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IN NORTH EAST CENTRAL EUROPE?**

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WHAT ARE THE EFFECTS OF CLIMATE CHANGE ON AGRICULTURE IN NORTH EAST CENTRAL EUROPE?

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Abstract

Global and climate changes influence the basic conditions for agriculture and so there is not only a demand for a consequent climate protection but also for an adaptation of agriculture to these global changing conditions. For the whole “Maerkisch-Oderland” district (60x40 km) within the moraine landscape of North-East-Germany mainly used for agriculture water balance, nitrogen and sulphur loads as well as crop yields are calculated for two land use and climate scenarios. The comparison between the Scenario2050 and the Scenario2000 reveals significant changes of the water balance (decrease in percolation water, increase in actual evapotranspiration) as well as the concentration of the examined nitrogen in the percolation water. For the study region the crop yields decrease only slightly if the CO₂ fertilizing effect is taken into account. Adaptation measures in reaction to the changing climate conditions for an economically secured and sustainable agriculture are recommended.

Keywords

climate change impact assessment, water balance, nitrogen load, crop yield, moraine landscape

1 Introduction

One of the most fundamental questions facing humanity today is, how global climate change will impact the terrestrial ecosystems, i.e. the cultivated landscapes? For a sustainable development of rural areas a high productive and environmentally sound agriculture plays an essential role. It can be expected, that climate changes have an increased influence on the agricultural productivity and the environment as well (EULENSTEIN et al (2006)). Up to now model-based research on climate impact on regions dominated by agriculture mostly deals with yield development, landscape water balance, nutrient dynamics and nutrient loads or endangerment of habitats separately. Results, however, rest on a modelling which is realised at the field scale level for a few crop types only or is based on roughly discriminated land use types (cropland / grassland / forest) with a low spatial resolution or else selective examinations. There are hardly any comprehensive eco-systemic simulations based on extensive, real site and land use data of an entire landscape section collected over several years.

Against this backdrop, an eco-systemic sensitivity analysis on the reaction of a well and detailed documented area dominated by agriculture under the real climate situation for 2000 and under a regional climate change scenario assumed for 2050 (GERSTENGARBE et al. 2003) are shown in an exemplary manner. As a basis it uses an un-changing continuation of current land use practice, taking extensive field-specific data of a typical agrarian landscape in the

partially drought endangered climate of North-East Germany as an representative example. Coherently modelled and interpreted for this study area are first, elements of the water balance, second, nutrient loads and percolation water concentrations for nitrate and sulphate, and third yields of agricultural crops. The climate change impacts on agriculture can be reduced using adapted and/or new land use systems and management practices.

2 Study area

As part of the district “Maerkisch-Oderland” the study area is located within the morain landscape of North-East Germany. The area extends over about 60 x 40 km and is situated approximately 50 km to the east of Berlin (Figure 1), i.e. between Berlin and the river Oder. The north-west and the south-west of the study area are parts of sandy-loamy moraine plateaus called “Barnimer Platte” and “Lebuser Platte”, respectively, with about 60 m MSL for both plateaus. The south-eastern part of the study area is located in the valley bottom of the “Oderbruch” region at 5-12 m MSL with mostly clayey alluvial soils. The recent climate of the study area is a drought continental climate with a significantly decreased precipitation gradient from west to east. In the study area, the major part of the land is used for agriculture (about 54,000 ha). On the arable land there are working 54 farms with 1,085 ha each in average (50 ... 7,200 ha). On 45 % of the arable land of the study area winter cereals are grown, followed by silage maize and rape with about 9 % each, alfalfa with 3 % and sugar beet with 2 % (Table 2). Land in the study area that is not used for agriculture but predominantly for forestry has not been taken into consideration. .

3 Model and simulation platform

To assess the consequences of regional climate changes in North-East German landscapes to the components of climatic water balance as well as the nitrogen and sulphate concentration in the percolation water the complex dynamic simulation models HERMES for soil nitrogen and SULFONIE for soil sulphate both developed by KERSEBAUM (KERSEBAUM (1989); KERSEBAUM (1995); WILLMS et al. (2006)) were used. The nitrogen and sulphate models take into account mineralization, denitrification and transport (by soil water) processes, an atmospheric deposition as well as the uptake by plants. The models run in a daily mode and with 0.1 m soil depth compartments, the modelling is confined to the rooting zone (max. 2 m). Both models contain a layer model for soil water and take into account a capillary rise from below 2 m. The potential evapotranspiration is determined according to HAUDE (1955) using crop-specific monthly factors.

To assess the climate change impact on yields of agricultural crops a three-stage statistical estimating algorithm with an additive combination is used. It applied a crop yield matrix according to KINDLER (1992) dependent on crop type and on site type according to the Medium Scale Site Map (MMK) for arable land (SCHMIDT and DIEMANN, 1991), a correction algorithm using additional MMK-site characteristics and climate parameters (temperature, precipitation, radiation, climatic water balance) as well as a cropping-year-dependent yield trend overlay. The basic crop yields from the yield matrix are increased or decreased depending on MMK-site characteristics and growth-dominant climatic parameters like the growth influencing temperature (according to ADLER (1987)) or the climatic water balance for the cropping period and are modified by crop depending correction algorithms (MIRSCHERL, 2003). The estimation of the atmospheric CO₂-effect on crop yields is based on results measured under field conditions (FACE experiment of the FAL Brunswick (WEIGEL et al., 2005) for winter barley, sugar beet, winter wheat and ray grass), which show in average a

10.7 % yield increase at 550 ppmv CO₂. For the 465 ppmv to be expected by 2050, a linear conversion was carried out.

For the simulation runs field-specific land use and agro-management data, arable land soil data from the MMK and weather data from the meteorological station Muencheberg representative for the study area were used. The spatially differentiated estimation of agricultural landscape indicators like crop yield productivity, for example, were undertaken using the *Spatial Analysis and Modelling Tool* (SAMT) (WIELAND et al., 2006).

4 Scenario definition

For the study area simulation runs for two scenarios (*Scenario2000* (initial situation) and *Scenario2050*) were realised characterising different land uses and climatic levels. Within each scenario simulation runs over a 9 years time period (*Scenario2000*: 1993-2001; *Scenario2050*: 2046-2054) are the basis for the scenario comparison concerning climate and land use change impacts on the study area.

The weather data (temperature, precipitation, sunshine duration/radiation) for the *Scenario2000* are taken from the meteorological station Muencheberg as daily real weather data. For the *Scenario2050* daily weather data for Muencheberg were taken from the climate scenario defined by the Potsdam Institute of Climate Impact Research (GERSTENGARBE, 2003) using a special statistical method. This climate scenario used for the *Scenario2050* is based on the ECHAM4-OPYC3 climate model of the Max Planck Institute for Meteorology Hamburg assuming the moderate emission scenario A1B-CO2 (increase of annual mean temperature by 1.4 K; decrease of annual precipitation by 112 mm) with a regionalization for the Federal State of Brandenburg. The climatic conditions of both scenarios are compared in Table 1.

The crop rotations, mean values for the nutrient balances and the yields for the *Scenario2000* were determined by means of yearly field-specific samplings from each farm within the study area. In average for the study area the mineral and organic nitrogen fertilizers were 102 kg N ha⁻¹ a⁻¹ and 38 kg N ha⁻¹ a⁻¹, respectively, and the mineral and organic sulphate fertilizers were 12 kg S ha⁻¹ a⁻¹ and 5 kg S ha⁻¹ a⁻¹, respectively. The nutrient balance values for the *Scenario2050* were taken unchanged from the initial situation according to the scenario definition. In both scenarios atmospheric depositions of 8 kg N ha⁻¹ a⁻¹ and 6 kg S ha⁻¹ a⁻¹ were assumed.

For the purposes of a sensitivity analysis in the *Scenario2050* the following basic conditions were maintained constant (as in the *Scenario2000*):

- soils with soil characteristics
- spectrum and percental distribution of agricultural grown crops including the accordant agro-management
- level of plant breeding
- atmospheric partial pressure of CO₂ and temperature-dependent respiration of plants.

In the concluding yield estimation model used for climate change impact predictions on yield productivity, breeding progress and influence of increasing CO₂ also were considered.

5 Simulation results

5.1 Scenario2000...

For the study area based on measured climate data a potential evapotranspiration of 510 mm a⁻¹ and an actual evapotranspiration of 417 mm a⁻¹ were calculated. In average the modelled water storage up to a depth of 2 m amounts 404 mm in autumn. The percolation rate (deeper than 2 m) averages at 143 mm a⁻¹ (Table 1). Values as low as 60–120 mm a⁻¹ occur

predominantly in the “Oderbruch” region, an area with clay soils, i.e. with a high field capacity. The nitrogen surplus of the period of examination averages at 55 kg N ha⁻¹ for the study area, the sulphur surplus at 15 kg ha⁻¹. The annual nitrogen loads differ between 25 and 100 kg N ha⁻¹ around the average of 60 kg N ha⁻¹ (Table 1). The modelled nitrate concentration in the percolation water varies between 150 and 300 mg l⁻¹, with an average of 232 mg NO₃ l⁻¹ (Table 1). There are comparable relations between load and concentration with sulphur and sulphate, respectively. The yield level for the initial situation (*Scenario2000*) is characterized by average crop yields of 5 t for winter cereal, 23 t for silage maize and 2.5 t for rape.

5.2 Scenario2050...

Although precipitation is lower by 20% in comparison to the *Scenario2000*, the calculated actual evapotranspiration is increased by 20 mm to 437 mm a⁻¹ (Table 1). This mainly results from warmer winter periods, whereas the increased temperature during summer induces no additional evapotranspiration. With 313 mm, the average water storage up to a depth of 2 m calculated for autumn is 91 mm lower in the *Scenario2050* compared with the *Scenario2000*. The average percolation rate goes down to 12 mm a⁻¹ (Table 1). At the clayey alluvial sites of the “Oderbruch” region, a decrease in percolation water of 100-140 mm a⁻¹ predominates, which reveals in the failure of significant percolation rates in 8 of the 9 simulated years. At the sandy sites, there is an even stronger decrease.

Table 1: Meteorological scenario definition and scenario results (Scenario2000 vs. Scenario2050)

	<i>Scenario2000</i>	<i>Scenario2050</i>
Annual mean temperature (°C)	8.1	9.5
Mean precipitation (mm a ⁻¹)	569	457
Sunshine duration (h a ⁻¹)	1698	1842
Actual evapotranspiration (mm a ⁻¹)	417*	437*
Percolation water (mm a ⁻¹)	143*	12*
Nitrogen load in percolation water (kg N ha ⁻¹ a ⁻¹)	60*	40*
Sulphur load in percolation water (kg S ha ⁻¹ a ⁻¹)	24*	8*
Nitrate concentration in percolation water (mg NO ₃ l ⁻¹)	232*	751*
Sulphate concentration in percolation water (mg SO ₄ l ⁻¹)	49*	132*

* calculated using HERMES and SULFONIE (KERSEBAUM 1995; WILLMS et al., 2006)

For the *Scenario2050*, an average nitrogen load of 40 kg ha⁻¹ is calculated if the nitrogen surplus remains unchanged at 55 kg ha⁻¹ (Table 1). As a result of decreased percolation rates in *Scenario2050* the calculated nitrate concentration in the percolation water was increased in average up to 751 mg l⁻¹. The amounts of discharge and percolation water concentration of sulphate react correspondingly (Table 1).

In average the agricultural yields calculated without the CO₂ fertilizing effect in the *Scenario2050* are lower by 7 % compared with the *Scenario2000*. For the different agricultural crops does it mean between 4% for triticale and 14 % for potatoes (Tabel 2). The spatial distribution of the yield decline is shown in Figure 1. In the “Oderbruch” region with clayey alluvial soils and higher soil water storage capacities the lowest losses occur (up to 5 % only). Taking into account the fertilizer effects of atmospheric CO₂ (from 375 ppmv in 2000 up to 465 ppmv in 2050) on yield in the study area the yield losses for spring and winter

cereals caused by drought and higher temperatures in *Scenario2050* can be compensate and light overcompensate (Table 2). For all other agricultural crops grown in the study area in average the losses are lower by about 5 %.

5.3 Scenario2000 vs. Scenario2050

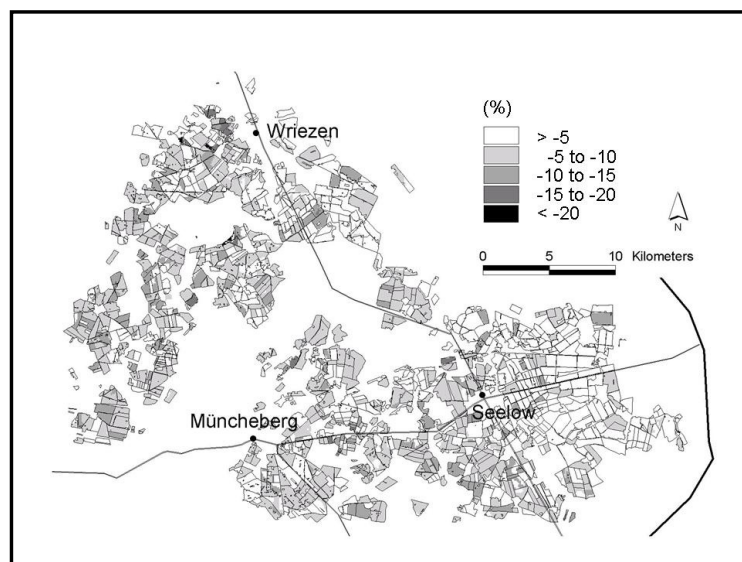
The comparison of simulation results of both scenarios (Scenario2050 vs. Scenario2000) reveals dramatic changes of the water balance (decrease in percolation water by 130 mm a^{-1} and increase in actual evapotranspiration by 20 mm a^{-1}) as well as the concentration of the examined nitrogen and sulphur in the percolation water, if the current land use practice is maintained until 2050. For the study area the yields of agricultural crops decrease only slightly, or hardly at all, if the CO_2 fertilizing effect (based on the Brunswick FACE experiment results) is taken into account (Table 2).

The increase of actual evapotranspiration only results from the warmer winter periods, due to insufficient soil water supply during summer. In the study area a decreased precipitation and an increased evapotranspiration lead to a ground-water recharge of 12 mm a^{-1} on average only under agricultural land, thus enabling the regional occurrence of years without any ground-water recharge. It is not only the anthropogenic water supply that would be affected but also the ecologically valuable wetland areas fed by ground water, which might lose their functioning as a result of water deficiency and eutrophication. If the extensive conifer forested areas besides the arable land provide any compensation for ground water shortage, is up to further research.

In addition, an increase in weather extremes higher than that assumed in the Scenario 2050 would restrict the adaptability of agriculture¹² (EULENSTEIN et al.2005) and also induce release of the nutrients so far stored in the upper soil into the groundwater.

The nitrate and sulphate loads of the percolation water declines by $20 \text{ kg ha}^{-1} \text{ a}^{-1}$ and $16 \text{ kg ha}^{-1} \text{ a}^{-1}$, respectively (Table 1). These lower values, which may be considered landscape-ecologically favourable, result (if input remains constant as defined above) in a nitrogen enrichment in the upper 2 m of the soil still progressing during *Scenario2050*. Despite the decrease of the loads, the concentration of nitrate in the percolation water more than triples in the study area up to 2050 as a result of even more dramatically decreasing percolation rates. If, when, and how strongly these small amounts of highly eutrophic percolation water impact the ground water and neighbouring ecosystems, depends particularly on the occurrence of high-rainfall weather extremes, a general unpredictability to this study.

Figure 1: Spatial distribution of agricultural yield decline in Scenario2050 compared with Scenario2000 (exclusive the effect of an increased atmospheric CO_2)



The resilience of scenario results mainly depends on the accuracy of sampling data, on used modelling approaches and on made assumptions. The consideration of the heterotrophic and autotrophic denitrification in the unsaturated zone, of a new state of equilibrium embodied into the Scenario2050, of a development-adapted agro-management up to 2050, of a plant breeding progress on drought resistance, of the potential respiration decrease of crops in the event of CO₂ partial pressure increase, and of change in frequency and amplitude of extreme meteorological conditions would restrict the accuracy of the statement considerably.

Table 2: Cropping rate, mean crop yield changes (Scenario2050 vs. Scenario2000) for the study area differentiated by CO₂ fertilizing effects

Crop	Cropping rate (%)	Mean crop yield change (%)	
		at 370 ppmv CO ₂	at 465 ppmv CO ₂
Winter rye	17	- 6	- 0,3
Winter wheat	16	- 5	0,5
Silo corn	9	- 8	- 3
Winter rape	9	- 11	- 6
Winter barley	6	- 5	0,5
Triticale	6	- 4	0,1
Sugar beets	2	- 9	- 4
Alfalfa	3	- 12	- 7
Summer barley	2	- 5	0,3
Summer rape	< 1	- 7	- 2
Summer wheat	< 1	- 4	0,9
Clover gras	1	- 13	- 8
Oat	1	- 5	0,2
Potatoes	1	- 14	- 9

Statements which hold relevance for the entire landscape can only be deduced if the non-agrarian land (about 30% of eastern part of the Federal State of Brandenburg, Germany, is forested) is included.

6 Adaptation measures by agriculture

In conclusion of these simulation results for the study area different adaptation measures in reaction to the changing climate conditions for a economically secured and sustainable agriculture are possible like for example:

- site-specific optimization of the whole production system for an effective water use and for the conservation of the soil organic matter
- integration of new drought resistance crops and varieties into adapted crop rotation
- scheduling of nitrogen fertilization in dependence on plant ontogenesis and water availability
- application of conserve soil tillage and direct sowing methods
- as possible year-round coverage of arable land for a lossless precipitation water infiltration
- effective usage of irrigation especially for potatoes, vegetables and special crops

- establishment of agro-forestry or hedge systems against erosion and evaporation especially in landscapes rare of structure elements

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