Universität für Bodenkultur Wien
Department für Wirtschafts- und
Sozialwissenschaften

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Hermine Mitter
Mathias Kirchner
Erwin Schmid
Martin Schönhart

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University of Natural Resources and Applied Life Sciences, Vienna
Department of Economics and Social Sciences

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Hermine Mitter, Mathias Kirchner, Erwin Schmid, Martin Schönhart

University of Natural Resources and Life Sciences, Vienna; Institute for Sustainable Economic Development; Doctoral School of Sustainable Development; Feistmantelstrasse 4; 1180 Vienna, Austria

phone: +43 1 47654-3664

fax: +43 1 47654-3692

e-mail: hermine.mitter@boku.ac.at mathias.kirchner@boku.ac.at erwin.schmid@boku.ac.at martin.schoenhart@boku.ac.at

URL: http://www.wiso.boku.ac.at/ http://dokne.boku.ac.at/

Abstract

Climate change affects agriculture differently due to the heterogeneity in bio-physical and economic conditions in Austria. Therefore, stakeholder and expert knowledge is required in regional vulnerability assessments to address region specific challenges and develop compatible adaptation strategies. In a transdisciplinary research project, a working group consisting of regional stakeholders and agricultural experts identified the effects of uncertain future precipitation on soil water erosion as well as the effectiveness of selected soil conservation measures as the most crucial knowledge gap. Consequently, potential sediment losses on cropland have been simulated with the RUSLE (Revised Universal Soil Loss Equation) methodology for several climate change scenarios using the bio-physical process model EPIC (Environmental Policy Integrated Climate) in an Austrian alpine foreland region. The model predicts an increase in sediment yield with higher precipitation sums for 2040 on average. However, reduced tillage and cultivating winter cover crops have been identified as effective adaptation options. The stakeholders have provided local knowledge in crop management and validated the model results according to their clarity, comprehensiveness, and meaningfulness. They confirmed its usefulness to inform farmers and support the public debate on regional climate change adaptation in agriculture.

Keywords

transdisciplinary regional vulnerability assessment, soil water erosion, EPIC, soil conservation measures, Austria

Introduction

Agriculture is highly interrelated with weather and climate and is thus considered as one of the most climate sensitive economic sectors (Parry 2000). However, farmers, policy makers, and extension experts are frequently unaware of the systems' complexity, the inherent uncertainties and effectiveness of adaptation strategies (Eitzinger et al. 2009; Olesen et al. 2011). This type of complex, multi-scale and multi-layered problems has been called "wicked" (Rittel and Webber 1973) or even "super wicked" (Levin et al. 2012) and calls for new approaches of integrating knowledge of regional stakeholders and scientists from different fields into impact and vulnerability assessments. In order to (i) address the imperfect understanding of complex systems under high uncertainty, (ii) provide sustainable mitigation and adaptation strategies, (iii) strengthen the interface between science and policy making, and (iv) facilitate well-informed decision and policy making, scientists have to integrate their disciplinary knowledge into transdisciplinary research processes. Though many authors claim the adequacy of tackling complex social and environmental challenges by a transdisciplinary approach (e.g. Scholz et al. 2006; Jahn 2008; Bammer 2012) examples of transdisciplinary empirical research are still scarce. Climate research remains dominated by the academic sector's power and interests (Welp et al. 2006; Wuelser et al. 2012). In this article, we contribute to this gap by providing a regional climate change vulnerability assessment developed in a transdisciplinary research process, which focuses on cropland soil water erosion in an Austrian alpine foreland region.

The research project "RIVAS – Regional Vulnerability Assessment for Austria" has been carried out by a multi-disciplinary team of natural and social scientists in the Austrian agriculturally important Mostviertel region. RIVAS aimed at preparing a transferable conceptual, methodological and procedural framework for regional vulnerability assessments, including the ideal design of a science-based stakeholder process. This research process is guided by the three phases of an idealised transdisciplinary research processes as suggested by Pohl and Hirsch Hadorn (2007): (1) Problem identification and structuring, (2) problem analysis, and (3) bringing results to fruition. Though the boundaries between these phases cannot be drawn exactly in the research process, they are still helpful to structure applied project work. In this article, the aims and tasks, the methodological challenges, the level of stakeholder integration, and the experiences gained are outlined for each phase.

The article is structured as follows: We first provide an overview on the case study area. Secondly, we analyse the case study and discuss it along the three phases of an idealised transdisciplinary research process, namely problem identification and structuring, problem analysis, and bringing results to fruition. We present a description of the applied quantitative research methods and results in the problem analysis section. Then a discussion is provided, followed by conclusions and outlook.

Case study area

The Mostviertel region (NUTS 3 region AT121) is located in the Lower Austrian alpine foreland. In total, there are approximately 11,000 farms in the region (Statistics Austria 2011). Roughly half of the total agricultural area is used as cropland (~75,000 ha) and permanent grassland (~81,000 ha), respectively (see Fig. 1a). Permanent grassland and forests prevail in the south, whereas in the north, corn (see Fig. 1c), barley and winter wheat production dominate land use (Statistics Austria 2011). Crops are also cultivated on steeply sloped farmland (slopes >15%; see Fig. 1b), located north and south to the fertile valley floor of the Danube River.

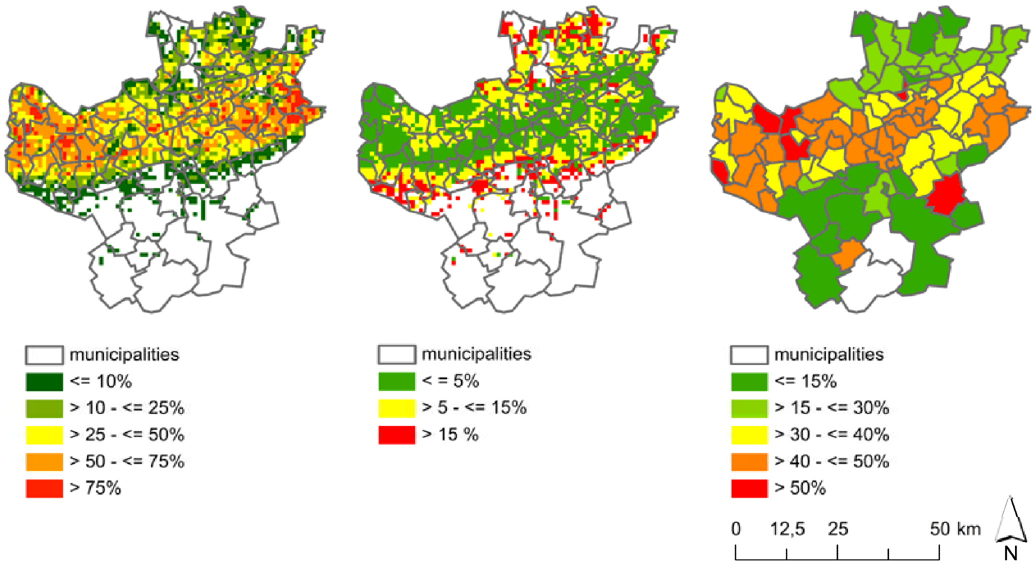


Fig. 1 Shares of cropland (a), slope classes (b) and corn (c) by 1 km² pixels and municipalities in the Mostviertel region

The regional climate is heterogeneous with respect to latitude and altitude despite its rather small size of ~3,400 km² (Statistics Austria 2012a). Mean annual precipitation sums range between ~550 mm in the north and ~1,400 mm in the south, mean annual temperatures between ~9 °C (~200 m above sea level) and ~3.5 °C (~1,500 m above sea level) (Strauss et al. 2012). The heterogeneity of topography, climate and farm types makes the Mostviertel region interesting for agricultural vulnerability assessments.

Problem identification and structuring

"Problem identification and structuring" is the most important phase in transdisciplinary research processes and includes (i) identifying relevant stakeholders involved in the problem field, (ii) determining knowledge gaps, and (iii) translating perceived societal problems into a scientific problem description (Pohl and Hirsch Hadorn 2007).

The relevant stakeholders involved in the problem field were identified by stakeholder mapping (for experienced approaches to stakeholder identification and analysis tools see e.g. Hernández-Jover et al. 2012) and by applying the snowball approach, whereby local and regional stakeholders are named as key individuals by previously identified stakeholders (see Biernacki and Waldorf 1981). For a continuous science-stakeholder interaction during the research project and beyond, a peer group was established including selected regional stakeholders and scientists. Participants were invited after mutual consultations between stakeholders and scientists. Finally, extension experts, public authorities, and teachers from farming schools formed part of the peer group.

In transdisciplinary research, the recursive process of problem framing and structuring in a team of stakeholders and scientists is deemed as the key element (Pohl and Hirsch Hadorn 2007). To adjust integrated models to a particular study region and investigate the adequacy of mitigation and adaptation alternatives, Rice et al. (2012) call for systematic stakeholder interactions and literature reviews aiming at the identification of stakeholder interests and pertinent mitigation and adaptation strategies. We managed the process of joint problem framing and structuring in three steps (in Table 1 we provide a summary on the participatory process):

(1) The first joint workshop in the study area aimed at informing the stakeholders about the scientific knowledge in climate research including the potential impacts on the agricultural sector and raising their awareness for adaptation options. In an oral presentation, the scientists gave an overview on the challenges agriculture might face in the next decades due to changing climatic conditions (*"making available what is known"*; Bammer 2012, 100). In the

discussion, the stakeholders were encouraged to exchange experiences and provide an ad-hoc evaluation of the regional vulnerability. A broad range of already existing and potential future problems has been addressed, among others soil erosion affected by heavy precipitation events, exposure of (alpine) pastures to drought, nitrogen pollution of groundwater in intensive agricultural areas, decreasing livestock due to an increasing number of biogas plants, and proliferation of (changed) pests and diseases in orchards. Stakeholders and scientists agreed on many relevant points; the added value provided by the stakeholders was the localisation of thematic areas and a ranking to local importance.

(2) After the first workshop, twelve semi-structured interviews were conducted with selected regional stakeholders including farmers, extension experts, policy advisers, policy makers and teachers of farming schools in order to acquire regional knowledge and to learn about the regionally perceived challenges of climate change in agriculture. The interviewees considered the following topics as most important for the Mostviertel region:

- farmland management: higher soil water erosion because of more frequently heavy precipitation events, damage to subsequent crops in the crop rotation because of heavy rainfall and/or run-off, desertification of porous soils because of increasing temperatures;
- livestock production: decrease in meat and milk yield because of heat stress and droughts, drinking water supply in mountainous regions, cooling of stables;
- orcharding: harder conditions for extensive orcharding because of increasing temperatures, higher infestation pressure of pests and changes in insecticide use, changes in varieties; and
- adaptation to climate change: changes in varieties, sowing dates, and fertilizer and pesticide use.

(3) The second workshop with the peer group aimed at specifying major societal problems in the study area, delineating the stakeholders' need for knowledge and translating the life-world perspective of the problem into a research question to be tackled by state of the art methods. The peer group discussed the interview results and reasons for contradictory statements. Some of the discrepancies were clarified with the help of the stakeholders' knowledge about the region and its development in recent years and decades. Based on the interview results, the discussion during the first workshop, the literature review, and the available resources (i.e. scientific knowledge, time), the scientists had pre-defined two thematic priorities for the Mostviertel region, namely "heavy precipitation events and soil water erosion" and "aridity and drought". Both thematic priorities were discussed informally with reference to a fact sheet summarizing the scope of the topics, available data and methods, and achievable results. The stakeholders confirmed the high relevance of the two topics for the study region though they all prioritized "heavy precipitation events and soil water erosion". Finally the peer group identified the impact of uncertain future precipitation on soil water erosion in crop production and the effectiveness of selected soil conservation measures as the most relevant knowledge gap.

As part of the problem analysis, the scientists reformulated and specified the research question in the following way: "In what extent do precipitation scenarios until 2040 affect soil water erosion on cropland and how effective are particular soil conservation practices?"

Table 1 Stakeholder integration into the research process and level of interactive knowledge generation

phase of research process	purpose of stakeholder integration	process description	level of interactive knowledge generation and setting	stakeholder participation
problem identification and structuring	sensitisation and awareness raising; provide information; narrow down the problem field	overview on the state of the art in climate research focussing on agriculture; providing specific information on the study area	1st workshop: presentation (one-way information from scientists to stakeholders)	peer group
	exchange experiences; narrow down the object of study	ad-hoc evaluation of regional vulnerability by the stakeholders; summary of experiences and perceptions of actual and future problems in agriculture	1st workshop: discussion (mutual one-way information)	peer group
	identify relevant problem areas and questions	get access to regional knowledge and stakeholder knowledge; learn about regionally perceived challenges, priorities and preferences, urgency etc.; determine the need for knowledge	expert interviews, semi-structured telephone interviews (one-way information from stakeholders to scientists)	regional stakeholders (including several peer group members)
	translate relevant societal problems into a scientific problem description; specify the research question	provision of information on interview results and discussion on contradictory statements; pre-selection of two thematic priorities; discussion of urgency, relevance and usefulness of both thematic priorities for the study area	2nd workshop: presentation (one-way information from scientists to stakeholders), discussion (mutual one-way information); joint generation of research question (collaborative research)	peer group
	clarify expectations for and ensure usability of research results	discussion of pros and cons of presentation formats for research results	2nd workshop: discussion (mutual one-way information)	peer group
problem analysis	determine a conceptual framework; improve the quality of the project design	discussion of the conceptual framework and definition of sub-goals	2nd workshop: discussion (mutual one-way information); joint definition of the conceptual framework and sub-goals (collaborative research)	peer group
	define data, models and scenarios to be used	information of stakeholders and joint discussion of data, model and scenario selection	2nd workshop: discussion using a fact-sheet (mutual one-way information); e-mail and/or telephone (one-way information from scientists to stakeholders)	peer group
	integrate knowledge of regional stakeholders and scientists into modelling; increase the acceptance	consult regional stakeholders and scientists for practical issues on cropping;	e-mail and/or telephone (one way information from stakeholders to scientists)	regional stakeholders

	of the project	validate model input data	face-to-face contact (mutual one-way information)	scientific expert
	provide comprehensive and clear results with a practical utility; reality and usability check of results	present and discuss preliminary results; validate preliminary results; discuss the presentation format of the results	3rd workshop: presentation (one way information from scientists to stakeholders); discussion (mutual one-way information)	peer group
bringing results to fruition	provide research results for further advisory and persuasion activities; pass the new insights on to e.g. farmers, decision-makers; strengthen the long-term effectiveness of the project	communicate the final results adequately (e.g. e-mail, print presentation)	providing the final results (one-way information from scientists to stakeholders)	peer group, interviewees and interested farmers, decision-makers etc.

Note: Wiek (2007) introduced four levels of interactive knowledge generation for transdisciplinary research: (1) one-way information, (2) mutual one-way information, (3) collaborative research, and (4) joint decision-making.

Problem analysis

In the “problem analysis” phase, the scientists acquired new scientific knowledge. They focused not only on the adjustment of agronomic simulation models to the framed research question and the case study region, but also on the integration of practical knowledge of peer group members and other regional stakeholders. The targets of the “problem analysis” phase proposed by Pohl and Hirsch Hadorn (2007), following the schematic approach by Jaeger and Scheringer (1998), have been adapted to regional vulnerability assessments, i.e. (i) determining a conceptual framework and structuring the research question into sub-questions or sub-goals, (ii) defining the data to be used, adapting the simulation models according to the specified sub-questions, developing scenarios, and (iii) answering the sub-questions and merging the results to an integrative vulnerability assessment.

Conceptual framework

During the second workshop in the study area, stakeholders and scientists discussed the conceptual framework and framed sub-goals. Potential indicators for assessing the vulnerability of cropland to soil water erosion under changing climatic conditions were addressed implicitly and finally defined by the scientists based on the selected sub-goals. The vulnerability assessment focused on:

- soil water erosion
  - impact of potential changes in mean climatic conditions (in particular annual precipitation sums) on sediment loss in crop production
  - suitability of different crop management practices as potential adaptation option

- crop yields
  - impact of potential changes in mean climatic conditions on crop yields
  - impact of different crop management practices on crop yields

- gross margins
  - impact of potential changes in mean climatic conditions on gross margins of crop production
  - impact of different crop management practices (i.e. crop yields, premiums, costs) on gross margins of crop production

These sub-goals were specified in cooperation with the stakeholders and investigated at regional level. Though the stakeholders would have been interested also in a small-scale analysis (e.g. particular fields identified as vulnerable), investigations at farm and field level could not be conducted due to insufficient spatial resolution of data and models (i.e. 1km² grid resolution). A comprehensive vulnerability assessment for the whole agricultural sector could not be provided because of the limited resources in the RIVAS project. Therefore, grassland farming and livestock production have not been considered in the quantitative analysis.

Data and methods

Scientists decided on data and methods and discussed their decision with the stakeholders during the second workshop in the study area and during further project steps. Regional stakeholders were asked to provide information on regional management patterns such as soil conservation measures or winter cover crops in different crop rotation systems.

The bio-physical process model EPIC (Environmental Policy Integrated Climate; Williams 1995) has been applied to simulate potential sediment yields on cropland. In particular, the widely accepted RUSLE (Revised Universal Soil Loss Equation) methodology (Renard et al. 1991; Renard et al. 1997) has been selected in EPIC as driving soil loss equation. EPIC has been applied on 1km² raster resolution interlinking data on weather, soil, topography and crop management to simulate (inter alia) important processes such as evapotranspiration, runoff, erosion, mineralization, nitrification, and respiration (Williams 1995; Izaurralde 2006). Management data include – inter alia – empirically derived crop rotations with the CropRota model (Schönhart et al. 2011). 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), regional climate change data from a statistical climate change model (Strauss et al. 2012), 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

$$A = R \times K \times L \times S \times C \times P$$

calculates the mean soil loss (A) by multiplying the rainfall-runoff erosivity factor (R), the soil erodibility factor (K), the slope length factor (L) and the slope steepness factor (S), the cover management factor (C), and the supporting practices factor (P) (Renard et al. 1991; Renard et al. 1997).

The simulations have been performed for different scenarios incorporating five climate change (precipitation) scenarios for the period 2010-2040 and three crop management practices. The scenario-based approach aims at covering the range of uncertain future precipitation and understanding the robustness of the investigated adaptation measures. The applied climate change (precipitation) scenarios (sc) have been derived from a statistical climate change model for Austria (Strauss et al. 2012) including an estimated rising trend in temperature (~0.05 °C per year) over all scenarios but different assumed precipitation sums (see Fig. 2):

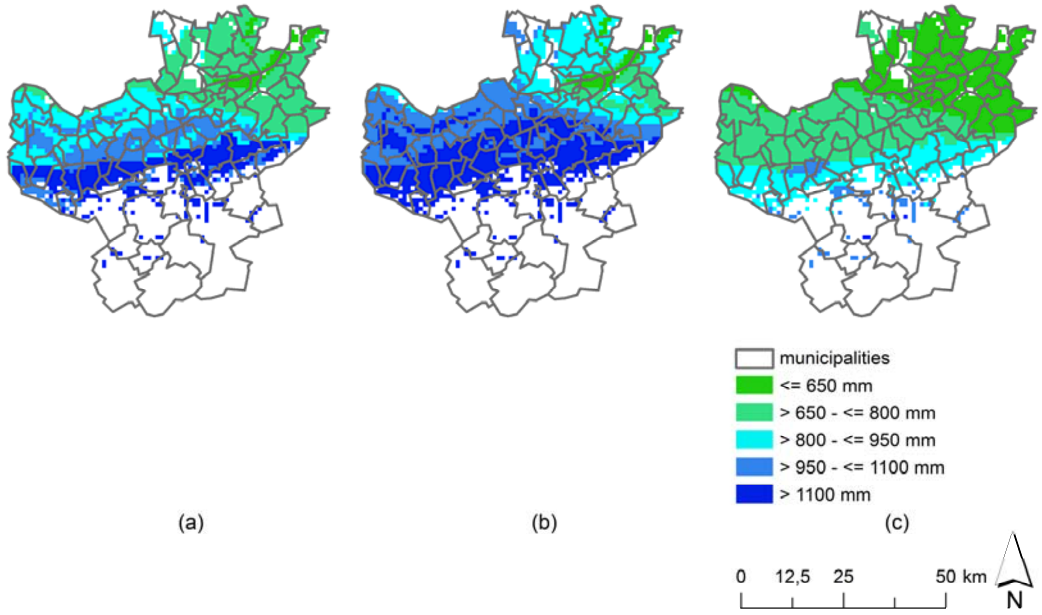


Fig. 2 Mean annual precipitation on cropland for scenarios sc01 (a), sc05 (b) and sc09 (c)

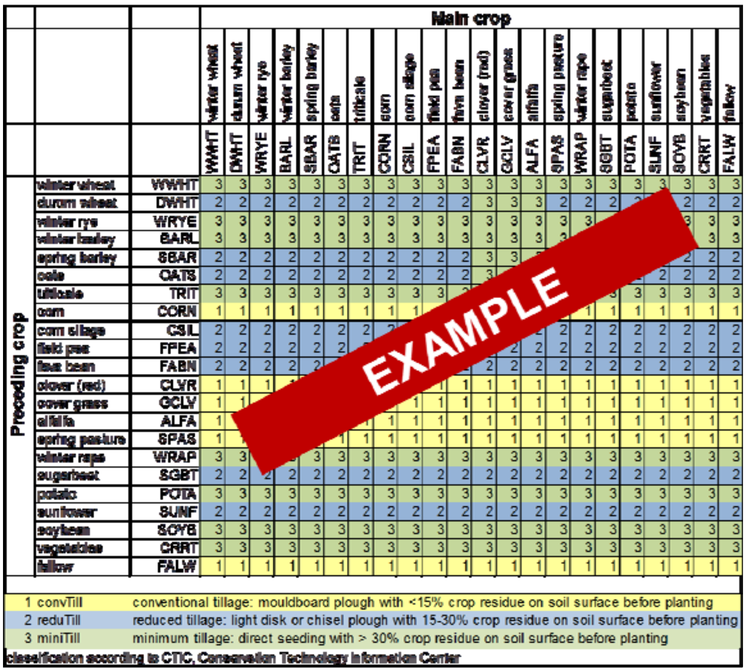
- sc01: unchanged precipitation, compared to the period 1975-2005 (past); reference scenario,
- sc05: daily precipitation is increased by 20% compared to sc01,
- sc09: daily precipitation is decreased by 20% compared to sc01,
- sc13: daily precipitation in the winter season (September to February) is increased by 20% compared to sc01, but the annual precipitation sum is kept constant,
- sc17: daily precipitation in the summer season (March to August) is increased by 20% compared to sc01, but the annual precipitation sum is kept constant.

The crop management practices comprise crop rotations with conventional and reduced tillage (classification according to CTIC, Conservation Technology Information Center 2003) as well as the cultivation of winter cover crops in crop rotation systems.

- conventional tillage: mouldboard plough with <15% crop residue on soil surface before planting.
- reduced tillage: conventional, reduced or minimum tillage is applied depending on 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: winter cover crops have been considered, if applicable in a crop rotation.

Soil water erosion vulnerability maps have been constructed with the simulated sediment yields by differentiating five vulnerability classes: (1) tolerable, (2) low, (3) moderate, (4) high, and (5) severe soil water erosion according to OECD (2001). The extent of erosion-prone areas as well as its change have been analysed by means of descriptive statistics and visual aids in order to show the impact of climate change (precipitation) scenarios on soil water erosion and to assess the effectiveness of soil conservation measures. Furthermore, impacts on dry matter crop yields and gross margins of crop production have been analysed as well. Gross margin is defined as revenues minus variable costs. Different crop management practices (conventional tillage, reduced tillage, winter cover crops) result in different revenues (depending on crop yields and agri-environmental premiums) and variable costs, respectively. Revenues are calculated based on simulated mean annual crop yields (in t/ha/a) multiplied by the respective mean annual crop prices of the period 1998-2011 (Statistics Austria 2012b) 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 Austrian Rural Development Programme; BMLFUW 2009). Variable costs of production such as purchase of seeds, pesticides, fertilizers, maintenance and fuel costs, service and insurance costs as well as the costs for applying soil conservation measures are derived from the standard gross margin catalogue (BMLFUW 2008) and from own data sources. Labour costs of crop production are taken into account with 10 €/h. Changes in fixed costs are not accounted for as stakeholders confirmed well-performing mechanization services and farm machinery co-operations in the region.

Practitioners and agronomic experts on crop farming provided information on crop management. They were named by the peer group and included farmers, extension service experts and a farming school teacher. The scientists provided a matrix (see Fig. 3) and a short guideline for its completion to identify regionally practicable soil conservation measures in various crop rotation systems. The various opinions contributed to a first validation of the model input data. After modelling, peer group members were consulted again to validate preliminary model results. According to Voinov and Bousquet (2010), stakeholders involved in the modelling and validation process build trust in the model. Therefore, this step has increased the credibility of model results to the regional stakeholders and is considered as a first step towards the third phase "bringing results to fruition".



			Main crop																					
			winter wheat	durum wheat	winter rye	winter barley	spring barley	oats	triticale	corn	corn silage	field pea	fava bean	clover (red)	cover grass	alfalfa	spring pasture	winter rape	sugarbeet	potato	sunflower	soybean	vegetables	fallow
			WWHT	DWHT	WRYE	BARL	SBAR	OATS	TRIT	CORN	CSIL	FPEA	FABN	CLVR	GCLV	ALFA	SPAS	WRAP	SGBT	POTA	SUNF	SOYB	CRRT	FALW
Preceding crop	winter wheat	WWHT	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	durum wheat	DWHT	2	2	2	2	2	2	2	2	2	2	2	3	3	3	2	2	2	2	[illegible]	2	2	2
	winter rye	WRYE	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	[illegible]	[illegible]	[illegible]	3	3	3
	winter barley	BARL	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3	3
	spring barley	SBAR	2	2	2	2	2	2	2	2	2	2	2	3	3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	2	2
	oats	OATS	2	2	2	2	2	2	2	2	2	2	2	3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	2	2	2
	triticale	TRIT	3	3	3	3	3	3	3	3	3	3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3	3	3	3	3	3
	corn	CORN	1	1	1	1	1	1	1	1	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	1	1	1	1	1	1
	corn silage	CSIL	2	2	2	2	2	2	2	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	2	2	2	2	2	2	2	2
	field pea	FPEA	2	2	2	2	2	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	2	2	2	2	2	2	2	2	2
	fava bean	FABN	2	2	2	2	2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	2	2	2	2	2	2	2	2	2	2	2
	clover (red)	CLVR	1	1	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	1	1	1	1	1	1	1	1	1	1	1	1
	cover grass	GCLV	1	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	alfalfa	ALFA	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	spring pasture	SPAS	1	1	[illegible]	[illegible]	[illegible]	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	winter rape	WRAP	3	3	[illegible]	[illegible]	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	sugarbeet	SGBT	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	potato	POTA	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	sunflower	SUNF	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
	soybean	SOYB	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	vegetables	CRRT	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
	fallow	FALW	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

1	convTill	conventional tillage: mouldboard plough with <15% crop residue on soil surface before planting
2	reduTill	reduced tillage: light disk or chisel plough with 15-30% crop residue on soil surface before planting
3	miniTill	minimum tillage: direct seeding with > 30% crop residue on soil surface before planting

classification according to CTIC, Conservation Technology Information Center

EXAMPLE

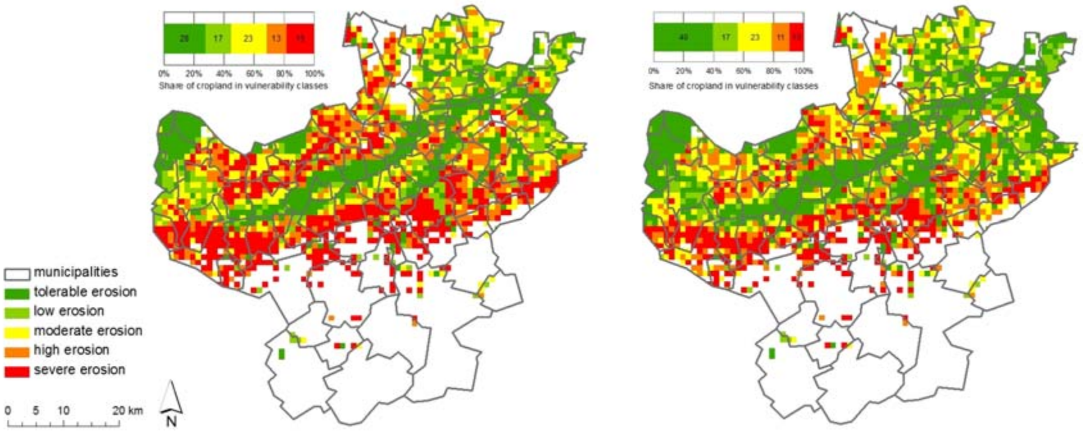
Fig. 3 Matrix for identifying the feasibility of soil conservation tillage within crop sequences

Results

The stakeholders were asked to comment on the preliminary results at the third workshop in the study area in order to validate model results. Due to their specific regional knowledge, stakeholders are able to identify erosion-prone areas based on simple indicators (e.g. if land-owners have to remove mud regularly after heavy rainfalls, their land is regarded as highly vulnerable to soil erosion).

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

Regional characteristics of vulnerability of cropland to soil water erosion with conventional tillage and the cultivation of winter cover crops are illustrated for the reference scenario (sc01, unchanged precipitation) (see Fig. 4). Particularly the steep and wet areas in the south are deemed to be most severely affected whereas the valley floor of the Danube River is not regarded as erosion-prone. Our model results show that conservation tillage is effective for reducing areas vulnerable to soil water erosion. However, the effectiveness varies spatially due to topographical and agronomic heterogeneities.



(a) (b)

Fig. 4 Vulnerability of cropland to soil water erosion in the Austrian Mostviertel region for the reference scenario (sc01) with conventional tillage (a) and winter cover crops (b)

The layer principle has been applied in order to visualise the procedure of erosion modelling schematically. It illustrates the interdependencies between regional characteristics such as precipitation sums or slope steepness and the vulnerability of cropland to soil water erosion and thus facilitates a stakeholder dialogue (see Fig. 5). This principle is characterized by presenting thematic content (regional characteristics) in individual GIS layers. The model results can be read as a combination of the thematic contents according to the applied RUSLE methodology.

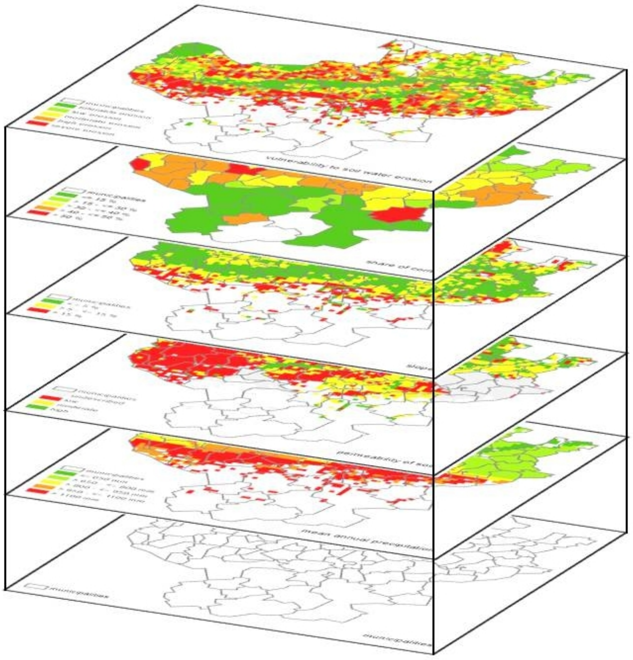


Fig. 5 The layer principle – a combination of GIS layers of various thematic contents

Impacts of climate change (precipitation) scenarios on vulnerability of cropland to soil water erosion are presented in Table 2. Regardless of the crop management practice, vulnerability of cropland rises with higher precipitation sums (sc05, +20% precipitation). Areas severely vulnerable to soil water erosion increase by ~76% (conventional tillage) to ~135% (winter cover crops) compared to the reference scenario (sc01, unchanged precipitation). Correspondingly, areas with tolerable soil water erosion are reduced by ~33% (winter cover crops) to ~53% (conventional tillage). Changes in areas severely vulnerable to soil water erosion (tolerable soil erosion) are higher (lower) with conservation measures than with conventional tillage due to smaller (higher) absolute baseline values in the respective reference scenario sc01 (i.e. areas in ha severely vulnerable to soil water erosion). Decreasing precipitation (sc09, -20% precipitation) leads to a

~76% (conventional tillage) and ~80% (winter cover crops) reduction of areas with severe vulnerability to soil water erosion, whereas areas with tolerable soil water erosion rise by ~42% (winter cover crops) and ~56% (conventional tillage), respectively. Model results for scenario sc13 with higher precipitation sums in winter (+20% from September to February) are similar to scenario sc01 (changes of areas with severe soil water erosion amount to a maximum of 10%) whereas higher precipitation sums in summer (sc17, +20% from March to August) result in higher vulnerability to soil water erosion.

Table 2 Vulnerability of cropland to soil water erosion and changes in vulnerability by climate change (precipitation) scenarios; (changes are relative to sc01)

climate change (precipitation) scenario	**sc01**	**sc05**	**sc09**	**sc13**	**sc17**
change in precipitation compared to sc01	**0%**	**+20%**	**-20%**	**+20% winter**	**+20% summer**
conventional tillage			**area in ha**		
tolerable erosion	21,047	9,961	32,907	20,841	17,244
low erosion	13,114	14,970	14,913	13,375	12,724
moderate erosion	17,870	14,527	16,868	16,906	17,945
high erosion	10,044	11,790	8,169	9,570	11,363
severe erosion	14,218	25,045	3,438	15,601	17,018
reduced tillage			**area in ha**		
tolerable erosion	23,701	12,106	35,096	24,095	18,637
low erosion	12,503	15,461	16,215	12,901	12,825
moderate erosion	18,644	14,534	16,722	17,747	18,744
high erosion	9,869	12,042	5,932	9,533	11,018
severe erosion	11,576	22,151	2,328	12,018	15,069
including winter cover crops			**area in ha**		
tolerable erosion	30,148	20,127	42,861	31,025	25,596
low erosion	12,829	12,360	14,574	12,792	11,949
moderate erosion	17,292	16,056	14,564	16,568	18,311
high erosion	8,670	10,489	2,806	8,093	10,016
severe erosion	7,354	17,262	1,488	7,816	10,422
ø changes in areas with conventional tillage			**changes in % from sc01**		
tolerable erosion	reference	-53%	56%	-1%	-18%
low erosion	reference	14%	14%	2%	-3%
moderate erosion	reference	-19%	-6%	-5%	0%
high erosion	reference	17%	-19%	-5%	13%
severe erosion	reference	76%	-76%	10%	20%
ø changes in areas with reduced tillage			**changes in % from sc01**		
tolerable erosion	reference	-49%	48%	2%	-21%
low erosion	reference	24%	30%	3%	3%
moderate erosion	reference	-22%	-10%	-5%	1%
high erosion	reference	22%	-40%	-3%	12%
severe erosion	reference	91%	-80%	4%	30%
ø changes in areas with winter cover crops			**changes in % from sc01**		
tolerable erosion	reference	-33%	42%	3%	-15%
low erosion	reference	-4%	14%	0%	-7%
moderate erosion	reference	-7%	-16%	-4%	6%
high erosion	reference	21%	-68%	-7%	16%
severe erosion	reference	135%	-80%	6%	42%

Several empirical studies (e.g. Reganold et al. 1987; Klik 2003; Liu et al. 2012; Prasuhn 2012) prove the positive effect of soil conservation measures on soil erosion. The model results show that such practices, i.e. reduced tillage and the cultivation of winter cover crops, are also effective under changing climatic conditions and precipitation patterns (see Fig. 6). Compared to conventional tillage, the median reduction of sediment losses are between ~7% (sc17, +20% summer precipitation) and ~13% (sc13, +20% winter precipitation) for reduced tillage practices and between ~24% (sc17, +20% summer precipitation) and ~31% (sc13, +20% winter precipitation) for additionally cultivating winter cover crops. The model results also indicate that the investigated soil conservation practices are not sufficient to prevent severe soil water erosion on some cropland especially with increasing precipitation sums. To further decrease vulnerability to soil water erosion, additional adaptation options (e.g. reducing root and/or row crops in the crop rotation, land use change to permanent grassland) may be required.

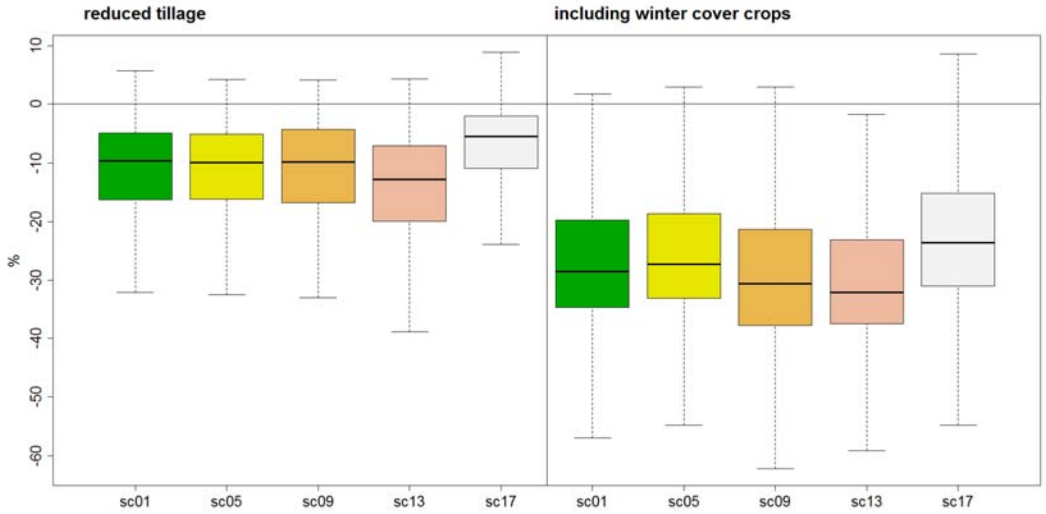


Fig. 6 Changes in sediment yield by conservation measures and climate change scenario in %; (changes are relative to conventional tillage)

Impacts on crop yields and gross margins by precipitation scenarios and crop management practices

Absolute and relative impacts of climate change and crop management practices on mean annual (dry matter) crop yields and gross margins are presented in Table 3. In general, near future climate change seems to have a moderate effect on gross margins, mainly due to the relatively little impact on crop yields. Regardless of the crop management practice, losses in mean annual crop yields and gross margins are simulated for scenarios sc09 (assuming lower precipitation sums) and sc13 (assuming a shift from summer to winter precipitation). Increases in mean annual crop yields and gross margins are simulated for scenario sc17 (assuming a shift from winter to summer precipitation).

Compared to conventional tillage, soil conservation measures often result in lower mean annual crop yields and gross margins in all climate change (precipitation) scenarios. On some pixels, crop yields are higher with soil conservation measures, especially when cultivating winter cover crops. This is mainly due to reduced soil losses over the 30 year simulation period.

According to the model results, the additional direct costs of cultivating winter cover crops are more than offset by current agri-environmental premiums though the overcompensation does not exceed the legal limit of 20%. With respect to economic results, average annual gross margins are higher for conventional tillage between ~27% and ~31% compared to reduced tillage and between ~40% and ~55% compared to winter cover cropping reflecting the magnitude of opportunity costs of conservation measures.

Table 3 Average annual gross margins, simulated crop yields, and relative changes in average annual gross margins and simulated crop yields for the Mostviertel region; (changes are relative to sc01)

climate change (precipitation) scenario	**sc01**	**sc05**	**sc09**	**sc13**	**sc17**
change in precipitation compared to sc01	**0%**	**+20%**	**-20%**	**+20% winter**	**+20% summer**
ø gross margin, WITH premiums			**in €/ha/a**		
conventional tillage	481	481	451	468	497
reduced tillage	465	464	438	454	478
including winter cover crops	557	561	517	544	569
ø gross margin, WITHOUT premiums			**in €/ha/a**		
conventional tillage	201	201	171	188	217
reduced tillage	145	144	118	134	158
including winter cover crops	117	121	77	104	129
ø dry matter crop yield			**in t/ha/a**		
conventional tillage	8.7	8.7	8.4	8.5	8.8
reduced tillage	8.3	8.3	8.0	8.2	8.4
including winter cover crops	8.4	8.4	8.0	8.2	8.5
ø changes in gross margin, WITH premiums			**changes in % from sc01**		
conventional tillage	reference	0.0%	-6.4%	-2.8%	3.2%
reduced tillage	reference	-0.3%	-5.9%	-2.5%	2.7%
including winter cover crops	reference	0.8%	-7.2%	-2.3%	2.2%
ø changes in gross margin, WITHOUT premiums			**changes in % from sc01**		
conventional tillage	reference	0.0%	-15.3%	-6.7%	7.7%
reduced tillage	reference	-0.9%	-18.9%	-7.9%	8.7%
including winter cover crops	reference	4.0%	-34.1%	-10.9%	10.5%
ø changes in crop yield			**changes in % from sc01**		
conventional tillage	reference	0.0%	-3.0%	-1.4%	1.6%
reduced tillage	reference	-0.2%	-2.8%	-1.3%	1.4%
including winter cover crops	reference	0.6%	-4.3%	-1.4%	1.4%

Bringing results to fruition

The third phase – bringing results to fruition – builds on the recursive synthesis of knowledge and enables adaptive learning. It aims at implementing the achieved results and evaluating their relevance for and impact on the region. One important element in this phase is to communicate comprehensible and useful research results. Stephens et al. (2012) claim that scientists in the field of climate change research should expend efforts on balancing richness (quantity of information communicated), robustness (accuracy of data and models and margin of uncertainty), and saliency (relevance and usefulness of the visualisation). In order to take this into account, knowledge on stakeholders' needs and preferences is required (de la Vega-Leinert et al. 2008). The question of adequately communicating results was already raised at the stage of problem identification and structuring. The involved stakeholders expected results to meet the following requirements:

- provide extreme examples of "best practice" and "poor practice" in order to show the large variety of management options and outcomes in the region,
- simplify correlations and interdependencies (e.g. by using convincing pictures),
- summarize the interactions between climate change as well as crop management and vulnerability to soil water erosion.

Transdisciplinary research process was officially finished with the third peer group workshop. Stakeholders were asked to validate the model results and reflect on their societal relevance and usability. They confirmed the spatial distribution of erosion-prone areas but stressed once again the importance of "unique extreme examples at farm or field level". The presentation of average gross margins for the whole study area was not considered useful for extension services. However, the scientists were not able to provide the requested "extreme examples" because of insufficient spatial resolution of data and models. Therefore, the stakeholders suggested using single pixels that show high changes in sediment yield and gross margins for further discussions despite the risk that emphasizing potential 'outliers' might lead to misinterpretations.

Discussion

Erosion modelling

Soil erosion models are considered as purposeful tools for assessing the impact of climate change on sediment yield (Toy et al. 2002). Despite their wide acceptance and application, Mullan et al. (2012) point out three fundamental limitations of modelling soil erosion under changing climatic conditions. The limitations comprise (1) the spatial scales at which climatic changes are represented, (2) the temporal scale at which climatic changes are represented, and (3) the representation of changes in land use and management. Limitations in spatial and temporal scale of climate data mainly result from inadequate downscaling techniques which are applied to bridge the mismatch of spatial and temporal scale between the coarse resolution of General Circulation Models (GCM) and the resolution required for erosion modelling (Mullan et al. 2012). We approach these limitations by using climate change data developed with a statistical climate change model for Austria (Strauss et al. 2012). Strauss et al. (2012) argue that near future regional climate changes could be better addressed by a statistical climate change model using historical meteorological data instead of statistically or dynamically downscaled outputs of GCMs. Climate data were available with a spatial/temporal resolution of 1 km² and 1 day. However, the development of sub-daily future climate information and intensity of heavy rainfalls could not be considered in the present work. Changes in land use and management are another driving force for soil erosion, but the need for incorporating these changes in erosion modelling is often ignored or neglected (Mullan et al. 2012). Only few recent contributions explicitly address the relations between soil erosion and changes in land use and management (e.g. Fu et al. 2006; Klik and Eitzinger 2010; Zhao et al. 2012). We consider regional crop rotations systems and crop management practices, i.e. reduced tillage and cultivating winter cover crops as adaptation options to climate change.

Soil erosion models can be classified into empirical and process-based models. Empirical models are subject to certain constraints of applicability (e.g. landslides and mudflows cannot be considered). In order to address these constraints, process-based models have been developed and used for predicting future erosion rates (Lal 2001). Though being aware of its constraints, we applied the empirically based RUSLE methodology for two reasons. First, the RUSLE is deemed powerful in relation to its simplicity (Toy et al. 2002). It incorporates several concepts from process-based erosion models and is thus considered as refinement of the widely used empirical erosion model USLE (Universal Soil Loss Equation) (Lal 2001). Various recent studies prove the usefulness of the RUSLE for regional scale investigations (e.g. Prasannakumar et al. 2012; Trabucchi et al. 2012). Secondly, the regional stakeholders are acquainted with the USLE as the agricultural land currently prone to soil water erosion has been determined with this method for a small river basin within the case study area (Strauss 2006). Therefore, we assume that both the methodology and the achieved results are easy to understand and reasonable for the stakeholders involved in the research process. We consider this useful in order to find common assent to the applied method in stakeholder meetings and decision-making processes.

Stakeholder knowledge integration

Though many impact and adaptation studies do not include stakeholders' knowledge (Reidsma 2010), engaging with agricultural land users and policy makers is deemed crucial in developing realizable concepts and determining potential adaptation measures (Webb and Stokes 2012). In order to (i) focus research on the needs of the society, (ii) address relevant challenges and reasonable adaptation options, (iii) foster the acceptance of the research results, and (iv) facilitate the implementation of the results, we have identified the relevant stakeholders in the study region and involved them in every important research step (see Table 1). A voluntary peer group of stakeholders and scientists was established to regularly analyse and reflect the on-going research. Voluntary engagement was considered important as volunteers may be inclined to spend an appropriate amount of time on the project, especially if they are engaged in all relevant phases as early as possible (Voinov and Bousquet 2010).The inclusion/exclusion of certain stakeholders and scientific disciplines co-determines the further research process especially for the purpose of defining key and side issues (Midgely 2000) and thus achieving public acceptance (Voinov and Bousquet 2010). Furthermore, mutual learning might be more dynamic within a group of heterogeneous stakeholders than within a homogenous group (Beers et al. 2006). In the project, the involved stakeholders covered a wide range of knowledge and experience, which ensured substantial knowledge inputs and discussions. Bergez et al. (2011) propose a two-level organisation for exchanging concepts and analyse results between stakeholders and scientists. At the first level in the project, the "restricted group" was responsible for analysing the problem. At the second level, the "expanded group" reviewed the work of the restricted group and came up with suggestions for improvement. This two-level organisation was proposed by the regional stakeholders and thus considered useful. Furthermore it stresses the relevance of project-specific approaches to stakeholder integration.

A continuous process of stakeholder integration, mutual learning, and knowledge exchange requires special care and scientists should provide feedback about the stakeholders' impact at each step (Korfmacher 2001; Voinov and Bousquet 2010). To achieve this target, we organised three workshops in the study area and communicated regularly with the peer group members. Organising a workshop at the beginning of the research process was an adequate setting for starting the science-stakeholder interaction and building trust. The workshops were also effective for an informal information exchange, open discussions allowing mutual learning, and the joint design of further research.

Integrating knowledge of regional stakeholders was relevant for (i) defining the research question, the conceptual framework and the climate change (precipitation) scenarios, (ii) providing information on crop management measures and thus validating some input data, and (iii) providing a reality and usability check of the preliminary results. Most effort was put on the joint generation of research questions. Based on the interview results and the ad-hoc evaluation during the first workshop, the scientists pre-selected two thematic priorities. Although this approach reduced the stakeholders' power in defining the research question, it proved to be effective, as it allowed coordinating regional concerns and scientific problems within an appropriate expenditure of time and resources. Contrary to the scientists' expectations, the regional stakeholders regarded the impacts of droughts and potential adaptation strategies as less urgent than the impacts of increasing precipitation sums on soil water erosion. For the study region, large-scale irrigation systems were not considered as relevant due to the following reasons: high investment costs, insufficient supply of groundwater, and small-scale agriculture. It might be that individual viewpoints, personal experience, mental models and value systems have influenced this decision (see Ludwig Fleck's concept of 'thought collectives' that share a particular 'thought style'; Fleck 1979). Due to the perceived increases in soil water erosion during recent years, the stakeholders might have overestimated the importance and urgency of this topic while underestimating others. Eliciting mental models in advance may be an option to eliminate this uncertainty (Pahl-Wostl 2002).

Integrating stakeholder knowledge on crop management in bio-physical modelling was challenging due to diverse expert perspectives, which had to be merged into one quantitative data set. Discussing the issue in a workshop instead of email and telephone conversations and a face-to-face meetings may be an alternative to achieve mutual learning and consolidated opinions.

Finally, the stakeholders provided a reality and usability check of the preliminary results. Maps turned out to be adequate tools for communicating erosion-prone areas. As the stakeholders are aware of the critical areas within their region, they could easily confirm and thus validate our model results. This validation test has been identified useful for widely applied models, such as the RUSLE, and is referred to as "face validation" (Rykiel 1996). Maps and graphs were also judged usable for extension activities whereas aggregated economic results were not considered usable. These conflicts of interests, approaches, and expectations of stakeholders and scientists are known from the literature (e.g. Gregrich 2003) and often result from the application of different criteria of relevance, effectiveness (Hollaender et al. 2008), and reliability of results. While researchers tend to fade out 'outliers', they emotionalize political and societal debates. Addressing, understanding, and negotiating such mismatches are deemed critical in transdisciplinary research processes (Bammer 2012). Indeed, stakeholders and scientists agreed that clear messages are indispensable for further activities. Nevertheless, model output uncertainties caused by imperfect process knowledge, gaps on local and regional data, and inherent limits to the predictability of climate change impacts have to be addressed and communicated. It is essential that stakeholders are aware of the underlying assumptions and caveats in order to develop and/or adopt detailed implementation and monitoring strategies. The main challenge is to balance clarity of the message and sincerity about the uncertainties (de la Vega-Leinert et al. 2008).

The appropriate degree of stakeholder integration depends on its aim and purpose. Based on Arnstein’s ladder of citizen participation (Arnstein 1969) and its adaptation to decision-making processes by Krütli et al. (2006), Wiek (2007) distinguishes four levels of interactive knowledge generation in transdisciplinary research, namely (level 1) one-way information (information goes either from scientists to stakeholders or vice versa), (level 2) mutual one-way information (information exchange), (level 3) collaborative research (joint generation of knowledge), and (level 4) joint decision making (see Table 1). Level 4 requires that strategic actors are involved in the research process. In our case study, stakeholders may decide on next steps towards convincing farmers of the effectiveness of soil conservation measures under changing climatic conditions (e.g. by designing an information campaign). As this step is not part of a regional vulnerability assessment, ‘joint decision making’ has not been achieved in this project. However, the case study explicitly aimed at ‘coproducing’ knowledge according to the three forms of public involvement by Callon (1999): public education (informing the public about scientific knowledge), public debate (discussions allow the public to advance scientific knowledge), and coproduction of knowledge by actively integrating the public into the process of knowledge generation.

Some authors claim that transparent, “bespoke” models should be developed from scratch for the study area and knowledge of stakeholders should be integrated in as many steps of modelling as possible (e.g. Gaube et al. 2009; Whatmore and Landström 2011). This approach is mainly based on two assumptions. First, models that are developed interactively by stakeholders and scientists within a research project are easy to communicate because stakeholders are aware of the model assumptions and the extent of the model reliability. Secondly, stakeholders may have observed regional characteristic phenomena and may possess precious knowledge for model building that would not be available for the scientists otherwise (Voinov and Brown Gaddis 2008). Though we agree on the advantages of this approach especially for local case studies, we have applied an existing, commonly accepted and widely used bio-physical process model and integrated stakeholders’ knowledge in some crucial research steps (see Table 1). This approach is probably less resource intensive for both stakeholders and scientists and represents the trade-off between the quality of knowledge integration and the costs of involvement (cf. Korfmacher 2001).

Conclusions and outlook

Integrating regional stakeholders in knowledge generation for a regional vulnerability assessment appears expedient to provide meaningful results. The idealised phases of transdisciplinary research projects have proved to be a helpful guiding principle for structuring the research process in regional vulnerability assessment. Minor adaptations have resulted from thematic, individual and regional characteristics.

Considerable effort should be spent on stakeholder identification and analysis as stakeholders are encouraged to co-determine on-going research and final results. First, scientists are challenged to make their interests, objectives and expectations explicit. Secondly, adequate stakeholder identification and analysis tools should be applied in order to reveal potential stakeholders, their implicit knowledge, institutional constraints and relationships.

At the core of the transdisciplinary research is the recursive problem framing, including the mutual learning process between stakeholders and scientists. Collaboration with the stakeholders was organised by means of workshops and guided interviews and resulted in a mutually defined research question: “In what extent do precipitation scenarios until 2040 affect soil water erosion on cropland and how effective are particular soil conservation practices?”

The impact of climate change (precipitation) scenarios on sediment yield as well as the effectiveness of soil conservation measures has been assessed by an interdisciplinary team of scientists. Regional stakeholders provided practical knowledge on soil conservation measures suitable for different crop rotations as well as validated input data for bio-physical process modelling. As expected, climate change – namely varying precipitation sums – affects the vulnerability of cropland to soil water erosion. Conservation measures are an effective adaptation option according to the model results. In addition, stakeholders provided a valuable reality check and feedback on model results with respect to meaningfulness and clarity. Scientists aimed at presenting the research results in target-group oriented manner. In particular, using maps for presenting outcomes of complex interdependencies has facilitated the communication. However, illustrations with 1km² spatial resolution encourage stakeholders to concentrate on single pixels and misinterpret extreme values, which should be avoided.

Stakeholders have approved the usefulness of the model results. Model outputs add to empirically observed data on soil water erosion and shall be used for further advisory and persuasion activities. Such activities aim at strengthening soil conservation, consolidating good farming practices, reducing adverse off-site effects of soil water erosion (e.g. nutrient losses and water impairments) and hence producing societal added value. The commitment of the peer group gives reason to expect that the project outcome informs the discussion on climate change adaptation requirements in agriculture in the Mostviertel region. It may therefore support the design of targeted policies as well as implementation of particular management measures. This is of particular importance as local initiatives and regional vulnerabilities are likely to be formed by broader social, economic and political arrangements (Smit and Wandel 2006).

The scientists plan to continue to work on the investigated subject. They want to integrate the obtained data into integrative land use models, to consider grassland farming and livestock production, to reveal further agro-environmental indicators, and to describe synergies and trade-offs between different land use systems. The project results are useful for both, stakeholders and scientists and might be a stimulus for public dialogue and scientific discourse.

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Bestelladresse:
Universität für Bodenkultur Wien
Department für Wirtschafts- und Sozialwissenschaften
Institut für nachhaltige Wirtschaftsentwicklung
Feistmantelstrasse 4, 1180 Wien
Tel: +43/1/47 654 – 3660
Fax: +43/1/47 654 – 3692
e-mail: Iris.Richter@boku.ac.at