Assessing the vulnerability of cropland to soil water erosion under climate change in Austria

Bewertung der Vulnerabilität von Ackerland hinsichtlich Bodenerosion unter veränderten klimatischen Bedingungen in Österreich

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Summary

We assess the vulnerability of cropland to soil water erosion and the effectiveness of two soil conservation measures in Austria. Potential sediment yields are simulated with the RUSLE (Revised Universal Soil Loss Equation) methodology for five climate change scenarios until 2040 using the bio-physical process model EPIC (Environmental Policy Integrated Climate). Cropland has been assigned to five vulnerability classes according to OECD (2001). Potential changes in mean annual crop yields and gross margins have been calculated. The model results indicate increasing sediment yields with higher precipitation sums. Reduced tillage and cultivating winter cover crops have been identified as effective adaptation options though they generally result in lower crop yields and gross margins. However, the additional variable costs are over-compensated by current agri-environmental premiums.

Keywords: vulnerability, soil water erosion, conventional tillage, soil conservation measures, climate change

Kurzzusammenfassung

Wir untersuchen die Vulnerabilität des österreichischen Ackerlands in Bezug auf Wassererosion sowie die Effektivität von zwei Bodenschutzmaßnahmen. Zur Berechnung des Bodenabtrags wurde das biophysikalische Prozessmodell EPIC (Environmental Policy Integrated Climate) unter Verwendung des Erosionsmodells RUSLE (Revised

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Universal Soil Loss Equation) für fünf Niederschlagsszenarien bis 2040 eingesetzt. Die Vulnerabilität des Ackerlands wird mit fünf Erosionsgefährdungsklassen nach OECD (2001) veranschaulicht. Im Weiteren werden durchschnittliche jährliche Pflanzenerträge und Deckungsbeiträge für unterschiedliche Bodenbearbeitungsformen berechnet. Die Simulationsergebnisse zeigen höhere Bodenabträge bei steigenden Niederschlagssummen. Die erosionsmindernde Wirkung von reduzierter Bodenbearbeitung und Winterbegrünung konnte bei allen Niederschlagsszenarien nachgewiesen werden. Die Ergebnisse zeigen, dass die derzeitigen Agrarumweltprämien die niedrigeren durchschnittlichen Pflanzenerträge und höheren variablen Produktionskosten der Bodenschutzmaßnahmen kompensieren.
Schlagworte: Vulnerabilität, Bodenerosion, konventionelle Bodenbearbeitung, konservierende Bodenbewirtschaftung, Klimawandel

1. Introduction

Soil water erosion is a natural landscape-shaping process, which can be accelerated by human activities such as land use, soil management, and cropping systems. Besides negative off-site effects (e.g. import of suspended load into watercourses, siltation of infrastructure), soil water erosion may induce harmful on-site damage to agricultural land and hence may impact the provision of a range of ecosystem services (JULIEN, 2010). Degradation processes like soil erosion impair agronomic productivity and environmental quality through their impact on soil quality. The most adverse effect on productive capacity of agriculture is caused by loss of topsoil depth (LAL, 2001).

In Austria, approximately 25% of all agricultural land is regarded as vulnerable to soil water erosion (STRAUSS, 2006). Driving forces for soil loss are rainfall amount and intensity, soil characteristics, slope length and gradient, ground cover and soil management (SCHWERTMANN et al., 1987). Climate change might increase future soil erosion rates unless robust soil conservation measures are adopted.

The Austrian Agri-Environmental Programme ÖPUL supports (inter alia) measures aiming explicitly at improving soil quality and reducing soil erosion, such as mulch and direct seeding or cultivating winter cover crops. Soil cover and crop management practices are frequently part of integrated assessments on climate change adaptation in

agriculture (e.g. THALER et al, 2012). Therefore, we analyse the impacts of different climate change scenarios on potential soil sediment yields to depict the vulnerability of cropland to soil water erosion in Austria. We also assess the effectiveness of two soil conservation measures, namely reduced tillage and cultivation of winter cover crops. Moreover, we investigate potential alterations in mean annual crop yields and gross margins under changing climatic conditions and crop management practices. The analysis should help to develop robust spatially adapted soil conservation strategies for Austrian farmers.
The article is structured as follows: section 2 provides an overview on the data and models applied. It is followed by results and discussion in section 3 and conclusion and outlook in section 4.

2. Data and method

The bio-physical process model EPIC (Environmental Policy Integrated Climate) has been used to simulate potential sediment yields and dry matter crop yields on cropland in Austria. In particular, we use the widely accepted RUSLE (Revised Universal Soil Loss Equation) methodology (RENARD et al., 1997) as the driving soil loss equation in EPIC. The most relevant crops for Austria (22 crops including e.g. cereals, protein crops, and oilseeds) have been simulated in crop rotations derived from the empirically based CropRota model considering - inter alia - regional characteristics of cultivation and the feasibility of crop sequences (SCHÖNHART et al., 2011). EPIC operates on a daily time step and interlinks information on weather, soil and topography as well as crop management. It is applied to simulate bio-physical outputs on Austrian croplands at 1 km raster resolution. The outputs comprise (inter alia) crop yield/forage yield, sediment yield, runoff, evapotranspiration, percolation, nutrient loads and nutrient uptake for nitrogen and phosphor, and soil organic carbon (WILLIAMS, 1995). The grid information contains data from 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), and crop management data from the Integrated Administration and Control System (IACS) data base as well as from expert knowledge.The empirically based RUSLE equation calculates the daily mean soil loss as follows:

A = R K L S C P,

where A is the computed soil loss, R is the rainfall and runoff erosivity factor, K is the soil erodibility factor, L is the slope length factor, S is the slope steepness factor, C is the cover management factor, and P is the supporting practices factor (RENARD et al., 1997).

Simulations with EPIC have been performed for various scenarios incorporating three crop management practices and five climate change scenarios for the period 2010 to 2040. The crop management practices comprise crop rotations with conventional and reduced tillage as well as the cultivation of winter cover crops in distinct crop rotation systems. The characterisation of conventional and reduced tillage follows the definition provided by the Conservation Technology Information Center CTIC:

- "conventional tillage": mouldboard plough with <15% crop residue on soil surface before planting.
- "reduced tillage": conventional, reduced or minimum tillage is applied where appropriate in the crop rotation system, i.e. light disk or chisel plough with 15-30% crop residue on soil surface before planting (reduced tillage), and direct seeding with >30% crop residue on soil surface before planting (minimum tillage), respectively.
- "winter cover crops": cultivated, where applicable in the crop rotation systems.

The climate change scenarios (sc) selected for the analysis have been derived from a statistical climate change model for Austria (STRAUSS et al., 2013). The scenario-based approach aims at covering the range of highly uncertain future precipitation sums and distributions to assess the robustness of the soil conservation measures. The applied climate change scenarios have an identical statistically significant rising trend in temperature (~1.5 °C until 2040) but assume different precipitation sums:

- sc01: reference scenario with precipitation patterns from 1975 to 2005,
- sc05: daily precipitation is increased by 20% compared to sc01,
- sc09: daily precipitation is decreased by 20% compared to sc01,
- sc13: shift in the seasonal precipitation distribution from the summer to the winter, daily precipitation in the winter season (Sep.-Feb.) is increased by 20% compared to sc01, constant annual precipitation sum,

- sc17: shift in the seasonal precipitation distribution from the winter to the summer, daily precipitation in the summer season (Mar.-Aug.) is increased by 20% compared to sc01, constant annual precipitation sum.

For all simulation results, soil water erosion vulnerability maps have been created with five vulnerability classes: (1) tolerable, (2) low, (3) moderate, (4) high, and (5) severe soil water erosion according to OECD (2001). The extent of areas prone to soil water erosion as well as its alteration has been analysed by means of descriptive statistics and visual aids with the objective of revealing the impact of climate change scenarios on soil water erosion and evaluating the effectiveness of soil conservation measures.

Moreover, impacts on mean annual dry matter crop yields and mean annual gross margins of crop production have been investigated for Austria. Gross margin is defined as revenues minus variable costs. Both, revenues (depending on crop yields and agri-environmental premiums) and variable costs vary among crop management practices. Furthermore, regional heterogeneity in environmental site conditions (e.g. climate, soil, topography) is reflected on the revenue side, as revenues are based on crop yields simulated by EPIC. Changes in fixed costs are neglected. Revenues are calculated by multiplying mean annual crop yields (in t/ha/a) by the respective mean annual crop prices of the period 1998-2011 provided by Statistics Austria and adding agricultural policy premiums such as € 280/ha/a of Single Farm Payment as well as € 40/ha/a for reduced tillage and € 160/ha/a for cultivating winter cover crops (according to the current ÖPUL; BMLFUW, 2009). Variable production costs include purchases of seeds, fertilizers, pesticides, fuel, and insurances as well as the costs for applying soil conservation measures and are derived from the standard gross margin catalogue (BMLFUW, 2008) and from own data sources. Labour costs of crop production are considered with € 10/h.

3. Results

3.1 Vulnerability of cropland to soil water erosion and effectiveness of conservation measures

Figure 1 depicts regional characteristics of cropland vulnerabilities to soil water erosion with conventional tillage and the cultivation of winter cover crops for the reference scenario (sc01, unchanged precipitation). Particularly the areas of the southeast and northwest plains and hills, the Alpine foreland as well as the Carinthian basin are deemed to be most severely affected. The model results indicate that areas vulnerable to soil water erosion can be protected by conservation tillage though its effectiveness varies spatially.

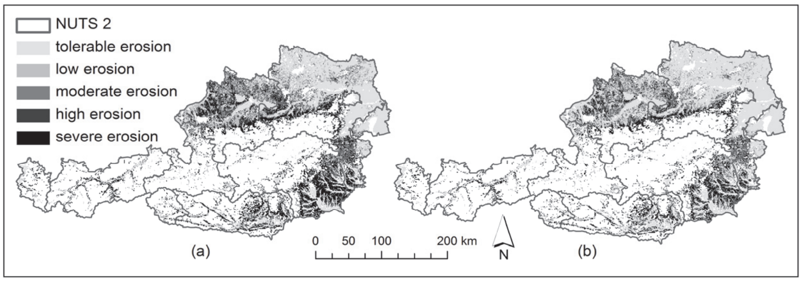

Fig. 1: Vulnerability of cropland to soil water erosion for the reference scenario (sc01) with conventional tillage (a) and winter cover crops (b)
Source: own calculations

Regardless of the crop management practice, model results indicate an increase in vulnerability to soil water erosion for the climate change scenarios sc05 (+20% precipitation) and sc17 (+20% summer precipitation). Scenario sc05 leads to a ~96% (conventional tillage) to ~153% (winter cover crops) increase in areas severely vulnerable to soil water erosion compared to the respective reference scenario under the same management (sc01). Scenario sc17 results in a ~21% (conventional tillage) to ~45% (winter cover crops) increase in areas severely vulnerable to soil water erosion. In our analysis, changes in areas severely vulnerable to soil water erosion are higher with conservation measures than with conventional tillage due to smaller absolute reference values in sc01. Consequently, total severely vulnerable areas with conservation measures remain still below those of conventional tillage even under climate change, i.e. severely vulnerable areas are ~26,690 ha (sc05) and ~14,760 ha (sc17) lower for reduced tillage and ~73,220 ha (sc05) and ~51,210 ha (sc17) lower for winter cover crops, respectively.

Model results for sc09 with -20% lower precipitation sums show a ~75% (conventional tillage) to ~83% (winter cover crops) decrease in areas with severe vulnerability to soil water erosion. The effects of sc13 with higher precipitation sums in winter are similar to those of sc01 (changes of areas with severe sediment yield amount to a maximum of ~9%).

Both soil conservation measures, i.e. reduced tillage and the cultivation of winter cover crops prove to be effective adaptation options. Maintaining soil cover during the winter season conserves soils even better than reduced tillage. In all climate change scenarios, areas vulnerable to moderate, high, and severe soil water erosion could be decreased by soil conservation measures. Compared to conventional tillage, the median reduction of sediment yield reaches ~5% (sc17, +20% summer precipitations) to ~12% (sc13, +20% winter precipitation) with reduced tillage practices and ~25% (sc17, +20% summer precipitations) to ~32% (sc13, +20% winter precipitations) with the cultivation of winter cover crops, respectively.

3.2 Gross margins for different climate change scenarios and crop management practices

Absolute and relative impacts of climate change scenarios and crop management practices on mean annual crop yields and gross margins compared to the reference scenario sc01 are presented in Table 1. Regardless of the crop management practice, losses in average crop yields and gross margins are calculated for scenarios sc13 (+20% winter precipitation) and sc09 (-20% precipitation), with the latter resulting even in negative average gross margins. Increases in average crop yields and gross margins are calculated for scenarios sc17 (+20% summer precipitation) and sc05 (+20% precipitation).

Conservation measures generally result in lower simulated crop yields and lower gross margins in all climate change scenarios. However, current agri-environmental premiums over-compensate additional variable costs of reduced tillage and cultivating winter cover crops.

Tab. 1: Levels and relative changes of average annual gross margins and simulated crop yields

	climate change scenarios				
	0% sc01	+20% sc05	-20% sc09	+20% winter sc13	+20% summer sc17
ø GM, WITH premiums			in €/ha/a		
conventional tillage	368	403	273	350	389
reduced tillage	376	408	283	359	393
incl. winter cover crops	491	535	389	476	504
ø GM, NO premiums			in €/ha/a		
conventional tillage	88	123	-7	70	109
reduced tillage	55	88	-37	39	73
incl. winter cover crops	51	95	-51	36	64
ø dry matter crop yields			in t/ha/a		
conventional tillage	6.9	7.1	6.3	6.7	7.0
reduced tillage	6.6	6.8	6.0	6.5	6.7
incl. winter cover crops	6.6	6.9	6.0	6.5	6.7
ø changes in GM, WITH premiums			change in % from sc01		
conventional tillage	ref	9%	-26%	-5%	6%
reduced tillage	ref	9%	-25%	-4%	5%
incl. winter cover crops	ref	9%	-21%	-3%	3%
ø changes in GM, NO premiums			change in % from sc01		
conventional tillage	ref	39%	-108%	-20%	23%
reduced tillage	ref	58%	-166%	-29%	32%
incl. winter cover crops	ref	87%	-200%	-30%	25%
ø changes in crop yield			change in % from sc01		
conventional tillage	ref	3%	-9%	-2%	2%
reduced tillage	ref	3%	-9%	-2%	2%
incl. winter cover crops	ref	4%	-10%	-2%	1%

Legend: GM (gross margin)
Source: own calculations

4. Conclusions and outlook

Various empirical studies (e.g. KLIK, 2003) prove the positive effect of soil conservation measures on soil water erosion. Our model results indicate that reduced tillage and cultivation of winter cover crops are effective measures under changing climatic conditions, with the latter being even more effective. In all climate change scenarios, the areas vulnerable to moderate, high and severe soil water erosion could be decreased when applying soil conservation measures. However, the

effectiveness varies spatially due to physical and agronomic heterogeneities in crop production.
Policies affect - inter alia - the type of land use and management and hence the rate of soil erosion (LAL, 2001). The ÖPUL promotes a number of soil conservation measures in order to encourage farmers to retain or implement these measures. In our model calculations, additional variable costs of reduced tillage and cultivating winter cover crops are more than offset by current agri-environmental premiums on average and therefore appear as attractive incentives for farmers. However, neither different fixed costs nor opportunity costs of soil conservation measures are yet considered in the analysis. In a next step, an integrated land use optimization model will be developed to analyse cost-effective climate change adaptation measures and their trade-offs to other agri-environmental policy objectives such as nitrate leaching. The spatially explicit results could inform the debate on planning and implementing cost-effective agri-environmental measures by considering spatial targeting. Nevertheless, uncertainties caused by imperfect process knowledge, gaps on local data, and inherent limits to the predictability of climate change have to be taken into account as well.

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