THE EFFECTS OF CLIMATE CHANGE ON NITROGEN AND SULPHUR LOAD IN PERCOLATION WATER FROM AGRICULTURE LANDSCAPE

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Abstract
Global and climate changes influence the basic conditions for agriculture. Therefore there is not only a demand for a strict climate protection but also for an adaptation of agriculture to changing conditions. For a study region of 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 were calculated for the actual and for a possible future situation. The comparison between the Scenario 2050 and the Initial Situation in 2000 revealed significant changes of the water balance (decrease in percolation water, increase in actual evapotranspiration) as well as of the concentration of nitrogen and sulphur in the percolation water. For the study region the crop yields decrease only slightly if the CO_2 fertilizing effect is taken into account. Adaptation measures in response to changing climate conditions to achieve an economically secured and sustainable agriculture are recommended.

Keywords
Climate change, impact assessment, nitrogen load, sulphur load, water balance, 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 highly productive and environmentally sound agriculture plays an essential role. It can be expected, that climate change has an increasing impact on agricultural productivity and the environment as well (Eulenstein et al. 2005, Lana 2013). For European agricultural production the entire range, spanning from local dramatic losses to relatively positive effects, is assumed (Maracchi et al. 2005, Ewert et al. 2005, Audsley et al. 2006). Another common result is that a changed landscape water balance causes endangering water deficiency for non-production ecosystems (Wessolek and Asseng 2006). Results, however, rest on modelling that is usually based on roughly discriminated land use types, e.g. cropland/grassland/forest (Rounsevell et al. 2006) with a low spatial resolution, or otherwise selective examinations.

Although Wessolek and Asseng's (2006) model predicts yields and water balance for North-East Germany with a high temporal resolution, their statement for 2050 is restricted to one crop at two sites with characteristic soil substrates.

Model-based research on climate impact on regions is still dominated by agriculture and considers mostly yield development, landscape water balance, nutrient dynamics and nutrient loads or endangerment of habitats separately. 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 actual climate situation of 2000 and under a regional climate change scenario assumed for 2050 (Gerstengarbe et al. 2003) are shown in an exemplary manner. It is based on 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 a representative example. Coherently modelled and interpreted for this study region are first, elements of the water balance, second, nutrient loads and percolation water concentrations for nitrate and sulphate, and third yields of agricultural crops. Climate change impacts on agriculture could be reduced using adapted and/or new land use systems and management practices.

2 Study region

As part of the Brandenburgian district "Maerkisch-Oderland" the study region is located within the moraine landscape of North-East Germany. The area extends about 60x40 km and is situated approximately 50 km east of Berlin, i.e. between Berlin and the river Oder. The north-west and the south-west of the study region 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 region 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 region is a semi-continental climate with a significantly decreased precipitation gradient from west to east. In the study region, the major part of the land is used for agriculture (about 54,000 ha) across 54 farms from 50 to 7,200 ha with 1,085 ha on average. Winter cereals are grown on 45 % of the arable land of the study region, followed by silage maize and rape with about 9 % each, alfalfa with 3 % and sugar beet with 2 %. Land in the study region that is not used for agriculture represents predominantly forestry and 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 nitrate 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 (1989 and 1995), Willms et al. (2006) and Eulenstein (2008) were applied. The nitrogen and sulphur 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.

4 Scenario definition

For the study region simulation runs for two scenarios are characterising different climatic levels (Initial Situation 2000 and Scenario 2050) were defined. Within each scenario the simulation runs over a 9 year time period (Initial Situation 2000: 1993-2001; Scenario 2050: 2046-2054) representing the basis for the comparison with respect to climate impacts on the study region.

The weather data (temperature, precipitation, sunshine duration/radiation) for the Initial Situation 2000 were taken from the meteorological station Muencheberg as daily real weather data. For the Scenario 2050 daily weather data for Muencheberg were taken from the climate scenario defined by the Potsdam Institute of Climate Impact Research (Gerstengarbe et al., 2003) using a special statistical method. This climate scenario underlying Scenario 2050 is based on the ECHAM4-OPYC3 climate model of the Max Planck Institute for Meteorology Hamburg (Germany) 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.

Tab. 1: Scenario definition by meteorological data and elements of climatic water balance.

	Initial Situation 2000 1993-2001	Scenario 2050 2046-2054
Annual mean temperature (°C) (Station Müncheberg)	8.1	9.5* (increase of 1,4K)
Mean precipitation (mm a^{-1}) (Station Müncheberg)	569	457* (decrease of 112)
Sunshine duration (h a^{-1})	1698	1842
Act. evapotranspiration (mm a^{-1})	417**	437**
Perculation water (mm a^{-1})	143**	12**
Change of storage (mm a^{-1})	9**	8**

* based on stochastic simulation per day (Fig. 1), from Gerstengarbe et al. (2003)
** simulated with HERMES (Kersebaum, 1989, 1995)

The crop rotations, mean values for the nutrient balances (Calculation method is described in: Eulenstein et al. 2014) and the yields for the Initial Situation 2000 were determined by means of yearly field-specific samplings from each farm within the study region. The average amount of mineral and organic nitrogen fertilizers was 102 kg N ha^{-1} a^{-1} and 38 kg N ha^{-1} a^{-1}, respectively, and the amount of mineral and organic sulphate fertilizers was 12 kg S ha^{-1} a^{-1} and 5 kg S ha^{-1} a^{-1}, respectively. For Scenario 2050 crop rotations and fertilizer inputs were taken unchanged from the initial situation.

At 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 sensitivity analysis, for Scenario 2050 the following basic conditions were also kept constant (as in Initial situation 2000):
- soils with soil characteristics
- spectrum and percental distribution of agricultural grown crops including the according agro-management
- level of plant breeding

5 Simulation results

5.1 Initial Situation 2000

From the measured climate data (Tab. 1, Fig.1) a potential evapotranspiration of 510 mm a^{-1} is calculated for the Initial Situation 2000. With 417 mm a^{-1}, the real evapotranspiration remains nearly 100 mm below that value. In the Initial Situation 2000, the modelled mean water storage up to a depth of 2 m amounts to 404 mm in autumn.

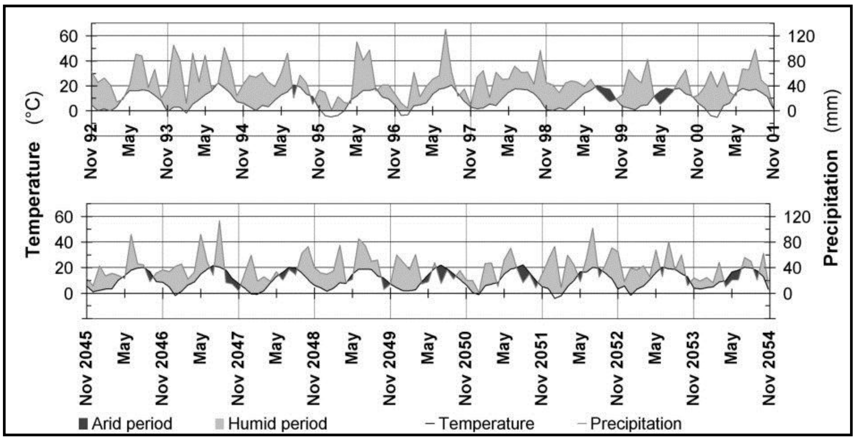

Fig. 1: Time series of precipitation and temperature for station Müncheberg.
Top: Initial Situation 2000 Bottom: Scenario 2050 (Gerstengarbe et al., 2003)

The infiltration rate (deeper than 2 m displaced soil water) averages at 143 mm a^{-1}. It correlates with the variances of the annual precipitation to a large extent. Values as low as 60-120 mm a^{-1} occur predominantly in the area of the clayey soils of the “Oderbruch” section with a high soil moisture capacity.

The nitrogen surplus of the period of examination averages at 55 kg ha^{-1} across all areas, the sulphur surplus at 15 kg ha^{-1} (Tab. 2). The annual nitrogen discharges of the Initial Situation 2000 differ between 25 and 100 kg ha^{-1} around the average of 60 kg ha^{-1}.

The difference between assessed N balance and modelled N discharge in a soil depth of 2 m indicates a reduction of the N storage in the soil layer up to a depth of 2 m of at least 5 kg ha^{-1}. Minor gaseous N losses in addition may increase this reduction.

The modelled nitrate concentration in the percolation water varies between 150 and 300 mg l^{-1}, with an average of 232 mg l^{-1}. There are comparable relations between load and concentration with sulphur and sulphate, respectively.

The yield level of the Initial Situation 2000 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 Scenario 2050

Although precipitation is 20% lower, an increase of the current evapotranspiration by 20 mm to 437 mm a^{-1} is calculated for Scenario 2050 (Tab. 1). This results from warmer winter periods, whereas increased temperature of the summer periods 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 than in the Initial Situation 2000. The average percolation rate goes down to 12 mm a^{-1}.

Tab. 2: Budgets and percolation water dynamics of N and S.

	Initial Situation 2000		Scenario 2050	
	N (kg $ha^{-1}a^{-1}$)	S (kg/$ha^{-1}a^{-1}$)	N** (kg $ha^{-1}a^{-1}$)	S** (kg $ha^{-1}a^{-1}$)
Atmospheric deposition	8*	6*	8**	6**
Input mineral fertilizer	102*	12*	102**	12**
Input farm yard manure	38*	5*	38**	5**
N_2 fixation by legume	9*	-	9**	-
Losses of farm yard manure by storage and application	-12*	-	-12**	-
Output harvesting products	-90*	-7*	-90**	-7**
Surplus	55*	15*	55**	15**
Load in percolation water	60***	24***	40***	8***
Concentration in percolation water	Nitrate (mg NO_3 l^{-1})	Sulphate (mg SO_4 l^{-1})	Nitrate (mg NO_3 l^{-1})	Sulphate (mg SO_4 l^{-1})
	232***	49***	751***	132***

* surveyed from aggregated plot budget of 54 farms with total 53573 ha
** under assumption of similar management as in Initial Situation 2000
*** simulated with HERMES / SULFONIE (Kersebaum, 1989 u. 1995, Willms et al., 2006)

At the clayey sites of the “Oderbruch” section, a decrease in percolation water of 100-140 mm a^{-1} predominates, which reveals in the failure of significant infiltration rates in 8 of the 9 simulated years. At the sandy sites, there is an even stronger decrease. However, due to the high infiltration rates in the Initial Situation 2000, this only locally induces the absence of any infiltration.

For Scenario 2050, an average nitrogen discharge of 40 kg ha^{-1} is predicted if the nitrogen surplus remains unchanged at 55 kg ha^{-1} (Tab. 2). The resulting increase of the nitrogen storage in a depth up to 2 m is due to a strong deceleration of the downward movement of the nitrate, as infiltration rates decrease until 2050. This process, which also applies to the sulphur dynamics, still continues in the Scenario 2050 time span.

As a result of decreased infiltration rates the modelled nitrate concentrations in the percolation water increase to a mean value of 751 mg l^{-1} (Tab. 2) with a maximum of 900 mg l^{-1}. The amounts of discharge of sulphur and percolation water concentration of sulphate respond correspondingly.

5.3 Differences Scenario 2050 to Initial Situation 2000

The conducted sensitivity analysis reveals dramatic changes of the water balance as well as the concentration of the examined nutrients N and S in the percolation water if the current land use practice is maintained until 2050 while yields decrease only slightly or hardly at all if the CO_2 fertilizing effect is taken into account.

Increase of the real evapotranspiration by 20 mm a^{-1} only results from the warmer winter periods, due to insufficient soil water supply during summer. Decreased precipitation and increased real evapotranspiration reduce ground-water recharge under agricultural land to 12 mm a^{-1} on average. Due to variability of site and weather conditions, years without any local groundwater recharge may occur.

The N load of the percolation water declines from 60 to 40 kg ha^{-1} a^{-1}, the S load from 24 to 8 kg ha^{-1} a^{-1}. These lower values, which may be considered landscape-ecologically favorable, result (if input remains constant as defined, cf. Tab. 2) in N enrichment in the upper 2 m of the soil still progressing during Scenario 2050. Despite the decrease of the loads, the concentration of nitrate in the percolation water more than triples on average (from 232 to 751 mg NO_3 l^{-1}) as a result of even more dramatically decreasing infiltration rates. The sulphate concentrations respond correspondingly.

Whether, when, and how strongly these small amounts of highly eutrophic percolation water impact the ground water and neighboring ecosystems, depends particularly on the occurrence of high-rainfall weather extremes, a general unpredictability in this study.

6 Adaptation measures by agriculture

In conclusion of these simulation results for the study region different adaptation measures in response to the changing climate conditions for an economically secured and sustainable agriculture are proposed:

- 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 resistant crops and varieties into adapted crop rotation
- scheduling of nitrogen fertilization in dependence of plant ontogenesis and water availability
- application of conservation soil tillage and direct sowing methods
- all-the-year coverage of arable land for reducing evaporation and surface runoff
- effective usage of irrigation especially for potatoes, vegetables and special crops
- establishment of agro-forestry or hedge systems to reduce erosion and evaporation especially in affected areas

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