Assessing the robustness of crop management practices under climate change in Austria

Analyse der Robustheit von Bewirtschaftungsformen im österreichischen Ackerbau unter veränderten klimatischen Bedingungen

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Summary

We analyze vulnerability implications of alternative crop management practices in order to assess their robustness under changing climatic conditions in Austria. Hence, we have developed an integrated assessment framework consisting of a statistical climate change model, a crop rotation model, the bio-physical process model EPIC, crop gross margin calculations, and a vulnerability surface approach. Level and variability of crop gross margins of various crop management practices serve as vulnerability indicators. Model results reveal that reduced tillage combined with winter cover cropping as well as moderate fertilization intensity are effective on national average, considering five climate change scenarios until 2040 and assuming constant prices, costs, and policy premiums. The presented approach contributes to the development and improved communication of viable adaptation measures in crop production.
Keywords: Integrated assessment, EPIC, vulnerability surface, crop production, adaptation, land use

Zusammenfassung

Wir analysieren die Auswirkungen alternativer Bewirtschaftungsformen im österreichischen Ackerbau auf die Vulnerabilität der Ackerpflanzenproduktion gegenüber globalen Klimaveränderungen. Dazu wurde ein integrativer Analyserahmen entwickelt, der aus einem statistischen Klimamodell, einem Fruchtfolgemodell, dem bio-

Erschienen im *Jahrbuch der Österreichischen Gesellschaft für Agrarökonomie*, Band 25: 13-22, Jahr 2016. On-line verfügbar: http://oega.boku.ac.at.

physikalischen Prozessmodell EPIC, Deckungsbeitragsberechnungen und dem Ansatz einer Vulnerabilitätsoberfläche besteht. Höhe und Variabilität von Deckungsbeiträgen unterschiedlicher Bewirtschaftungsformen dienen als Vulnerabilitätsindikatoren. Die Modellergebnisse zeigen, dass reduzierte Bodenbearbeitung kombiniert mit dem Anbau von Winterzwischenfrüchten sowie moderate Düngungsintensität im nationalen Durchschnitt effektive Maßnahmen zur Anpassung an Klimaveränderungen sind. Die Effektivität wurde unter Berücksichtigung von fünf Klimawandelszenarien bis 2040 und unter der Annahme, dass Preise, Kosten und Agrarprämien konstant bleiben, ermittelt. Der präsentierte Ansatz trägt zur Entwicklung und verbesserten Kommunikation effizienter Anpassungsmaßnahmen in der Ackerpflanzenproduktion bei.

Schlagworte: Integrative Analyse, EPIC, Vulnerabilitätsoberfläche, Pflanzenproduktion, Anpassung, Landnutzung

1. Introduction

Agricultural vulnerability to climate change varies considerably between agro-environmental zones. These differences become particularly evident in Austria where climate models do not agree on the direction of precipitation change. The high uncertainty in precipitation sums and patterns can be mostly attributed to Austria's geographical location as it is situated in a transition zone between rising winter precipitation in northern Europe and declining summer precipitation in southern Europe (GOBIET et al., 2014). Such diverging climate model results affect the accuracy of crop yield simulations (GLOTTER et al., 2016). In general, crops can utilize rising temperatures and elevated atmospheric CO_2 concentrations if water is not limiting in the vegetation period and heat stress is absent. This is mainly true for the alpine region in western Austria where grassland is the most widespread land cover. In the cropland dominated eastern and south-eastern parts of Austria already existing water shortages may be exacerbated by higher temperatures, induced evapotranspiration, and heat stress (SCHÖNHART et al., 2014; MITTER et al., 2015a). The high climate sensitivity of crop production in Austria emphasizes the need for systematic agricultural vulnerability and adaptation assessments at national and regional scales. We aim at analyzing vulnerability implications of various crop management practices that can be employed by farmers autonomously in response to changes in weather and climate conditions and in order to reduce negative or take advantage of potential positive impacts. Thereby, we reveal the scope for robust autonomous climate change adaptation strategies in Austrian crop production.

The article is structured as follows. In section 2, we introduce the integrated assessment framework both in a graphical and formal way which is applied to the Austrian cropland. In section 3, we present and discuss selected results, and in section 4 we draw conclusions.

2. Integrated assessment framework

We apply a spatially explicit integrated assessment framework to investigate the robustness and vulnerability implications of crop management practices in Austrian agriculture. Figure 1 provides a graphical overview on the integrated assessment framework applied in this analysis. Similar integrated assessment frameworks have been utilized to analyze climate change impacts and identify viable adaptation measures in Austrian agriculture (STRAUSS et al., 2012; SCHÖNHART et al., 2014; MITTER et al., 2015a, b). The main extension refers to a vulnerability surface approach as suggested by LUERS (2005).

The bio-physical process model EPIC (Environmental Policy Integrated Climate, WILLIAMS, 1995) is applied to simulate (i.a.) annual crop yields at 1 km grid resolution for five climate change scenarios until 2040 and alternative crop management practices. The Austrian cropland of about 1.3 million ha is represented by 40,244 grid cells. The CO_2 fertilization effect is taken into account in EPIC.

The climate change scenarios are derived from ACLiReM (Austrian Climate Change Model using Linear Regression), a statistical climate change model for Austria (STRAUSS et al., 2012; 2013). ACLiReM provides daily weather data for six parameters, i.e. minimum and maximum temperature, precipitation, solar radiation, relative humidity, and wind speed. Based on observed daily weather station data, a rising temperature trend of ~0.05 °C per year has been identified for Austria in the period 1975-2007. This trend is projected to continue in the future period (2010-2040) and forms the basis of the five climate change scenarios. Assumptions on precipitation sums and seasonal distributions define the climate change scenarios.

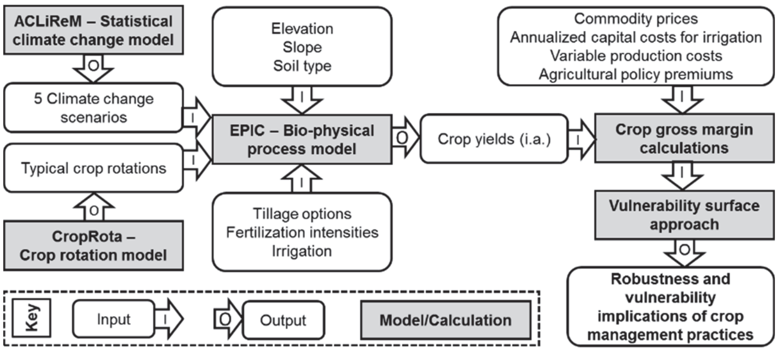

Fig. 1: Integrated assessment framework
Source: OWN ILLUSTRATION

The reference scenario REF assumes that daily precipitation patterns are similar to the historical period. The scenarios WET/DRY are characterized by an increase/decrease in daily precipitation sums by 20% compared to REF. In scenarios ShiftWIN and ShiftSUM, we assume a shift in the seasonal precipitation distribution from the summer to the winter and vice versa, i.e. daily winter/summer precipitation increases by 20% and daily summer/winter precipitation decreases such that the annual precipitation sums remain at the historically observed level. The selected climate change scenarios represent contrasting but plausible changes in climate until 2040, if compared to data from Regional Climate models (RCMs) for Austria (see e.g. GOBIET et al., 2014).
Specified crop management practices considered in EPIC include:

- crop rotations derived from the crop rotation model CropRota which considers 22 major crops cultivated on about 90% of the total Austrian cropland (SCHÖNHART et al., 2011),
- three tillage options, i.e. conventional tillage, reduced tillage, and reduced tillage combined with cultivating winter cover crops, and
- three fertilization intensity levels, i.e. high, moderate, and low.

Average annual crop gross margins of typical crop rotations are calculated by cropland grid cell and climate change scenario. They are defined as revenues minus variable production costs. Revenues are calculated by multiplying simulated annual crop yields with the respective agricultural commodity prices averaged over the period 1998-2011 (provided by Statistics Austria) and adding agricultural policy premiums such as a uniform decoupled payment of 280,- €/ha as well as agri-environmental payments for reducing fertilization rates (moderate intensity in EPIC, 85,- €/ha), abandoning commercial fertilizer inputs (low intensity in EPIC, 115,- €/ha), reduced tillage (40,- €/ha), and reduced tillage including the cultivation of winter cover crops (160,- €/ha). Variable production costs are derived from historical values and include costs for seeds, fertilizers, tillage operations, pesticides, fuel, and insurance. Labor costs (10,- €/h) are taken into account as well. Commodity prices, variable production costs, and agricultural policy premiums are held constant in the future period which allows us to filter out the impact of climate change on crop gross margins. Additionally, we investigate the effect of abolishing agricultural policy premiums on the robustness of crop management practices in the five climate change scenarios.

A vulnerability surface approach is used to assess vulnerability implications of crop management practices. Vulnerability is often defined as a function of exposure (E), sensitivity (S), and adaptive capacity (AC) where vulnerability increases with higher E and S of the system and with lower AC (PARRY et al., 2007). LUERS (2005) developed a two-dimensional diagram to represent the functional form of vulnerability. An indicator of E and S of the system is presented on the horizontal axis and the systems state relative to a threshold of damage on the vertical axis. AC refers to a system's capability to decrease vulnerability either by reducing E or S or by increasing the state relative to the damage threshold which is represented by a changing position on the vulnerability surface.

In our analysis, the coefficient of variation (CV) of crop gross margins is used as an indicator for E and S of agricultural systems to climate change. The CV has been chosen because it represents the climate-induced inter-annual variability in crop gross margins. The state of the system is represented by the level of crop gross margins considering bio-physical (crop yields) and socio-economic components (input and output prices as well as agricultural policy premiums). The threshold of damage is set to 1,- €/ha acknowledging that positive gross margins have to be realized in order to ensure the long-term viability of a farm. In the vulnerability surface diagram, crop management practices are located in the bottom right/top left corner if their application increases/decreases a farm's vulnerability to changing climatic conditions. Contour lines of 'equal vulnerability' (LUERS, 2005) are defined by dividing the variables plotted on the x- by those on the y-axis and improve the comparability of the investigated crop management practices. They are normalized by the average values found in the analysis, i.e. the contour line of V=1 represents the average of the analyzed crop management practices in terms of level and CV of crop gross margins in the considered climate change scenarios.

3. Results and discussion

Figures 2 and 3 show the vulnerability surface diagrams for the investigated crop management practices (three tillage options and three fertilization intensities) and the five climate change scenarios REF, WET, DRY, ShiftWIN and ShiftSUM at national level. The bandwidth of annual crop gross margins is plotted on the y-axis and represents the spatial variability of the model outputs. The dots represent the mean value of crop gross margins across all spatial units. The CV of crop gross margins is plotted on the x-axis and reflects the inter-annual variability in average crop gross margins. In both diagrams, the contour line V=1 presents the average of all investigated adaptation measures, meaning that farmers applying crop management practices located below this line are – on average – more vulnerable to climate change than those opting for crop management practices located above this line. Note that only values between the 10^{th} and 90^{th} percentile are shown.

The robustness of the three tillage options (conventional tillage, reduced tillage, and reduced tillage in combination with winter cover cropping) is depicted for the five climate change scenarios in Figure 2. Model results reveal that reduced tillage combined with winter cover crops (presented in light grey) is most robust on national average. It shows higher average levels and lower inter-annual variability of crop gross margins than conventional and reduced tillage, regardless of the climate change scenario. The preferred crop management practice is less clear if conventional and reduced tillage are compared because of the decisive influence of the climate change scenarios on the CV of crop gross margins. In general, crop production is found to be most vulnerable under dry climate conditions, i.e. in the climate change scenario DRY, whereas all tillage options are better off under wet climate conditions, i.e. in the climate change scenario WET.

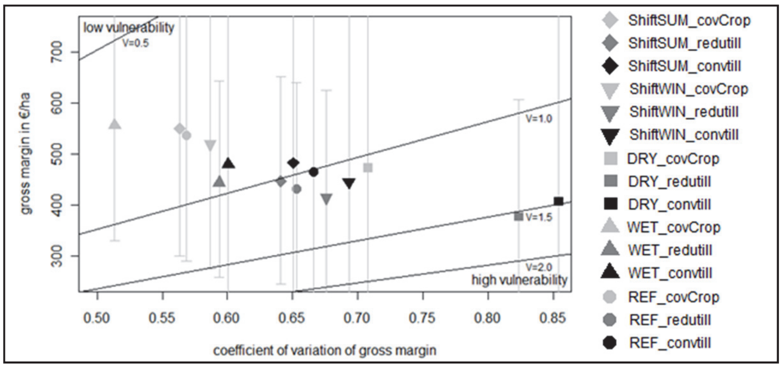

Fig. 2: Vulnerability surface diagram for the three tillage options (convtill = conventional tillage, redutill = reduced tillage, covCrop = reduced tillage with winter cover cropping) and the five climate change scenarios for the period 2010-2040 (REF, WET, DRY, ShiftWIN, ShiftSUM) at national level
Source: OWN CALCULATIONS

Assuming that agricultural policy premiums (i.e. uniform decoupled payment and agri-environmental payments) are abolished, conventional tillage is most robust, followed by reduced tillage (not shown in the vulnerability surface diagram). This result is in line with other modeling studies showing that crop yield losses and additional variable costs of cultivating winter cover crops are, on average, overcompensated by current premium levels (MITTER et al., 2014).
Figure 3 shows vulnerability implications of the three fertilization intensities. Moderate fertilization intensity (presented in dark grey) is, on national average, most robust under the five selected climate change scenarios and if prices, costs, and agricultural policy premiums remain constant. Under current climate conditions, moderate fertilizer inputs are already applied on about 70% of Austrian cropland. However, public payments for moderate fertilization rates were abandoned by the latest reform of agri-environmental payments which may lead to notable intensification. If agricultural policy premiums are not considered in the analysis, the robustness of high and moderate fertilization intensity is similar in REF, WET, ShiftWIN and ShiftSUM on national average (not shown in the vulnerability surface diagram).

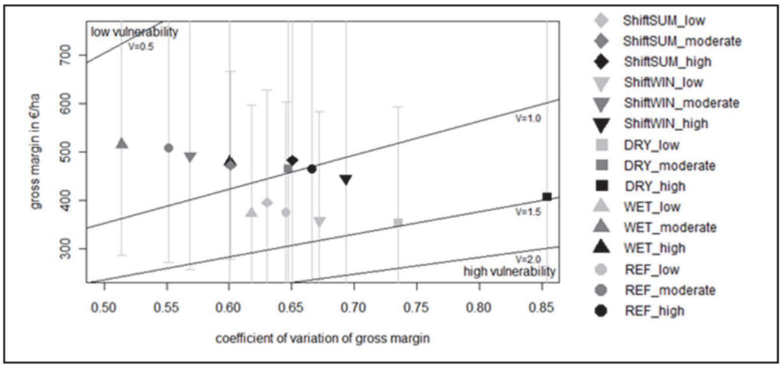

Fig. 3: Vulnerability surface diagram for the three fertilization intensities (high, moderate, low) and the five climate change scenarios for the period 2010-2040 (REF, WET, DRY, ShiftWIN, ShiftSUM) at national level
Source: OWN CALCULATIONS

Under dry climate conditions, moderate fertilizer inputs are, on average, more robust than high ones. Intensification under changing climatic conditions is reasonable and suggested by other modeling studies (e.g. KIRCHNER et al., 2015; MITTER et al., 2015a, b). However, optimal fertilization rates are site- and crop-specific and may decrease in the next decades (LEHMANN et al., 2013).

4. Conclusions and outlook

Climate change may affect agricultural vulnerability, which highlights the need to identify viable adaptation measures. We have developed an integrated assessment framework to analyze and compare vulnerability implications of various crop management practices under five climate change scenarios in Austria. Effective crop management practices have been identified by illustrating their relative position in a vulnerability surface diagram which facilitates the prioritization of climate change adaptation measures. The model results indicate that reduced tillage in combination with winter cover cropping as well as moderate fertilization intensity are the most robust crop management practices on national average, under the assumption of constant prices, costs and agricultural payments. However, it should be noted that the ranking may look different from region to region and also depends on the climate change scenario. Developed to evaluate alternative management practices and inform policy decisions (LUERS, 2005), the vulnerability surface approach has proven effective in empirical studies (see e.g. SEIDL et al., 2011) and for the presented agricultural vulnerability study. Bio-physical and socio-economic aspects which affect crop management choices have been considered in the analysis including e.g. soil, topography and climate conditions, current levels of commodity prices, production costs and agricultural policy premiums as well as the abolishment of agricultural policy premiums. However, the vulnerability assessment is limited to crop productivity and crop gross margins and could be broadened by (i) including environmental outcomes in the vulnerability indicators, (ii) considering additional crop management practices and adaptation measures, (iii) comparing vulnerabilities between homogenous crop production regions, (iv) evaluating policy scenarios, and (v) considering stakeholders' preferences in defining vulnerability indicators. Integrated agricultural vulnerability and adaptation assessments require a great diversity of data and methods, which may impede communication with agricultural stakeholders (MITTER et al., 2014). The vulnerability surface approach offers a promising framework for effectively communicating quantitative model results and thus informing the design of adaptation strategies, action plans and extension activities.

Acknowledgements

This research has been supported by the research project Private Adaptation Threats and Chances: Enhancing Synergies with the Austrian NAS implementation (PATCH:ES) funded by the Austrian Climate Research Program.

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