Knowledge integration of local stakeholders, experts and scientists into bio-physical modelling for regional vulnerability assessment

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Abstract

Climate change is likely to differently affect agricultural production across Austria. In order to address relevant corresponding challenges and potential adaptation strategies, knowledge of stakeholders and experts should be integrated into the research process of regional vulnerability assessments. Therefore a case study analysis has been initiated in the transdisciplinary research project "RIVAS – Regional Vulnerability Assessment for Austria". A working group consisting of local stakeholders and scientists identified the effects of uncertain future precipitation on soil erosion as well as the effectiveness of selected soil conservation measures as the most crucial knowledge gap. Potentials for soil sediment losses have been simulated with the widely accepted RUSLE (Revised Universal Soil Loss Equation) methodology using the bio-physical process model EPIC (Environmental Policy Integrated Climate). Practitioners and regional experts provided input with respect to soil conservation measures. The model predicts an increase in soil sediment loss with higher precipitation sums. Reduced tillage and cultivating winter cover crops have been identified as effective adaptation strategies. The stakeholders have assessed the results according to their clarity, comprehensiveness, and meaningfulness. The usability of the results has been confirmed and might facilitate farmers' perceptions and decisions as well as the public debate on climate change adaptation in agriculture.

Keywords

transdisciplinary, case study, vulnerability, soil erosion, conventional tillage, conservation tillage, Austria

1 Introduction

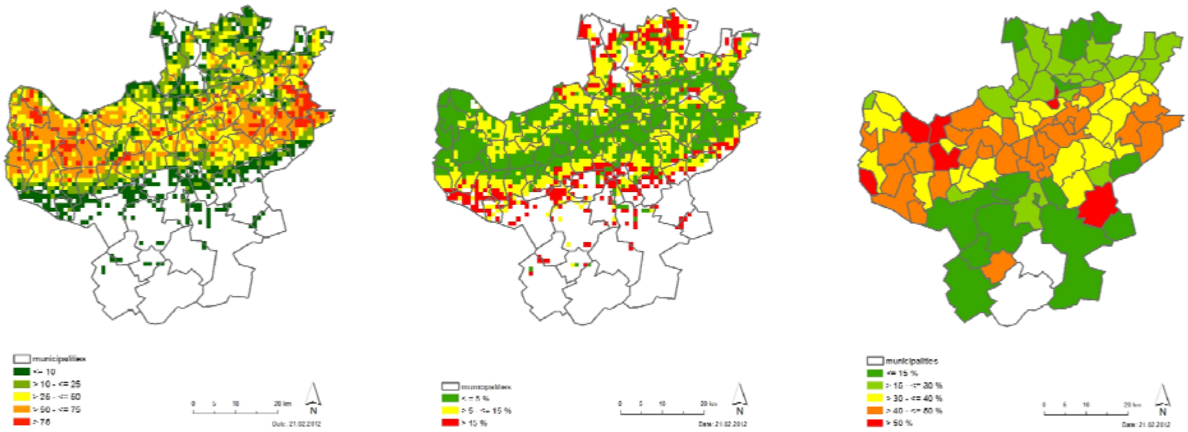
Agriculture is highly interrelated with weather and climate and is thus considered as one of the most climate sensitive sectors (Parry, 2000). Although agricultural land users, policy makers, and consultants are conscious that agrarian production depends on changes in climatic conditions, they are frequently unaware of the systems' complexity, the inherent uncertainties and potential adaptation strategies (Eitzinger et al., 2009; Olesen et al., 2011). This type of 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 local stakeholders, experts and scientists in impact analyses. In order to (i) address the imperfect understanding of the complex systems, (ii) provide sustainable mitigation and adaptation strategies, (iii) strengthen the interface between sciences and policy, and (iv) facilitate well-informed decision and policy making, scientists have to integrate their disciplinary research frontiers (i.e. state of the art) into a transdisciplinary research processes. Though many authors claim the adequacy of tackling complex social and environmental challenges by a transdisciplinary approach (e.g. Jahn, 2008, Bammer, 2012), climate research is still dominated by the academic sector's power and interest (Wuelser et al., 2012). In this article, we provide vulnerability analysis for the agricultural sector of the Mostviertel region developed in a transdisciplinary research process.

In the agriculturally important Mostviertel region in Austria, the transdisciplinary research project "RIVAS – Regional Vulnerability Assessment for Austria" has been carried out by a multi-disciplinary team of natural and social scientists. RIVAS aims at preparing a transferable conceptual, methodological and procedural framework for regional vulnerability assessments, including the design of a science-based stakeholder process. This article focuses on one aspect of the project – at analysing the vulnerability of the agricultural sector in the case study area. The research process is guided by the three phases of an idealised transdisciplinary research processes 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 clearly in the research process, these phases are helpful to structure the research work. Consequently, the aims and tasks, the methodological challenges, and the experiences gained are outlined for each phase.

The article is structured as follows: section 2 provides an overview on the case study area. In sections 3, 4, and 5, the case study is analysed and discussed by the three phases of an idealised transdisciplinary research process, followed by conclusions and outlook.

2 Case study area

The Mostviertel region (NUTS 3 region AT121) is located in the Lower Austrian Alpine foreland and comprises of four administrative districts: Amstetten, Melk, Scheibbs, and Waidhofen an der Ybbs. Roughly half of the total agricultural area is used as cropland (~75.000 ha) and grassland (~81.000 ha), respectively (see 1a). The southern part of the Mostviertel region is dominated by grassland and forests. Mainly corn (see 1c), barley and winter wheat are grown on approximately 10,000 farms in the region (Statistik Austria, 2011). Crops are also cultivated on steeply sloped farmland (slopes >15%; see 1b), located north and south to the fertile valley floor of the Danube River.



(a) (b) (c)

Figure 1: Shares of cropland (a), slopes (b) and corn (c) in the Mostviertel region

The regional climate is heterogeneous with increasing mean annual precipitation sums from north to south and decreasing mean annual temperatures with rising altitudes. 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.

3 Problem identification and structuring

The "problem identification and structuring"-phase is the key element of transdisciplinary research processes and includes (i) the identification of relevant actors involved in the problem field, (ii) the specification of a peer group comprising of local and regional practitioners and scientists for a continuous science-stakeholder interaction in the duration of the research project (and even longer), (iii) the determination of the need for knowledge, and (iv) the translation of perceived societal problems into a scientific problem description by the peer group (Pohl and Hirsch Hadorn, 2007).

The relevant actors involved in the problem field were identified by a thorough screening and by applying the snowball approach, whereby local and regional experts are named as key individuals by previously identified stakeholders (see Biernacki and Waldorf, 1981). For an active cooperation and exchange between stakeholders and scientists, a peer group comprising of selected practitioners and scientists was established. Participation in the peer group was decided after mutual consultations between practitioners and scientists on a voluntary basis. Finally representatives of various farmers' advisory boards and the agricultural education sector interested in potential impacts of climate change on agriculture formed part of the peer group. The inclusion/exclusion of certain stakeholders and disciplines co-determines the further research process especially for the purpose of defining central and marginal issues (Midgley, 2000). Fortunately in our project involved stakeholders covered a wide range of knowledge and experience in agricultural topics and regional development. Members complemented each other; the composition of the group was well balanced and adequate for the subject being treated. Valuable knowledge inputs and vivid discussions were ensured.

In transdisciplinary research, the recursive process of problem framing and structuring in a team of stakeholders and scientists is deemed the key element (Pohl and Hirsch Hadorn, 2007). For analysing the vulnerability of crop production in the Mostviertel region, this process was managed in three steps.

(1) The first joint workshop in the study area aimed at informing the stakeholders about the scientific knowledge in climate research and the potential impacts on the agricultural sector, and raising their awareness for adaptation. In an informal 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). During the following discussion the stakeholders were encouraged to exchange experiences and provide ad-hoc evaluation of the regional vulnerability. A broad range of already existing and potential future problems have 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 regional experts was the localisation of thematic areas.

(2) After the first workshop, twelve guided interviews have been conducted with selected regional experts including farmers, extension service experts, policy advisers, policy makers and representatives of the agricultural education sector in order to acquire local knowledge and to learn about the locally perceived challenges of climate change in agricultural production. The interviewees considered the following topics as most important for the Mostviertel region:

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

(3) The second workshop aimed at specifying the 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 considering the state of the art in the relevant disciplines. During the workshop, the peer group discussed the interview results and reasons for contradictory statements. Some of the discrepancies could be cleared with the help of the stakeholders' knowledge about the region and its development in recent years and decades. Then stakeholders and scientists worked together on defining the research question. Based on the interview results, the discussion during the first workshop, a literature review, and the available resources (i.e. scientific knowledge, time), the scientists had identified two thematic priorities for the Mostviertel region, namely "heavy precipitation events and soil 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 erosion”. Finally the peer group identified the impact of uncertain future precipitation on soil 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: ***“How do precipitation scenarios until 2040 affect soil erosion on cropland and how effective are particular soil conservation practices?”***

Contrary to expectations, the stakeholders regarded the impacts of droughts and potential adaptation strategies as less urgent. For the study region, large-scale irrigation systems were not considered relevant for 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 the decision (see Ludwig Fleck’s concept of ‘thought collectives’ that share a particular ‘thought style’; Fleck, 1979). Due to the mainly subjectively perceived increases in soil erosion in recent years (also caused by increased corn cultivation), the stakeholders might have overestimated the importance and urgency of this topic. However, the potential consequences of other dangers or risks might have been underestimated.

Though the pre-selection of thematic priorities by the scientists reduced the stakeholders’ power in defining the research question, this approach proved to be effective, as it allows coordinating regional concerns and scientific problems in a satisfactory way and with an appropriate expenditure of time and resources. However, the pre-selection was based primarily on the statements of local and regional experts during the interviews and the first workshop in the study area.

4 Problem analysis

In the “problem analysis”-phase, the team of scientists worked on the development of new knowledge. They focused not only on the adjustment of agronomic simulation models to the framed research question and the region under study, but also on the integration of practical knowledge of peer group members and other regional experts. 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. In this context, problem analysis consists of (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 bringing together the sub-results to an integrative vulnerability assessment. The level of inter-individual interaction in knowledge integration, such as information, consultation, and collaboration (Wiek, 2007) is reflected for each step.

4.1 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 erosion under changing climatic conditions were addressed implicitly and finally defined by the scientists based on the selected sub-goals. The vulnerability analysis focused on:

- **soil erosion**
  - impact of potential changes in climatic conditions (in particular precipitation sums) on sediment loss in crop production
  - suitability of different crop management practices as potential adaptation strategy
- **crop yields**
  - impact of potential changes in climatic conditions on mean crop yields
  - impact of different crop management practices on mean crop yields
- **gross margins**
  - impact of potential changes in 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 in small-scale analysis (i.e. analysis for small areas or fields identified as particularly at risk), 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 analysis for the agricultural sector could not be provided because of the limited resources and the aim of multi-sector analysis in this research project. Therefore, grassland farming and livestock production have not been considered in the analysis.

4.2 Data and method

Scientists decided on data and methods and *informed the stakeholders* during the second workshop in the case study area and during further project steps. Practitioners and regional experts were asked to *provide information* on practical issues concerning soil conservation measures.

The bio-physical process model **EPIC** (Environmental Policy Integrated Climate) has been applied to simulate potential soil sediment losses on cropland in the Mostviertel region. In particular, the widely accepted **RUSLE** (Revised Universal Soil Loss Equation) methodology (Renard et al., 1997) has been selected in EPIC as driving 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). 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), 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

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

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., 1997).

The simulations have been performed for different scenarios incorporating three crop management practices and five climate change scenarios for the period 2010-2040. According to Scholz 2011, endogenous, action-based variables representing selected adaptation measures as well as exogenous variables representing changes in the environment have been included in an integrated model analysis.

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

The applied **climate change scenarios (sc)** have been derived from a statistical climate change model for Austria (Strauss et al., 2012) assuming an identical rising trend in temperature (~0.05 °C per year) but different precipitation sums:

- **sc01:** unchanged precipitation, compared to the period 1975 to 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,
- **sc17:** daily precipitation in the summer season (March to August) is increased by 20%, compared to sc01.

Soil erosion vulnerability maps have been constructed with the simulated sediment losses 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 scenarios on soil erosion and 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 total revenues (depending on crop yields and agri-environmental premiums) and variable costs, respectively. Changes in fixed costs are not accounted for. 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 (Statistik Austria, 2012) 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 as well as service and insurance costs 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.

Practitioners and regional experts have been *consulted* for practical issues such as placing soil conservation measures or winter cover crops in different crop rotation systems. Knowledge exchange has been organized informally using email and telephone. The most challenging task was to explain scientific knowledge gaps as well as to understand, mediate, and aggregate diverse expert perspectives into one quantitative data set for bio-physical process modelling. The various experts' opinions contributed to a first validation of the model input data. After modelling, experts have been consulted again to validate preliminary model results. This step has increased the credibility of model results to local experts and is considered as a first step towards the third phase "bringing results to fruition".

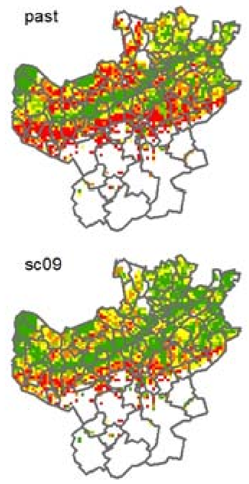
4.3 Results

At the third workshop, stakeholders were asked to *comment on* the preliminary results. Integrating stakeholders' regional knowledge and experience should act as a reality check for the vulnerability assessment to be produced.

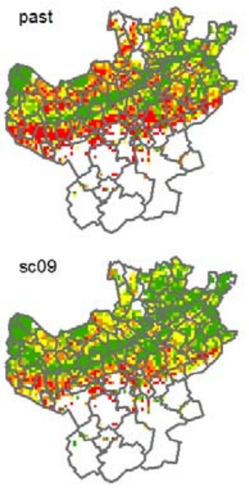
4.3.1 Vulnerability of cropland to soil erosion and the effectiveness of conservation measures

Figure 2 illustrates regional characteristics of vulnerability of cropland to soil erosion. In general, soil sediment loss is higher on steeper areas and under increasing precipitation sums. Both soil conservation measures, i.e. reduced tillage and the cultivation of winter cover crops are effective for reducing areas vulnerable to soil erosion under climate change, with the latter being even more effective. However, the effectiveness varies spatially due to physical and agronomic heterogeneities.

Model results show an increase in soil sediment loss for the scenario with higher precipitation sums (sc05, +20% precipitation) regardless of the crop management practice. Areas severely vulnerable to soil erosion increase by ~76% (conventional tillage) to ~135% (winter cover crops) compared to the reference scenario (sc01, unchanged precipitation). Correspondingly areas with tolerable soil loss are reduced by ~33% (winter cover crops) to ~53% (conventional tillage). Scenario sc09 (-20% precipitation) leads to a ~76% (conventional tillage) to ~80% (reduced tillage) reduction of areas with severe vulnerability to soil erosion, whereas areas with tolerable soil erosion rise by ~42% (winter cover crops) to ~56% (conventional tillage). Model results for the scenario sc13 with higher precipitation sums in winter (+20% from September to February) are similar to scenario sc01 (changes of areas with tolerable or severe soil erosion ±10%) whereas higher precipitation sums in summer (sc17, +20% from March to August) result in higher vulnerability to soil erosion (see Appendix 1 and 2).



(a)



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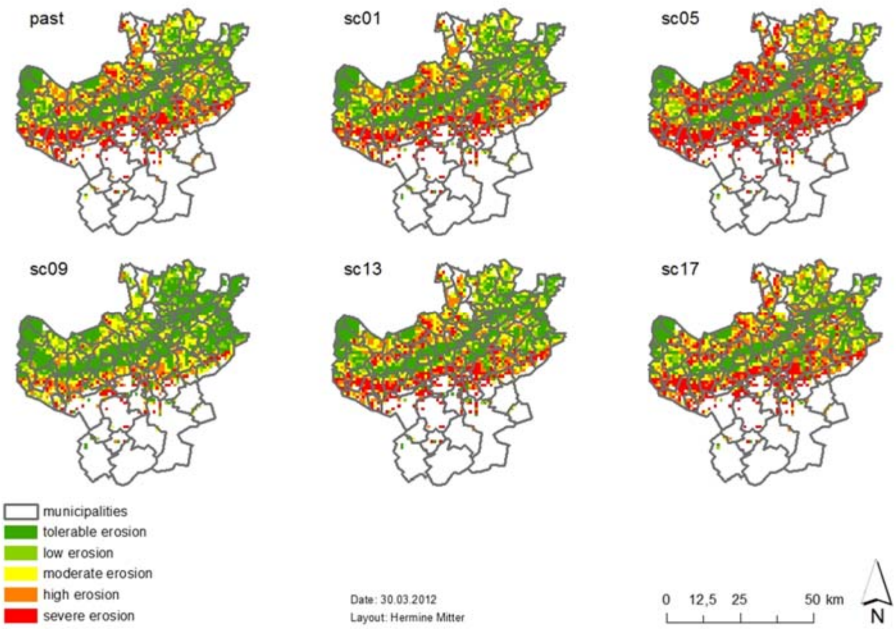

(c)

Figure 2: Vulnerability of cropland to soil erosion in the Austrian Mostviertel region with conventional tillage (a), reduced tillage (b), and winter cover crops (c)

Various empirical studies (e.g. Klik, 2003, Berner et al., 2008) proved the positive effect of soil conservation measures on soil erosion. Our model results indicate that these practices are also effective under changing climatic conditions and precipitation patterns (see Figure 3).

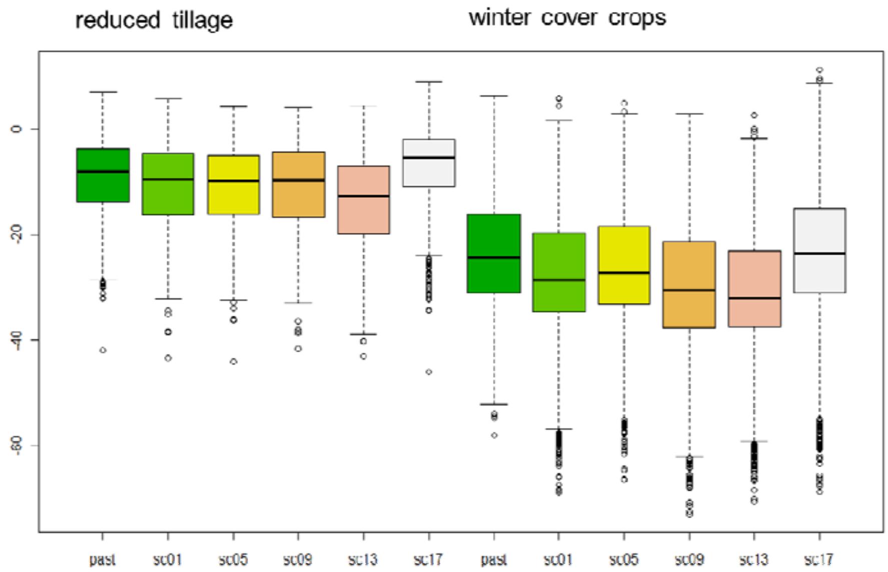

Figure 3: Changes in soil sediment loss by conservation measures and climate change scenario in %; (changes are relative to conventional tillage)

In all precipitation scenarios, areas vulnerable to moderate, high and severe soil erosion could be decreased when applying soil conservation measures. Compared to conventional tillage, soil sediment loss can be reduced by ~6% (sc17, +20% precipitation in summer) to ~13% (sc13, +20% precipitation in winter) with reduced tillage practices. Under climate change scenarios sc01 (reference), sc05 (+20% precipitation) and sc09 (-20% precipitation) reduced tillage practices could decrease soil sediment loss by ~10%. With winter cover crops soil sediment loss can be reduced by ~27% (sc17) to ~34% (sc09 and sc13) compared to conventional tillage. Under climate change scenarios sc01 and sc05 soil sediment loss could be decreased with winter cover crops by ~31% and ~29%, respectively.

4.3.2 Impacts of crop management practices on crop yields

Model results also include average annual crop yields per hectare (dry matter) under different climate change scenarios and crop management practices. Table 1 shows absolute numbers (in t/ha/a) and the changes (in %) compared to the reference scenario sc01.

In comparison to conventional tillage the use of soil conservation measures generally results in lower average crop yields in all precipitation scenarios. However, results reveal that in some pixels crop yields produced are higher with soil conservation measures, especially when cultivating winter cover crops (see Figure 4). This is mainly due to less soil losses over the simulation period resulting into less nutrient losses.

In the Mostviertel region changes in precipitation sums generally have little influence on average crop yields (see Table 1). With conventional tillage, higher precipitation sums in summer (sc17) raise crop yields by ~1.6% and lower precipitation sums (sc09) reduce them by ~3% on average. Reduced tillage only leads to an increase in average crop yields (~1.4%) with higher summer precipitation (sc17). In all other climate change scenarios simulated crop yields decline (between ~0.2% and ~2.8%) on average. Cultivating winter cover crops shows similar results i.e. higher precipitation sums in summer (sc17) raise (~1.4%) and lower precipitation sums (sc09) reduce (~4.3%) crop yields on average.

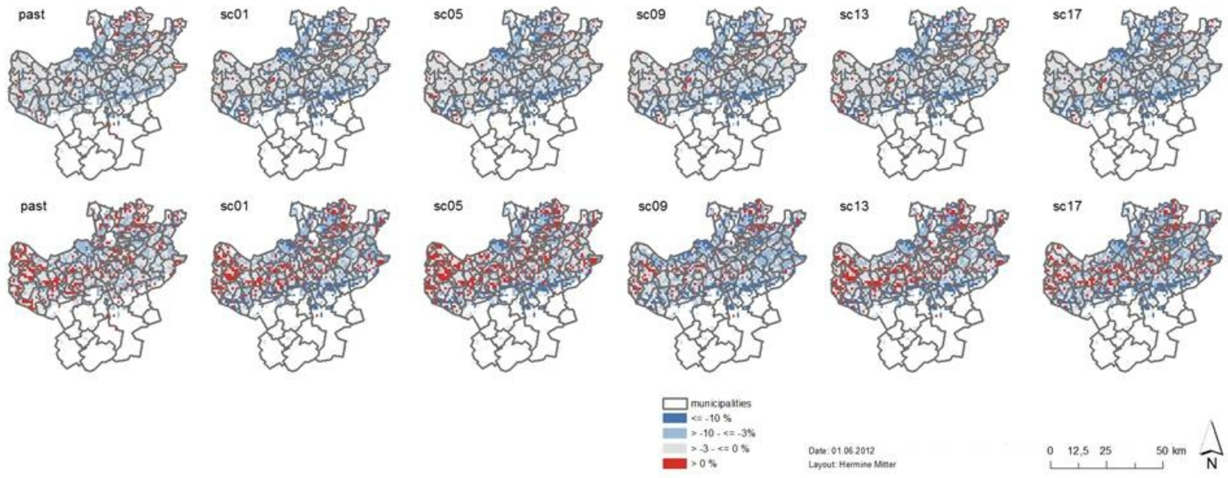

Figure 4: Changes in average crop yield in % when applying soil conservation measures: reduced tillage (top), winter cover crops (bottom); (changes are relative to conventional tillage)

4.3.3 Gross margins and their variation under different crop management practices

Impacts on gross margins are presented in Table 1 for absolute values and for relative changes (compared to the reference scenario sc01). In general, near future climate change seems to have a moderate effect on gross margins, mainly due to the relatively little impacts on crop yields (see chapter 4.3.2). Regardless of the crop management practice, losses are simulated for scenarios sc09 (between ~5.9% and ~7.2% considering agricultural policy premiums and between ~15.3% and ~34.1% without premiums) and sc13 (between ~2.3% and ~2.8% considering agricultural policy premiums and between ~6.7% and ~10.9% without premiums). In contrast, increases in average gross margins between ~2.2% and ~3.2% considering agricultural policy premiums and between ~7.7% and ~10.5% without premiums are simulated for scenario sc17 assuming higher summer precipitation and are confirmed with scenario sc05.

The additional direct costs of cultivating winter cover crops are more than compensated by current agri-environmental premiums. However, average annual gross margins (without premiums) 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 1: 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)

	period 1975-2005	**period 2010-2040** *climate change scenarios*				
		0%	+20%	-20%	+20% winter	+20% summer
	past	sc01	sc05	sc09	sc13	sc17
ø gross margin in €/ha/a – *WITH* premiums						
conventional tillage	463	481	481	451	468	497
reduced tillage	462	465	464	438	454	478
incl. winter cover crops	551	557	561	517	544	569
ø gross margin in €/ha/a – *WITHOUT* premiums						
conventional tillage	183	201	201	171	188	217
reduced tillage	142	145	144	118	134	158
incl. winter cover crops	111	117	121	77	104	129
ø dry matter crop yields in t/ha/a						
conventional tillage	8.6	8.7	8.7	8.4	8.5	8.8
reduced tillage	8.3	8.3	8.3	8.0	8.2	8.4
incl. winter cover crops	8.4	8.4	8.4	8.0	8.2	8.5
ø changes in gross margin in % – *WITH premiums*						
conventional tillage		reference	0.0%	-6.4%	-2.8%	3.2%
reduced tillage		reference	-0.3%	-5.9%	-2.5%	2.7%
incl. winter cover crops		reference	0.8%	-7.2%	-2.3%	2.2%
ø changes in gross margin in % – *WITHOUT* premiums						
conventional tillage		reference	0.0%	-15.3%	-6.7%	7.7%
reduced tillage		reference	-0.9%	-18.9%	-7.9%	8.7%
incl. winter cover crops		reference	4.0%	-34.1%	-10.9%	10.5%
ø changes in crop yield in %						
conventional tillage		reference	0.0%	-3.0%	-1.4%	1.6%
reduced tillage		reference	-0.2%	-2.8%	-1.3%	1.4%
incl. winter cover crops		reference	0.6%	-4.3%	-1.4%	1.4%

5 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 present research results in the formats preferred by the stakeholders (de la Vega-Leinert, 2008). The question of communicating results adequately was already raised at the stage of problem identification and structuring. According to the involved stakeholders, results were expected to meet the following requirements:

- provide examples of “best practice” and “worst case” in order to show the variety of options in the region,
- simplify correlations and interdependencies (e.g. by using convincing pictures).

Formally, the transdisciplinary research process was completed with another workshop in the case study area addressed to the peer group. At the workshop, the stakeholders were asked to validate the results and reflect on their societal relevance and usability. However, the stakeholders stressed once again the importance of “unique extreme examples at farm or field level”. The presentation of gross margins was not considered useful for further advisory or persuasion activities but scientists were not able to provide the requested "extreme examples" because of insufficient spatial resolution of data and models. Therefore, stakeholders suggested using single pixels that show high changes in soil sediment loss and gross margins for further discussions but scientists expressed concern that emphasizing potential 'outliers' might lead to misinterpretations. Such differences between interests, approaches, and expectations of stakeholders and scientists have already been discussed several times (e.g. Heymann, 2000; Gregrich, 2003). While researchers tend to fade out 'outliers', they emotionalize political and societal debates. Addressing, understanding and negotiating such mismatches is deemed as critical element in transdisciplinary research processes (Bammer, 2012).

Stakeholders and scientists agreed that clear messages are indispensable for advisory and persuasion activities. Nevertheless model output uncertainties caused by the imperfect process knowledge, gaps on local data, and inherent limits to the predictability of impacts of climate change have to be addressed. It is essential that practitioners are aware of the underlying assumptions and uncertainties in order to develop and/or adopt detailed implementation and monitoring strategies. The challenge is to find a good balance between *"honesty about the uncertainty of the results and clarity of the message conveyed"* (de la Vega-Leinert, 2008, 116).

6 Conclusions and outlook

Farmers are increasingly facing challenges about the vulnerability of farm business and uncertainty of future climatic conditions and impacts. Integrating local practitioners and experts in knowledge generation for a regional vulnerability analysis was expedient. The idealised phases of transdisciplinary research projects have proved to be a helpful guiding principle for structuring the research process in the case study area. Minor adaptations have resulted from thematic, individual and regional characteristics.

At the core of the transdisciplinary research is the recursive problem framing, including the mutual learning process between practitioners and scientists. Collaboration with the stakeholders was organised in the form of workshops and guided interviews and resulted in the following research question: *"How do precipitation scenarios until 2040 affect soil erosion on cropland and how effective are particular soil conservation practices?"*

The impact of climate change scenarios on soil sediment loss as well as the effectiveness of soil conservation measures has been assessed by an interdisciplinary team of scientists. Regional actors 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 erosion and conservation measures have been proved to be an effective adaptation option.

In addition, stakeholders have provided a valuable reality check and gave feedback on model results with respect to meaningfulness and clarity. Scientists have emphasized on presenting the research results target-group oriented. In particular, using maps for presenting outcomes of complex interdependencies has facilitated the communication. However, illustrations with a spatial resolution of 1km² might encourage stakeholders to concentrate on single pixels and interpret extreme values. This should be avoided.

Stakeholders have approved the usability of the model results. Model outputs add to empirically observed data on soil 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 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. It may therefore support the design of targeted policies as well as implementation of particular management measures.

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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Appendix

1. Changes in the extent of vulnerability to soil erosion by precipitation scenarios (sc) and five vulnerability classes in %; (Changes are relative with respect to sc01)

		soil erosion vulnerability class				
tillage system	sc	1	2	3	4	5
conventional	sc05	-53	14	-19	17	76
	sc09	56	14	-6	-19	-76
	sc13	-1	2	-5	-5	10
	sc17	-18	-3	0.4	13	20
reduced	sc05	-49	24	-22	22	91
	sc09	48	30	-10	-40	-80
	sc13	2	3	-5	-3	4
	sc17	-21	3	0.5	12	30
winter cover crops	sc05	-33	-4	-7	21	135
	sc09	42	14	-16	-68	-80
	sc13	3	-0.3	-4	-7	6
	sc17	-15	-7	6	16	42

2. Share of cropland in soil erosion vulnerability classes under different crop management practices