotic and biotic environmental indicators (e.g. CO_2 emissions, changes in soil organic carbon) can be substantial. Assuming future price and cost trajectories from the literature, gross margins increase between 2% and 4% on average. A closer look to individual farms reveals the need to coordinate mitigation and adaptation policies in order to reduce adverse environmental and ecological effects, i.e. trade-offs, and increase synergies between environmental outcomes.

Key words

Land use modelling, climate change, adaptation, mitigation, landscape, optimization

1 Introduction

Climate change poses fundamental challenges on agricultural production. The impacts, however, will be heterogeneous from global and continental to the landscape level. In the 5th Assessment Report of IPCC, Porter et al. (2014) highlight different crop impact results across continents. For example, their meta-analysis shows wheat yield gains in temperate regions with raising temperatures subject to adaptation, while yields in tropical regions may decrease considerably at higher temperatures of up to +5°C even if farmers adapt. However, even within temperate regions, heterogeneous impacts can expected. Iglesias et al. (2011) analysed crop yield changes, adaptation options and subsequent economic impacts for European regions. While continental and alpine regions may gain from climate change up to 2080 by increasing agricultural production on average, mediterranean regions likely will lose yields, GDP from agriculture and export gains. Scaling down to the national level, such as the alpine region, repeats a heterogeneous pattern. Kirchner et al. (2015) analysed contrasting climate change scenarios for Austria at NUTS-3 resolution and revealed considerable differences among regions and climate change scenarios. Even at the local landscape level within Austria, heterogeneous impacts from climate change with gaining and losing farms can be expected (Schönhart et al., 2015). Autonomous adaptation by farmers usually aims at mitigating negative and utilizing positive climate change impacts. However, trade-offs are likely between private and societal land use objectives such as climate change mitigation, landscape maintenance, or biodiversity protection, and heterogeneity in impacts can also be expected for environmental amenities.

Heterogeneity in the results of climate change impact and adaptation studies at all scales results from i) methodological differences, ii) uncertainty, and iii) bio-physical and socio-economic heterogeneity. With respect to i), time scales of studies, the consideration or negligence of adaptation options, or the system boundaries determine results. System boundaries are defined by the range of represented impacts, e.g. whether only direct impacts from changes in temperature and precipitation on crop growth are considered or also changes in pest and disease pressure, or whether future prices are exogenously assumed or endogenously modelled and thereby also impacted by climate change. Uncertainty is inherent in the natural system as well as the scientific methodologies. A major driver of heterogeneity in the results comes from the diversity and uncertainty of climate change scenarios. Examples for iii) include the heterogeneity among regions with respect to weather conditions and resulting climate change impacts, soil properties, altitude, or exposition. A particular farming system results from such bio-physical location factors as well as surrounding socio-economic conditions such as farm structure, agricultural policies, education levels of farmers, access to markets, etc. and are a major driver of impacts from and vulnerability to climate change.

We have shown that case studies at different spatial scales indicate heterogeneous climate change impacts and adaptation responses. Consequently, spatial heterogeneity has to be taken into account in order to derive efficient mitigation and adaptation strategies for private land users and public authorities. Integrated modelling frameworks (IMF) on land use systems can serve as decision support tools. They transfer climate change signals into expected bio-physical outcomes by accounting for heterogeneous production conditions (e.g. soil characteristics, farm types) and diverse economic and environmental settings. Vulnerability and adaptation options as well as trade-offs and synergies between different environmental objectives can be revealed.

In this article, we develop and apply such IMF. Methods and data as well as scenarios have been presented in Schönhart et al. (2015) and applied to a cropland dominated landscape in Austria. In this article the IMF is adapted to and applied on a grassland dominated landscape in the same region.

2 Methods and data

2.1 Integrated modelling framework

The IMF combines the crop rotation model CropRota (Schönhart et al., 2011b), the bio-physical process model EPIC (Williams, 1995) and the bio-economic farm model FAMOS[space] (Schönhart et al., 2011a) as presented in Schönhart et al. (2015).

CropRota generates typical crop rotations at farm and regional level based on observed land use and agronomic judgments on the value of crop sequences. In total, seven crop rotations are provided for each farm. They are input to EPIC, which is applied to calculate crop yields and environmental impacts from different climate change scenarios, management variants (e.g. crop rotations, tillage, intensity, irrigation, mowing frequency). Crop yields and environmental outcomes are transferred to FAMOS[space] and are unique for each crop on a particular field under a specific management and climate.

FAMOS[space] is a static spatially explicit generic mixed-integer mathematical programming model at farm level. It seeks for gross margin maximizing production choices subject to field and farm resource endowments. Interactions among farms are not considered yet but sales and purchases of livestock, feed, and fertilizer are management variants. The farm specific resource endowments include on-farm family labor, livestock housing capacity, as well as land represented by field size and soil quality. In this version, we allowed farms in FAMOS[space] to extend their livestock housing endowments subject to empirically derived cost functions (based on FADN data, LBG, 2011). Management (adaptation) variants include crop rotation choices, establishment or removal of landscape elements (i.e. orchard trees), soil management (e.g. cover crops and minimum tillage), land use intensity levels (i.e. fertilizer application rates, mowing frequency on meadows), and irrigation as well as changes in livestock diets and numbers. Besides production and management alternatives within a particular land cover category, transitions between four different land covers, i.e. cropland, grassland, forestry, and abandoned land are available in particular policy scenarios. With respect to forests, only afforestation on former agricultural land are considered. Existing forests are neither represented in FAMOS[space] nor in the output indicators. All output indicators are calculated ex-post to the optimization. It includes total farm gross margins, soil sediment load and soil organic carbon content, Greenhouse gas (GHG) emissions and biodiversity indicators.

IACS data from several years (2000-2008) serve as central data source for fields and farms. Gross margins on annual farm production activities are calculated from the standard gross margins catalogue (BMLFUW, 2008) and literature surveys. Annuities for SRF (short rotation forestry) and permanent forestry on data from the Austrian advisory board for agricultural engineering and development (ÖKL) and standard gross margins (BMLFUW, 2008). Region specific forestry yield data is derived from Kirchner et al. (2015) based on results from the forest growth model Caldis vâtis (Kindermann, 2010). Farm labor demand is based on a detailed set of standard working units (Handler et al., 2006) and literature reviews. Family farm labor endowments result from farm survey data from the year 1999. A digital soil map (Bundesforschungs- und Ausbildungszentrum für Wald, Naturgefahren und Landschaft, BFW), and a digital elevation map (Bundesamt für Eich- und Vermessungswesen, BEV) complement the field characteristics of the case study landscape. Future market price developments are based on OECD-FAO (2013) and adapted to national circumstances.

2.2 Scenarios

Simulations in the IMF are based on scenarios to anticipate plausible future changes in climate and policies (see Table 1 and Table 2). The scenarios are based on Schönhart et al. (2015). Market prices and other socio-economic parameters are kept invariant among the scenarios. With respect to policies, three mitigation and adaptation scenarios have been developed and combined with three climate scenarios until 2040. In the IMF, the climate signal drives the bio-physical output of EPIC and is subsequently transmitted to FAMOS[space], while the mitigation and adaptation policies directly impact land use and livestock choices in FAMOS[space].

Table 1: Agricultural policy assumptions and climate change scenarios

Scenario name	Agricultural policies	Climate change
REF_2040	• no dairy quota • no livestock premiums • regional farm payment • greening: max 75% of single crop, min 5% fallow land, no permanent grassland conversion • 2008 levels of less favored area payments • no agri-environmental program	no
CS01_i/m/a/m&a	like REF_2040 if not stated otherwise (see Tab. 2)	+1.5°C / ±0% precipitation
CS05_i/m/a/m&a	like REF_2040 if not stated otherwise (see Tab. 2)	+1.5°C / +20% precipitation
CS09_i/m/a/m&a	like REF_2040 if not stated otherwise (see Tab. 2)	+1.5°C / -20% precipitation

Note: i: impact, m: mitigation, a: adaptation

Source: Schönhart et al. (2015)

The climate and policy scenario impacts are compared to a reference scenario *REF_2040*. *REF_2040* is presented in Table 1 and includes major changes of the CAP reform 2014-2020 and market policies such as the abolition of the dairy quotas and suckler cow premiums, the introduction of regional single farm payments and greening. A major difference to the current situation is the absence of any agri-environmental program (AEP). AEPs are not represented in *REF_2040* because they are similar to many mitigation and adaptation policies and therefore covered in the policy scenarios. The scenario analysis aims at assessing the effectiveness of mitigation and adaptation policies, which is achieved by comparing scenario results to a counterfactual reference. Furthermore, *REF_2040* is defined by the current climate situation.

To analyze climate change impacts, we apply three contrasting climate change scenarios (Table 1). The climate change scenarios cover six climate parameters at daily resolution and are based on a statistical climate model and historic trend observations (Strauss et al., 2013). A significant temperature trend has been observed in the past for Austria, which is linearly extrapolated to +1.5°C in 2040. Scenarios on precipitation have been developed to capture the inherent uncertainties of precipitation changes in the future (Gobiet et al., 2014). Scenario *CS01* imitates past precipitation patterns. Total daily precipitation increases by 20% in *CS05* and decreases by 20% in *CS09*, i.e. patterns of daily precipitation events are similar to past observations but different with respect to rainfall volumes.

We define four policy scenarios to model i) climate change impacts including autonomous adaptation (*CSXX_i*, were *CSXX* is synonymous to all the three climate change scenarios *CS01*, *CS05*, and *CS09*), ii) mitigation policies (*CSXX_m*), iii) planned adaptation policies (*CSXX_a*) and iv) a combination of mitigation and adaptation policies (*CSXX_m&a*). All policy scenarios as well as *REF_2040* have in common identical market conditions and most elements of the CAP reform but are different with respect to their specific policies (Table 2). The CAP reform is implemented differently only with respect to the greening measures, i.e. relaxed in *CSXX_m* and abolished in *CSXX_a* and *CSXX_m&a*.

Table 2: Mitigation and adaptation policy scenarios

Scenario	Mitigation policies	Adaptation policies
REF_2040	no	no
CS01_i CS05_i CS09_i	no	no
CS01_m CS05_m CS09_m	• energy crops and SRF on fallow land • premium for orchard meadows and SRF • premium for afforestation • premium for reduced tillage & cover crops • premium for reduced fertilization intensity	no
CS01_a CS05_a CS09_a	no	• irrigation premium • abolishment of greening (see Tab. 2) • premium for maintenance of steep grassland
CS01_m&a CS05_m&a CS09_m&a	• premium for orchard meadows and SRF • premium for afforestation • premium for reduced tillage (& cover crops) • premium for reduced fertilization intensity	like CS01_a – CS09_a

Note: i: impact, m: mitigation, a: adaptation, SRF: short rotation forestry, min.: minimum
Source: Schönhart et al. (2015)

In the impact scenario *CSXX_i* no additional policies beyond *REF_2040* are introduced. Compared to *REF_2040* this scenario presents climate change impacts based on autonomous adaptation such as crop and crop rotation choices, dietary choices for livestock, irrigation, fertilization and land cover change. The portfolio of policies in *CSXX_m* supports soil carbon sequestration and the production of agro-fuels. Establishment of SRF and cultivation of energy crops (i.e. corn, rye, soybean, sunflower, winter wheat, winter barley, rapeseed) is allowed on fallow land in the greening measure. Premiums for orchard meadows and SRF (120€/ha per year (p.a.)) as well as afforestation (one-time payment of 3850€/ha) should enhance soil carbon and agro-fuels supply in the future. Reduced tillage (40€/ha p.a.) and reduced tillage including sowing of cover crops (150€/ha p.a.) enhance soil carbon sequestration. Measures on reduced fertilization intensity aim on N_2O emission reductions and biodiversity enhancement. Participation in the latter is possible only for the whole farmland and additionally requires extensification of grassland (5% of total grassland area on a farm) and establishment of fallow land on cropland (2% of total cropland area on a farm). All premium levels in *CSXX_m* imitate the Austrian AEP ÖPUL in the rural development programming period 2007-2013. Apart from the expected positive climate impacts, the measures in *CSXX_m* should be favorable to other environmental concerns, such as biodiversity enhancement, landscape protection, reduced nutrient leakage, and erosion control. The overarching strategy of *CSXX_a* is to maintain the adaptive capacity of farmers towards climate change and agricultural production. Consequently, the greening measures (see Table 2) are abolished. Annual premiums for maintenance of steep meadows (slope ≥ 25% and < 35%: 105 €/ha, ≥ 35% and < 50%: 235 €/ha, > 50%: 370 €/ha) and an irrigation premium of 40€/ha p.a. are introduced in *CSXX_a*. Scenario *CSXX_m&a* combines the policy portfolios of *CSXX_m* and *CSXX_a*. It offers most freedom to the modelled farms with respect to land use choices and consequently will show equal or higher total farm gross margins than either *CSXX_m* or *CSXX_a*.

2.3 Case study landscape

We apply the IMF on 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 core of the case study landscape is a rectangle covering ~3,000 ha. It includes all agricultural fields which are represented by the IACS system, i.e. nearly all agricultural areas excluding forest patches, infrastructure and open water. We model those 118 farms that manage at least one field within the core of the case study landscape. Furthermore, we model all fields belonging to an individual farm. Consequently, the case study consists also of farms and fields situated outside the core of the case study landscape. These fields and farms are represented in most results except for spatial indicators and maps.

The case study landscape is located in the montane zone where afforestation may threaten traditional agricultural land use in the future. Consequently, it features a large diversity of farms in terms of farm type (mixed farms, crop farms and livestock farms), farm size, and production intensity. Observed average annual precipitation is about 1.250mm and the average temperature ranges between 7-8°C (unpublished data based on Strauss et al., 2013). The landscape is dominated by permanent grassland to feed ruminant livestock (Figure 1). Even the most important field crops are grassland variants such as temporary grassland (26%) and red clover grassland (17%) followed by silage maize (16%), winter barley (10%), and winter wheat (8%).

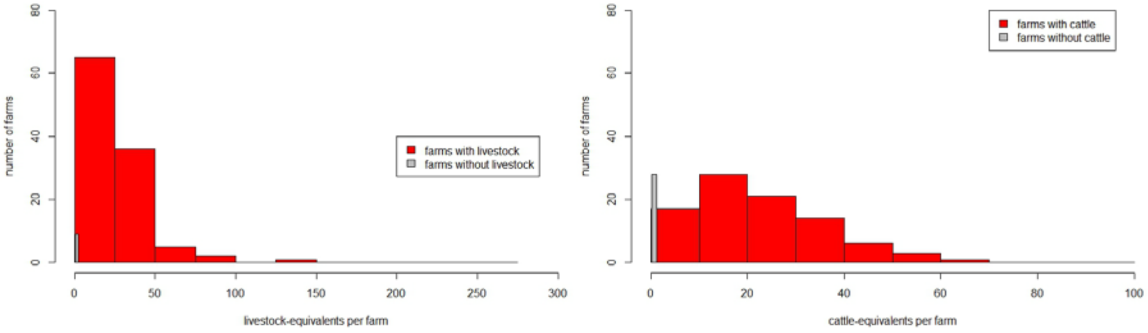

Figure 1: Number of farms with livestock (left; in livestock equivalents, 1 livestock equivalent = 1 adult cow) and with cattle (right)

3 Results and Discussion

Figure 2 shows the changes in total farm gross margins at landscape level. On average all climate change and policy scenario combinations lead to increases in aggregated total farm gross margins at landscape level with ranges between +2% in the impact scenario and +4% in the mitigation and adaptation scenario (Figure 2, left). Productivity gains from climate change have been modelled by previous studies already (e.g. Ciscar et al., 2011; Schönhart et al., 2014; Kirchner et al., 2015). Especially grassland yields are expected to increase under moderate temperature increases and enhanced CO_2 concentrations (e.g. Hopkins and Del Prado, 2007). However, our results strongly depend on the modelled impacts of climate change on crop yields – mainly forage yields – which are difficult to assess due to diverse species composition. Further research should focus on the uncertainty from bio-physical crop yield modelling. For individual farms, results show a considerable spread within each scenario (Figure 2, right), i.e. some farms in the model face small losses from climate change, while others can gain from higher temperatures and CO_2 concentrations as well as changes in precipitation levels. Nevertheless, differences in precipitation levels hardly impact gross margins. It can result from both low sensitivity to changing precipitation and high adaptive capacity in the model. With respect to the former, even declines of 20% in precipitation to 1.000mm obviously provide sufficient rainfall amounts in the region, while increases to 1.500mm may harm some crops as indicated by the results. With respect to the policy scenarios, relaxation of set-aside obligations and introduction of agri-environmental premiums to mitigate climate change positively impact gross margins, while impacts of adaptation policies are minor. It may result from the low share of cropland in the case study landscape as those policies are targeted mainly towards cropland.

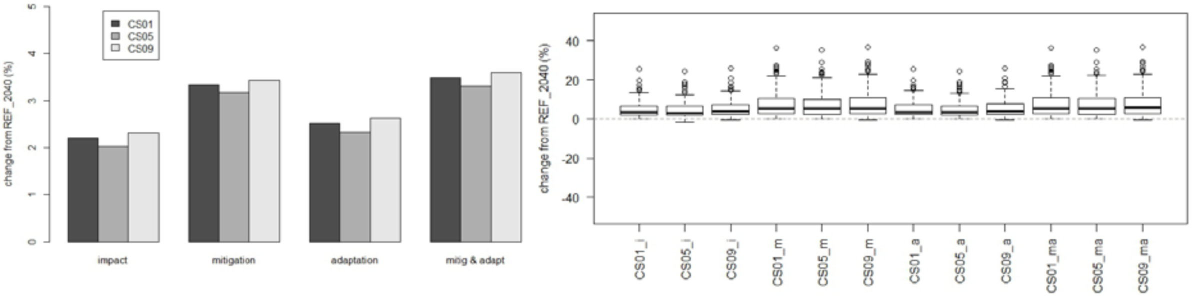

Figure 2: Changes in total farm gross margin aggregated at the landscape level (left) and distributions of changes in total farm gross margin at farm level (N=118; right) for four policy and three climate scenarios compared to REF_2040

Changes in gross margins result from land use changes, which are covered by several indicators. Figure 3 shows changes for seven land use categories, i.e. cropland, intensive and extensive grassland, orchard meadows, SRF, set-aside, and afforested area. The cropland area is impacted by two contradicting land use changes, i.e. conversion of cropland to SRF and conversion of permanent grassland (intensive and extensive grassland) to cropland. The former results from subsidies in the mitigation scenario, the latter from relaxing greening requirements in the adaptation scenario. Orchard meadows are vulnerable to market conditions and policies (Schönhart et al., 2011a). Subsidies in the mitigation scenario maintain those ecologically and aesthetically important landscape elements at the level currently observed in the landscape, while lacking policies in the impacts or adaptation scenario lead to losses in gross margins. Also afforestation is of concern in the region with up to 100 ha of additional forest area for climate scenario CS05 in the mitigation policy scenario.

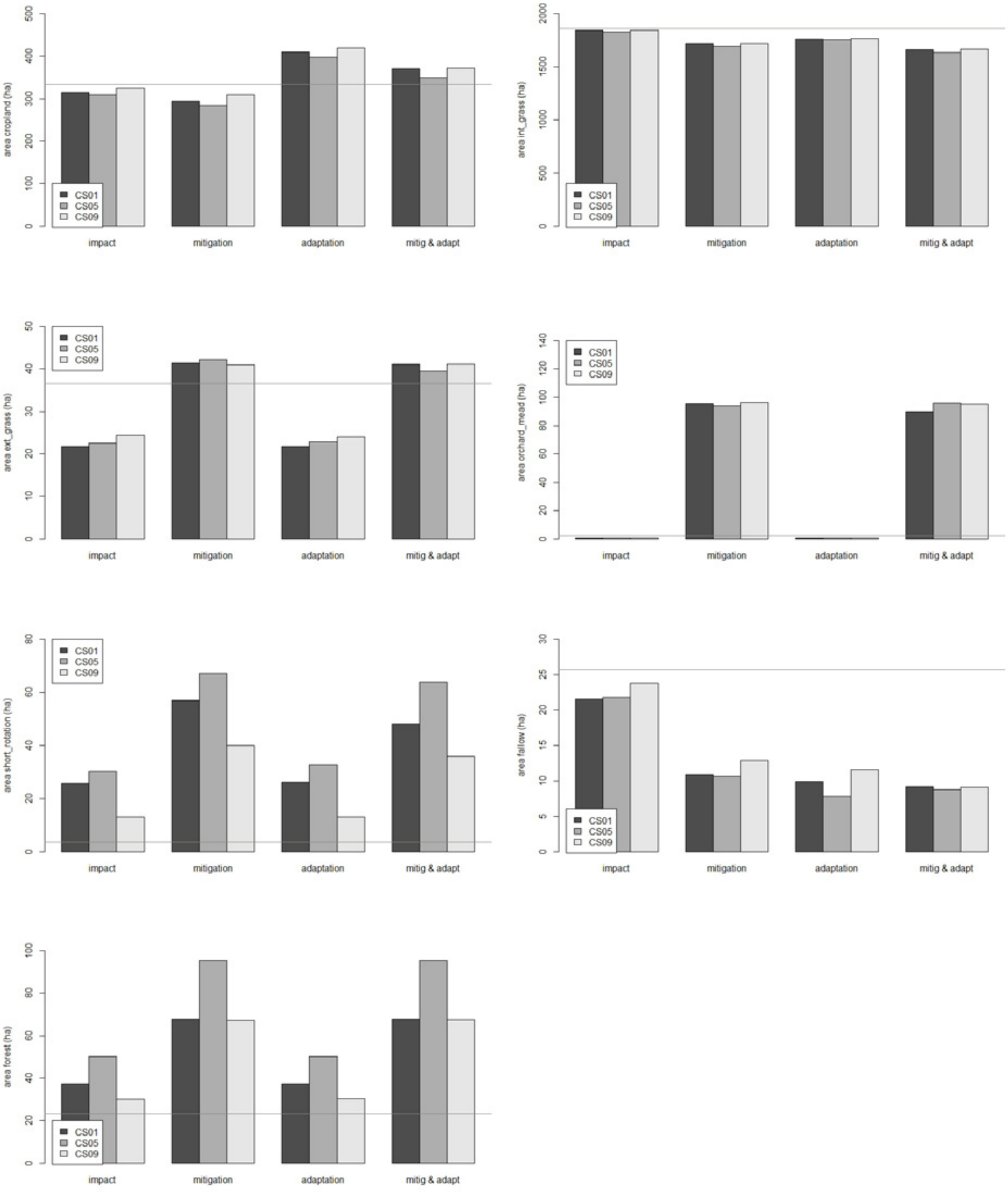

Figure 3: Total cropland, intensive and extensive grassland, orchard meadows, SRF, set-aside, and afforested area at landscape level (in ha) for four policy and three climate scenarios

Besides changes among land use categories (Figure 3), land use intensity is also governed by climate change and policies. Figure 4 presents changes in nitrogen fertilization intensity at landscape level. Climate change reduces intensity by about 10% among all climate scenarios. Extensification policies in the mitigation scenario reduce levels by further 5%, while adaptation policies increase nitrogen use again. It results from cropland conversion, which shows increasing nitrogen fertilization under climate change, while permanent grassland is managed less intensively under climate change. These results appear counterintuitive as one may expect intensification from improved growing conditions. In the model, however, the limited tradability of forage products, the high costs of increases in herd size beyond resource endowments, and limitations on manure application seem to prevent more intensive grassland use. On the contrary, model farms use their grassland less intensive for the same total yields under climate change or convert to cropland if allowed in the adaptation policy scenario. Such results clearly call for in-depth research and sensitivity analysis and should be subject to further research.

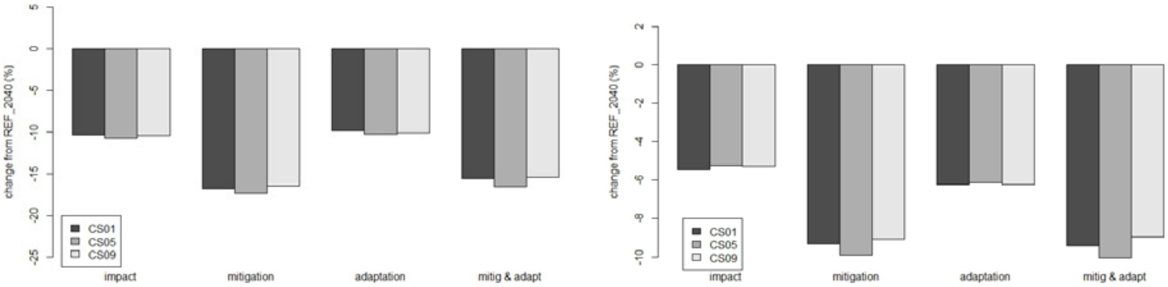

Figure 4: Changes in nitrogen fertilization intensity (left) and agricultural greenhouse gas emissions (right) at landscape level from REF_2040 for four policy and three climate scenarios.

GHG emissions mainly result from livestock, fertilization, and soil carbon depletion. All three sources are covered in the IMF. Figure 4 presents changes in GHG emission from fertilization and livestock production for both cropland and permanent grassland. They are correlated with the nitrogen fertilization intensity and indicate effective GHG emission abatement in the mitigation scenario. While many indicators have been moderately sensitive to different climate change scenarios so far, stronger impacts are modelled for soil organic carbon (SOC; Figure 5) with losses in CS05 (+20% precipitation) and gains in CS09 (-20% precipitation). Relative changes are larger on cropland but from a lower absolute basis.

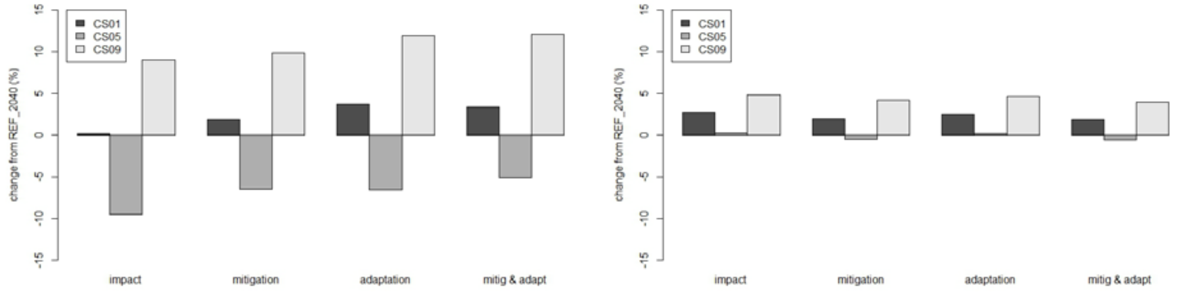

Figure 5: Changes of soil organic carbon (SOC) from REF_2040 on cropland (left) and permanent grassland (right) for four policy and three climate scenarios

Changes in SOC are triggered not only by climate but also by soil management, which is presented in Figure 6. Premiums on reduced tillage combined with cover crops substantially increase its use in the mitigation scenario, while reduced tillage alone is already applied in the impact scenario on about half of total cropland. This results in larger increases of SOC or lower losses in the mitigation scenario compared to the impact scenario. The further increases of SOC in the adaptation scenario cannot be explained by these management changes and require in-depth analysis.

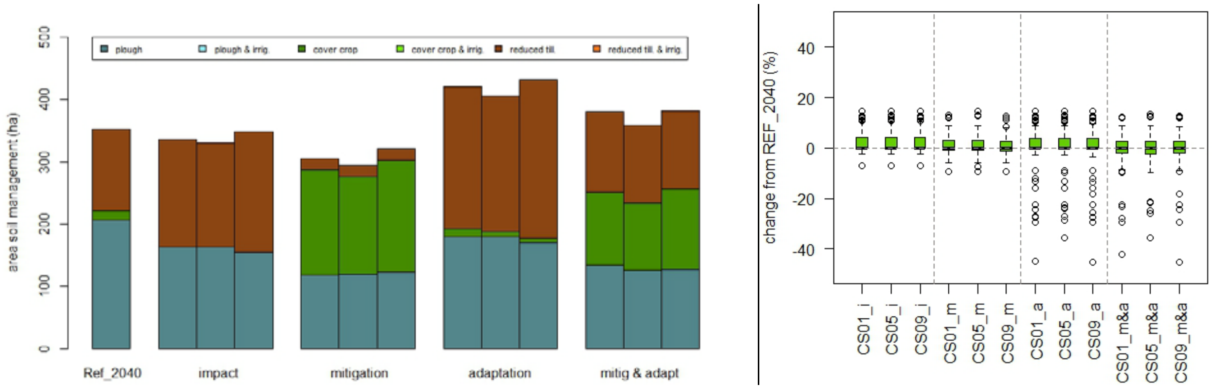

Figure 6: Soil management on cropland (ha) for the reference without climate change (REF_2040) and four policy and three climate scenarios (order of climate change scenarios in each block: CS01, CS05, CS09) (left) and changes of vascular plant species richness from REF_2040 for four policy and three climate scenarios (right)

Changes in land use management such as conversion among land use categories, changes in fertilization intensity, or soil management impact ecosystems and biodiversity. Figure 6 (left) shows impacts from policies on vascular plant species richness. More intensive land use is expected to trigger species losses in the adaptation scenario, which is indicated by a substantial increase of outliers. However, average diversity among the mitigation and adaptation scenario does not change a lot, which should be subject to further analysis.

5 Conclusions

On average, climate change and the assumed mitigation and adaptation policies increase farm incomes above the reference situation with current climate conditions in the IMF. However, such average results are based on considerable heterogeneity among farms, which justifies resource demanding spatially-explicit modelling. Results from the IMF reveal the need to coordinate mitigation and adaptation policies in order to reduce adverse environmental and ecological effects, i.e. trade-offs, and increase synergies between environmental outcomes. For example, increasing flexibility such as in the assumed adaptation scenario can increase environmental burden, while mitigation policies can reduce the adaptive capacity of farmers.

The IMF proves to be effective in revealing heterogeneity of farm impacts and responses to climate change and climate change policies. Further research should aim at addressing model uncertainties with respect to data, model parameters and model linkages. For example, the modelled decreasing fertilization intensity due to climate change should be subject to sensitivity analysis to scrutinize whether the model is too rigid concerning adaptation of livestock production in grassland dominated regions.

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