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The Environmental Effects of Global Changes on Northeast Central Europe in the Case of Non-Modified Agricultural Management

Wiggering, H.[1, 2]*, Eulenstein, F.[1], Mirschel, W.[1], Willms, M.[1], Dalchow, C.[1] & J. Augustin[1, 3]

[1] Leibniz-Centre for Agricultural Landscape Research, Eberswalder Straße 84, D-15374 Müncheberg, Germany
wiggering@zalf.de, feulenstein@zalf.de, wmirschel@zalf.de, mwillms@zalf.de, cdalchow@zalf.de, jaug@zalf.de

[2] University of Potsdam, Institute of Geoecology, P.O. Box 601553, D-14415 Potsdam, Germany

[3] Martin Luther University Halle-Wittenberg, Institute for Agricultural and Nutritional Science, Adam-Kuckhoff-Strasse 17b, D-06108 Halle (Saale), Germany

* Corresponding author

Abstract

Climate impact scenarios for agriculture usually consider yield development, landscape water balance, nutrient dynamics or the endangerment of habitats separately. Scenario results are further limited by roughly discriminated land use types at low spatial resolution or they are restricted to single sites and isolated crops. Here, we exemplify a well data based comprehensive sensitivity analysis of a drought endangered agrarian region in Northeast Germany using a 2050 climate scenario. Coherently modelled results on water balance and yields indicate that agricultural production may persist, whereas wetlands and groundwater production will be negatively affected. The average percolation rate decreases from 143 mm a^{-1} to 12 mm a^{-1}, and the average yield decline broken down by crops ranges from 4% for summer wheat to 14% for potatoes (main cereals: 5%).

Keywords

Climate Scenario, Land Use, Water Balance, Crop Production

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1 Introduction

Research into climate impact on regions dominated by agriculture usually deals separately with yield development, landscape water balance, nutrient dynamics or endangerment of habitats. For european agricultural production the entire range, spanning 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 Northeast Germany with a high temporal resolution, their statement for 2050 is restricted to one crop at two sites with characteristic soil substrates. In fact, there are virtually no comprehensive ecosystemic simulations based on extensive, real site and land use data from an entire landscape section, collected over a period of several years.

Figure 1. Research area (approx. 50 km east of Berlin). For a detailed presentation of the investigated plots see Figure 2.

Against this backdrop, we show an ecosystematic sensitivity analysis of the reaction of a well-documented predominantly agrarian area under a climate scenario assumed for 2050 (Gerstengarbe et al. 2003) in an exemplary manner, based on an investigation for the government of the Federal State of Brandenburg (Wiggering et al. 2005). It is based on an unmodified continuation of current land use practice, taking extensive field-specific data of an agrarian landscape in the partially drought endangered climate of Northeast Germany to the east of Berlin as a representative example. Elements of the water balance and yields of agricultural crops are coherently modelled and interpreted for this research area.

2 Research Area

The research area, which spans approx. 60 x 40 km, is situated roughly 50 km to the east of Berlin (Figure 1). Most of the land is used for agriculture (54 farms totalling approx. 54,000 ha, dominated by cash cropping). The measured and calculated data are restricted to the agricultural plots (Figures 1 and 2). The largest proportion of the area (45%) is used for winter cereal, followed by silage maize and rape (9%). Forage plants amount to as little as 9% and grassland to 3% (Table 3). Land within the research area that is not used for agriculture but predominantly for forestry has not been taken into consideration. The north-western part of the research area forms part of the sandy-loamy moraine plateaus of Barnim and Lebus with Haplic Albeluvisols/Dystric Arenosols, which are approx. 60 m

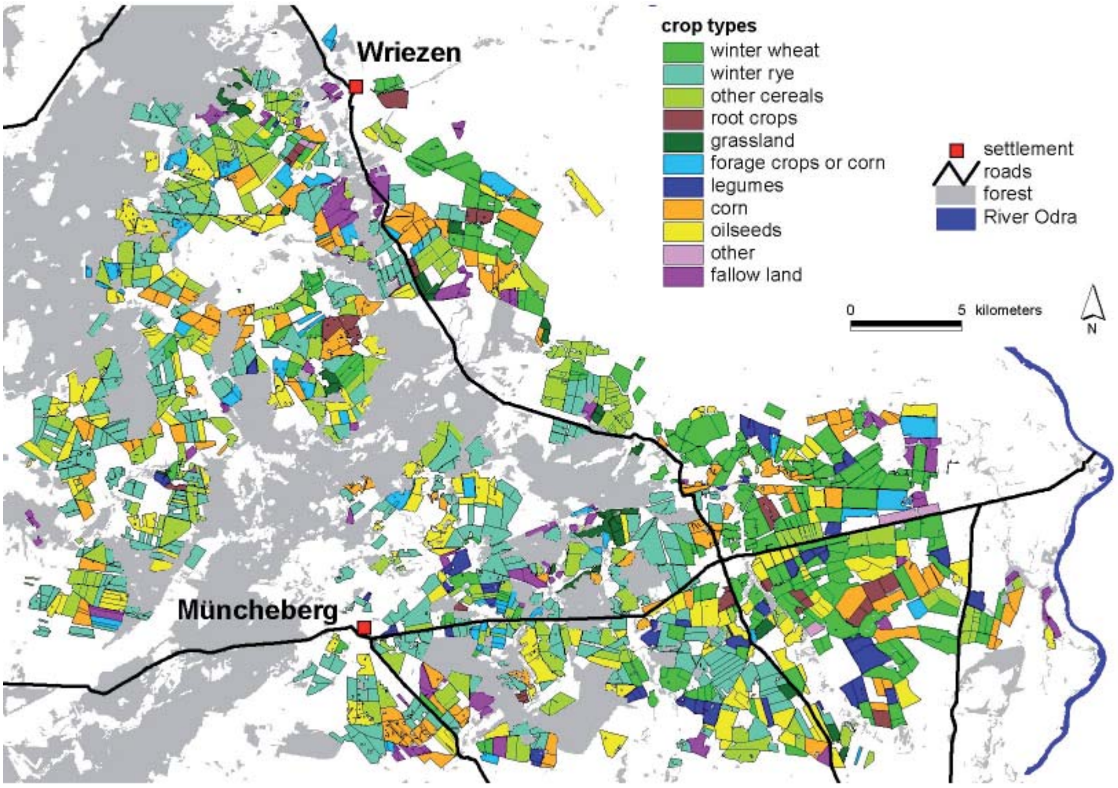

Figure 2. Investigated plots within the research area showing the distribution of crops for the Initial Situation 2000.

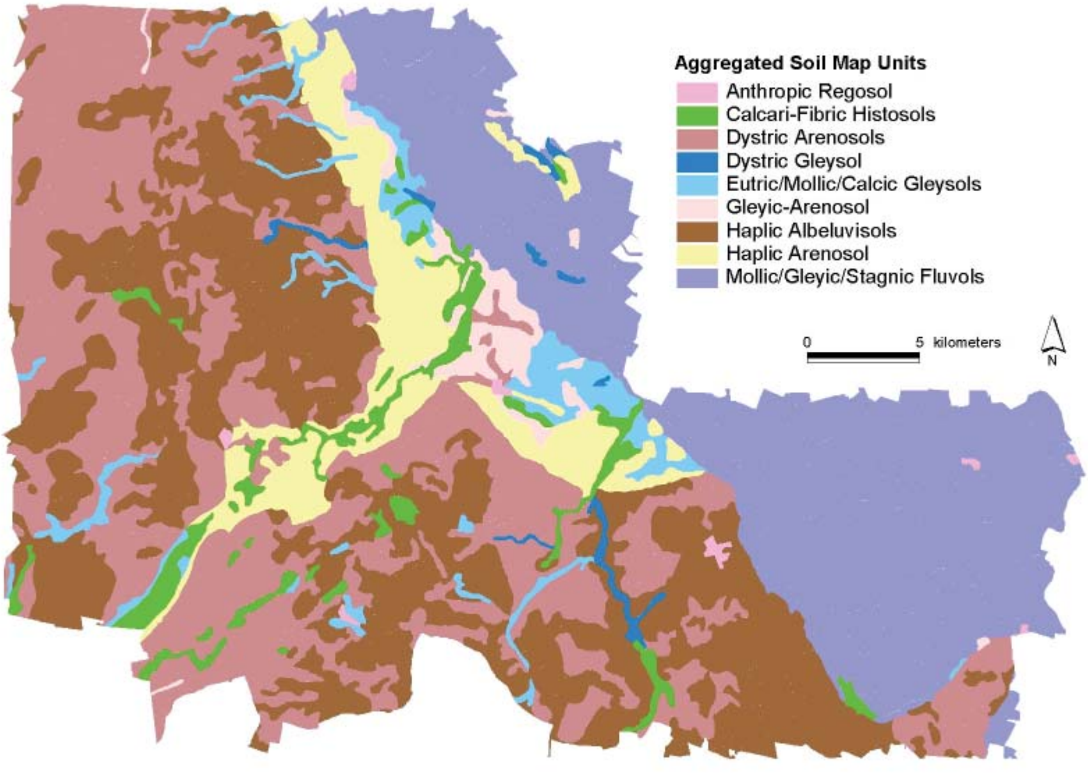

Figure 3. Aggregated soil map of the research area based on FAO-classification, derived from digital German Soil Survey Map of Germany 1:300.000 (BÜK 300).

MSL. The south-eastern part is located in the alluvial plain of the Oderbruch region with clayey Fluvols at 5-12 m MSL (Figures 1 and 3).

3 Model and simulation platforms

3.1 The HERMES and SULFONIE models

The amounts of real evaporation and seepage water at a ground depth of below 2m was simulated using the HERMES model (Kersebaum 1995) on the basis of land use, soil and weather data. The HERMES simulation model is an advancement of the models of nitrogen dynamic in farmland by Kersebaum (1989). It takes into account processes of nitrogen mineralisation, heterotrophic denitrification, transport of nitrate into the ground water, atmospheric nitrogen deposition as well as nitrogen uptake by plants. The model works with a temporal termination of one day and a 10 cm depth clipping of the soil. It is restricted to the range of the root zone (max. 200 cm). Capillary rise from layers beneath 200 cm are taken into account. A sketch of the model is presented in Figure 4. On the basis of this model approach, Kersebaum created the SULFONIE model using individual sub-modules from HERMES to illustrate the essential processes of water and substance dynamics in the root zone (Willms et al. 2006). An easy capacity approach was chosen to describe the water balance. Unlike the so-called “mechanistic” water models, which are based on the potential concept, a “functional” approach with associated shorter computing time has the advantage that it is consi-

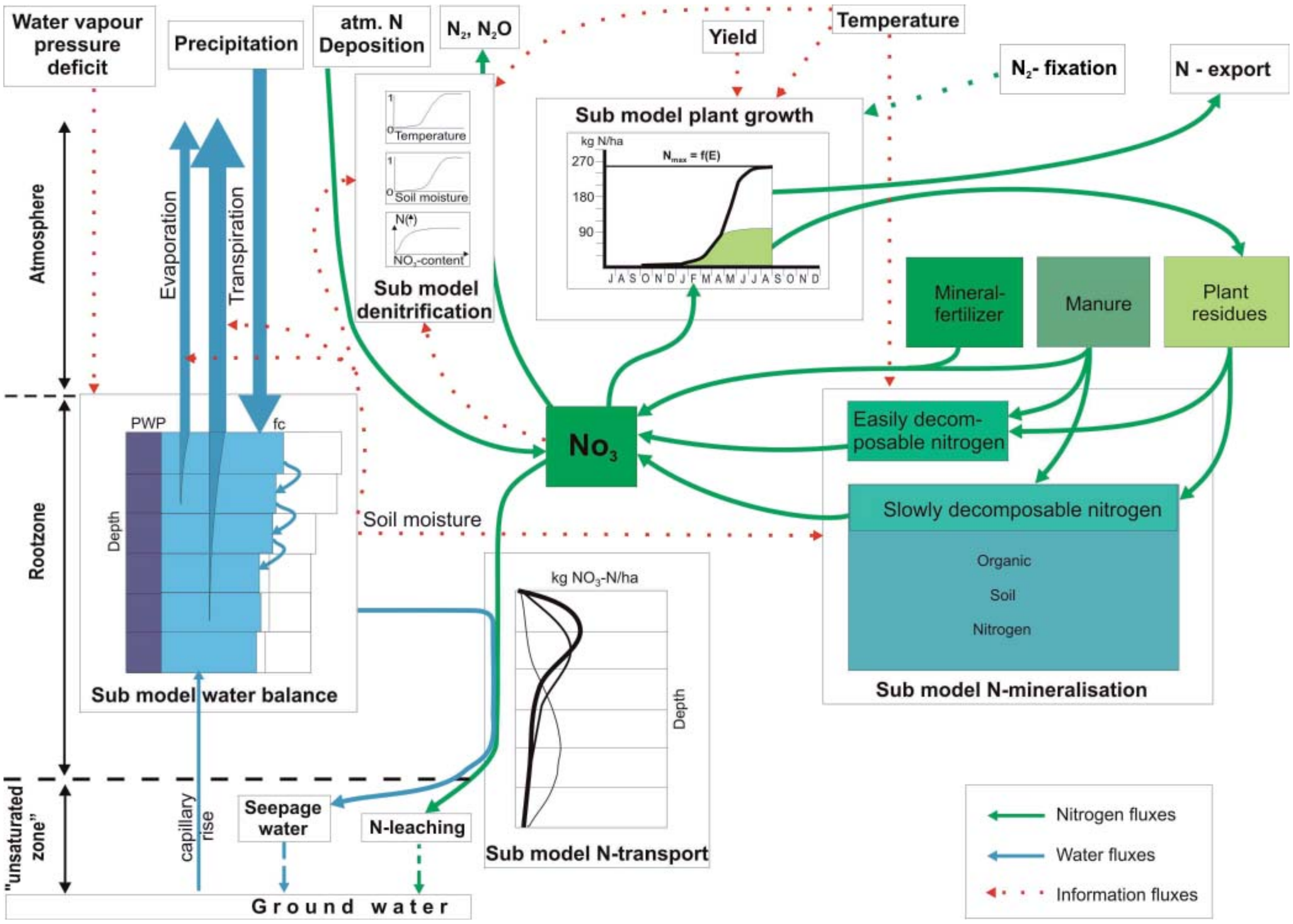

Figure 4. Sketch of the HERMES and SULFONIE models.

derably easier to derive the parameters (Addiscott and Wagenet 1985). The accepted flexibility of the physically based ("mechanistic") model approach goes along with a higher sensitivity towards the necessary hydrolytic functions as well as the lower general conditions. As a result of existing inaccuracy on large-scale soil data, the greater accuracy of such a model approach makes it much better than the capacity approach. The capacity parameters needed in the model approach (water content at field capacity and permanent wilting point) are derived according to the pedologic mapping manual (AG Boden 1994) from the texture class of the soil, taking into consideration the ground water gap, mold concentration and stone concentration. Potential evaporation (ETp) is calculated following Haude (1955) using culture-specific monthly factors (FkF and FkU), following Heger (1978) and the German meteorological service (Friesland et al. 1998) using the water vapour pressure saturation deficit at 14:30 (SD14) in mm Hg. Central European Time (MEZ) is used for the data; Central European Summer Time (MESZ) is not taken into account.

For the time when the fields are not cultivated, monthly factors for nongrown ground (FkU) are automatically used. Since crop-specific factors do not exist for all crops in the research area, these factors must be estimated from similar plant types for some crops. This is a matter of initial assumption, which requires greater specification and validation. Potential evaporation is reduced, depending on ground water content, to real evaporation (rET), whereas different soil layers are involved, depending on the root penetration depth. The term "real evaporation" used in this work is a synonym for the term "current evapotranspiration", which is also used in the literature.

3.2 Crop yield model YIELDSTAT

Crop type-dependent natural yields were estimated using a three-stage statistical algorithm with an additive combination of a site type-dependent crop yield matrix, a correction algorithm using site characteristics and a yield trend overlay. First of all, a statistic approach to estimate basic natural yields was developed by Kindler (Kindler, 1992). This approach was based on thousands of yield observations of representative fields, distributed over arable and grasslands from over 300 large agricultural enterprises within different climatic regions of East Germany up to the beginning of

Table 1. Crop yield (CY, t ha^{-1}) for winter wheat (WW) and triticale (TR), depending on MMK site types (ST) (according to Kindler 1992, modified and expanded by Mirschel et al. 2006a).

Diluvial soils			Alluvial soils			Loess soils			Disintegrated soils		
ST	CY_{WW}	CY_{TR}	ST	CY_{WW}	CY_{TR}	ST	CY_{WW}	CY_{TR}	ST	CY_{WW}	NY_{TR}
D1a	3.5	3.7	Al1a	6.1	5.6	Lö1a	7.6	7.1	V1a	7.0	6.5
D2a	3.7	4.2	Al1b	5.8	5.3	Lö1b	7.2	6.7	V2a	6.5	6.0
D2b	4.0	4.6	Al1c	5.5	5.0	Lö1c	6.8	6.3	V2c	6.1	5.7
D3a	4.4	4.6	Al2b	5.6	5.1	Lö2c	6.6	6.1	V3a	6.1	5.7
D3b	4.7	4.7	Al2c	5.2	4.8	Lö2d	6.4	5.9	V3b	6.0	5.5
D3c	4.5	4.4	Al3a	6.2	5.7	Lö3a	7.6	7.1	V3c	5.0	4.6
D4a	5.4	5.2	Al3b	5.9	5.4	Lö3c	6.8	6.3	V4a	5.6	5.2
D4b	5.7	5.5	Al3c	5.7	5.3	Lö4b	6.8	6.3	V4b	5.0	4.8
D4c	5.7	5.4				Lö4c	6.3	5.8	V5a	5.9	5.4
D5a	6.0	5.4				Lö5b	6.7	6.2	V5b	5.8	5.5
D5b	6.5	5.7				Lö5c	6.5	6.0	V5c	5.0	5.4
D5c	6.5	5.6				Lö6b	6.4	5.9	V6b	5.5	5.3
D6a	6.2	5.8				Lö6c	6.0	5.5	V7a	5.4	4.9
D6b	6.7	6.2							V7b	5.5	5.1
D6c	6.7	6.2							V7c	4.8	4.7
									V8a	5.5	5.5
									V9a	4.4	4.9

the 1990s for comparable climatic conditions. Kindler's approach was then modified and enhanced by Mirschel et al. 2006a. The basic crop yield matrix developed in this modified approach combines different arable crops (winter wheat, winter barley, winter rye, triticale, spring barley, oats, potatoes, sugar beet, winter rape, maize for silage, clover, clover-grass-mix, lucerne, lucerne-grass-mix, field grass) and two grassland types (intensive grassland, extensive grassland) with 56 different types of agricultural sites. The crop yield matrix for winter wheat and triticale is given in Table 1. The agricultural site types are based on the Medium-Scale Site Map (MMK) for arable land (Schmidt and Diemann 1991), which exists for the whole eastern territory of Germany.

Next, the basic crop yield was corrected, giving extra charges to positive or negative yield, depending on different site-specific characteristics, such as stoniness, slope steepness, altitude, hydromorphy, soil quality index[1], crop growth-relevant temperature according to Adler (1987), mesoscalic climatic zones (ClZo) according to Adler (1987), climatic water balance (CWB, precipitation minus evapotranspiration) using modified extra charge functions according to Kindler (1992). These functions were modified, depending on the availability of site-specific data. In place of the long-term average values for CWB, the CWB values for the real cropping years taken into account were used here. The CWB values were calculated separately for each crop type, taking the crop-typical vegetation period into consideration, i.e. for winter wheat, for instance, the calculation time was from September of the sowing year to August of the year of harvest. The potential evapotranspiration necessary to calculate the CWB values was computed using the approach following Wendling et al. (1991), which only requires daily values for global radiation and temperature. All MMK site types marked with V1 … V9 are site types with disintegrated soils. The MMK hydromorphy categories taken in to account, are characterised as follows: site types influenced by ground water (G1- moderate, G2 - intensive, G3 - extreme); site types influenced by waterlogging (S1 - moderate, S2 - intensive, S3 - extreme); site types mainly affected by waterlogging with groundwater and site types mainly affected by groundwater with waterlogging. The corresponding calculation algorithms for winter wheat and triticale are given by Mirschel et al. (2003).

Since the statistical approach is based on observation data from the 1980s and 1990s, only the genetic and plant breeding level and the agro-management level of this time period are taken into account. In the past decade, however, there have been significant developments in the area of breeding new varieties of agricultural crops that are more productive. Furthermore, there have also been rapid developments in agro-management, especially regarding fertilization and plant protection. All these elements focus on higher crop yields. In order to take all of these aspects into account, a yield trend approach was combined with the yield estimation procedure. In order to execute the spatially differentiated estimation of agricultural crop yields, the YIELDSTAT model was implemented into a methodological frame and software package called SAMT (Spatial Analysis and Modelling Tool), designed by the Leibniz Centre for Agricultural Landscape Research (ZALF). A detailed description of the latest version 2.0 of the open source software package SAMT is given by Wieland et al. (2006). Different model applications with SAMT are described in Mirschel et al. (2006b). The implementation scheme of the crop yield estimation algorithm into SAMT is given in Figure 5. The model's regionalisation is realised on the basis of gridded information. The whole study area is subdivided into 100 m grids. All model input information exists as grid maps and is managed by SAMT.

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[1] The soil quality index, which ranges from 1 to 100, is assumed to be based on the parent material of the soil, its pedogenetic development stage and the hydrological boundary conditions. The lowest values are attributed to the poor diluvial sandy soils and the highest values to the chernozoms from loess. The soil quality index was developed in the 1930s for the land evaluation of agriculturally used land in Germany.

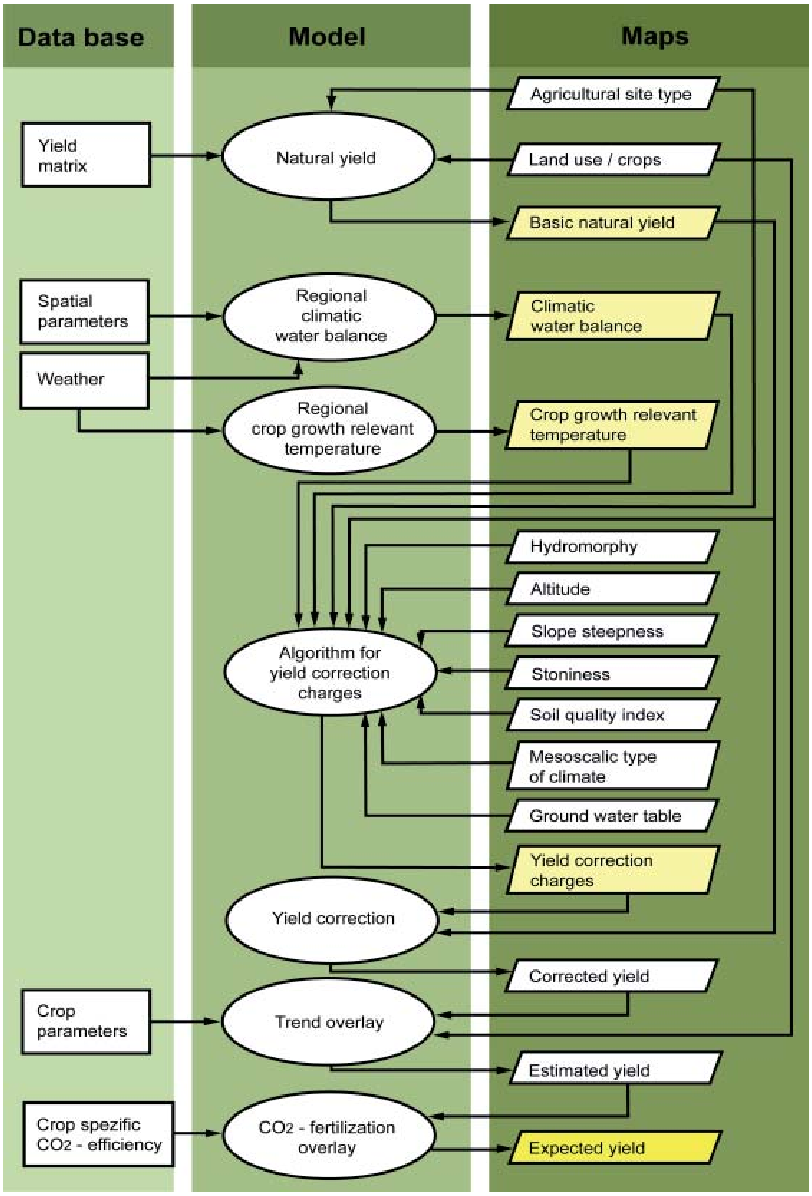


Figure 5. Implementation scheme of the crop yield estimation algorithm YIELDSTAT into the Spatial Analysis and Modelling Tool (SAMT).

4 Definition of Scenarios

The following examination periods, each spanning 9 years, are compared (Table 2, Figure 6):

1) The Initial Situation 2000, described by the use of the meteorological standard parameters of Müncheberg station as well as complete 9-year nutrient balances (crops, yields and fertilization) of individual sites.
2) Scenario 2050, defined by temperature courses, radiation and precipitation of the Potsdam Institute for Climate Impact Research (Gerstengarbe et al., 2003) from data resulting from the model run ECHAM4-OPYC3 of the Max Planck Institute for Meteorology Hamburg on the basis of the moderate emission

Table 2. Scenario definition by meteorological data and elements of climatic water balance.

	Initial Situation 2000 1993-2001	Scenario 2050 2046-2054
Annual mean temperature (°C) (Müncheberg Station)	8.1	9.5* (increase of 1.4K)
Mean precipitation (mm a^{-1}) (Müncheberg Station)	569	457* (decrease of 112)
Duration of sunshine (h a^{1})	1698	1842
Real evapotranspiration (mm a^{-1})	417**	437**
Percolation water (mm a^{-1})	143**	12**
Change of storage (mm a^{1})	9**	8**

* based on stochastic simulations per day (Figure 6) from Gerstengarbe et al. (2003)
** simulated using HERMES (Kersebaum, 1989, 1995)

scenario A1B-CO2 (IPCC 2001) and regionalised for the Federal State of Brandenburg (annual mean temperature plus 1.4 K, annual precipitation minus 112 mm a^{-1}).

In Scenario 2050, the following basic conditions were kept constant (as in the Initial Situation 2000) for the purpose of the sensitivity analysis:

- soils, cropping percentages, crop spectrum and management of crop production
- state of crop breeding
- atmospheric concentration of CO_2 and temperature-dependent respiration of plants.

Breeding progress and increasing concentration of CO_2 are also considered in separate concluding yield modelling.

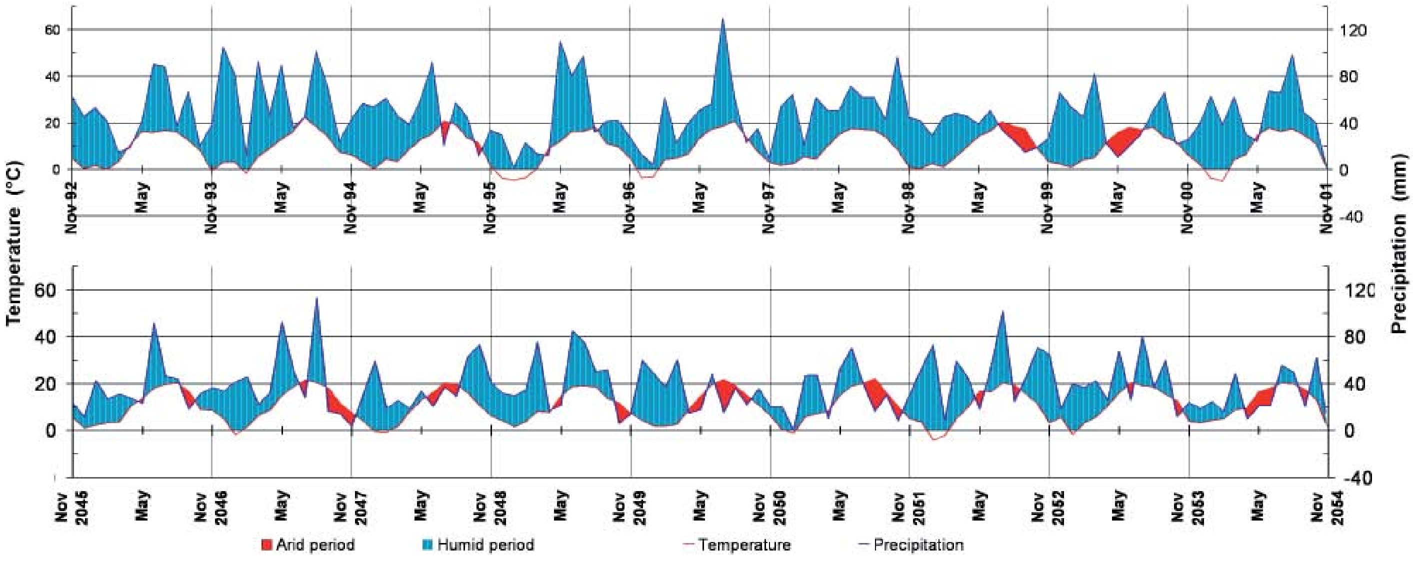


Figure 6. Time series of precipitation and temperature for Müncheberg station. Top: Initial Situation 2000, Bottom: Scenario 2050 (Gerstengarbe et al., 2003)

5 Methods

5.1 Determination of the Initial Situation 2000

The components of the climatic water balance were determined using the simulation models HERMES and SULFONIE (Section 3.1) on the basis of field-specific land use and soil data, and weather data from Müncheberg station. The mean value of the nutrient balance and yields of the Initial Situation 2000 are determined by means of yearly field-specific samplings of the research area, weighted by area (Eulenstein et al. 2003).

5.2 Determination of Scenario 2050

The components of the climatic water balance were determined by means of model runs analogous to the Initial Situation 2000, only with changed climate parameters for Scenario 2050. The spatially differentiated estimation of yield changes was undertaken using the Spatial Analysis and Modelling Tool (SAMT), as described in Section 3.2. The concluding estimation of the effect of CO_2 on yields is based on results measured under field conditions (FACE experiment of the FAL Braunschweig (Weigel et al. 2005) for winter barley, sugar beet, winter wheat and ray grass), which show a 10.7% yield increase at 550 ppmv CO_2. A linear conversion was carried out, which revealed 465 ppmv to be expected by 2050.

6 Results

6.1 Initial Situation 2000

From the measured climate data (Table 2, Figure 6) a potential evapotranspiration of 510 mm a^{-1} is calculated for the Initial Situation 2000. At 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. The percolation rate (displaced soil water below 2 m) averages at 143 mm a^{-1} (Figure 7). This value correlates largely to the variances of annual precipitation. Values as low as 60-120 mm a^{-1} predominantly occur in the area of clayey soils in the Oderbruch region, with a high soil moisture capacity (Figure 8). The higher percolation rate in 1999 despite lower precipitation is caused by the fact that, at a soil depth of 2 m, seepage water from the previous year is initially percolated. Since precipitation rates are relatively low for this year, the soil moisture is exhausted more rapidly, which explains the low content of soil

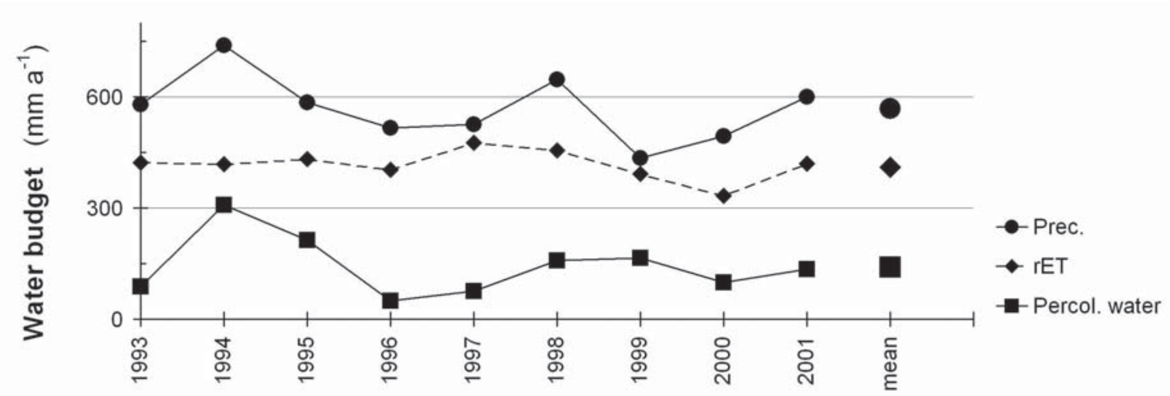
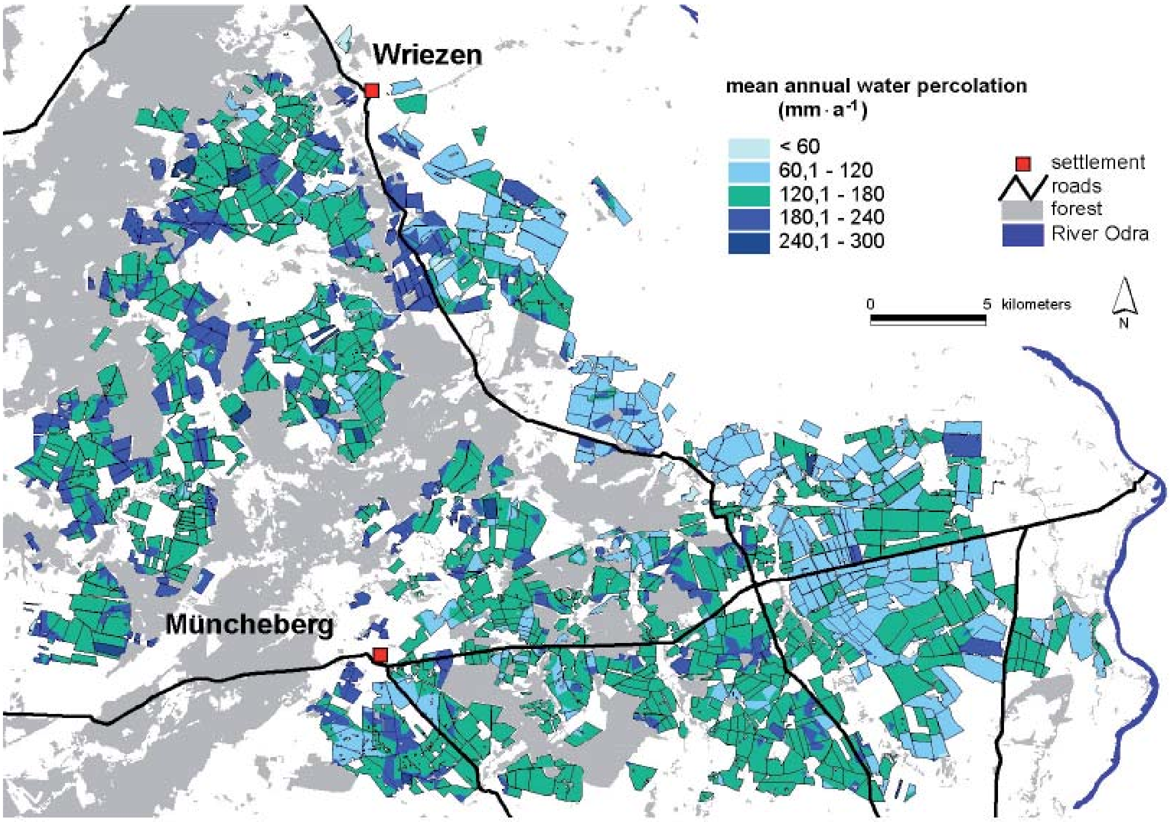


Figure 7. Time series of simulated water budget of Initial Situation 2000.
(Prec. = precipitation, rET = real evapotranspiration).



Figue 8. Mean annual water percolation of the Initial Situation 2000.

water towards the end of the hydrological year 1999. The yield level of the Initial Situation 2000 is characterised by average crop yields of 5 t for winter cereal, 23 t for silage maize and 2.5 t for rape.

6.2 Scenario 2050

Although precipitation is 20% lower, an increase in real evapotranspiration by 20 mm to 437 mm a^{-1} is calculated for Scenario 2050 (Table 2). This value results from warmer winter periods, whereas increased temperature in the summer periods does not induce any additional evapotranspiration. In general, real evapotranspiration relates to precipitation rates. At the rate of 313 mm, the average water storage up to a depth of 2 m calculated for autumn is 91 mm lower in Scenario 2050 than in the Initial Situation 2000. The average percolation rate declines to 12 mm a^{-1} (Figure 9). At the clayey sites of the Oderbruch region, a decrease in percolation water of 100-140 mm a^{-1} predominates (Figures 10 and 11), which reveals the failure of significant percolation rates in 8 of the 9 simulated years. There is an even stronger decrease at the sandy sites. However, due to the high percolation rates in the Initial Situation 2000, this only induces the absence of any local percolation. A moister weather pattern was (stochastically) assumed for the year 2052, which leads to a slight increase of the stored soil moisture towards the end of the hydrological year.

It can be derived from these computations of the climatic water balance components that, under the climate changes to be expected in the medium-term future, the stress situations experienced by crops due to the water yield could increase. Evaporation, particularly in the winter months, will probably increase, due to rising temperatures. Nonetheless, seen from the whole extent of the change to evaporation, the increase in water deficiency for agricultural crops can be classed

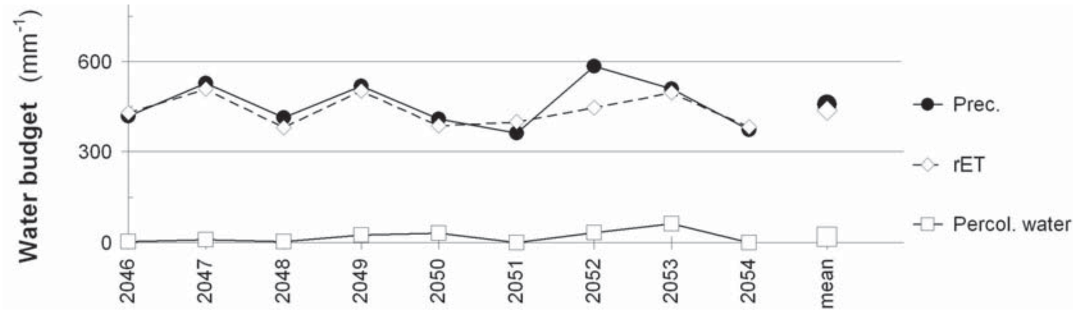


Figure 9. Time series of the simulated water budget of Scenario 2050. (Prec. = precipitation, rET = real evapotranspiration).

as relatively moderate. For this reason, negative consequences for the formation of yield under average conditions ought to remain manageable. The crucial element for the economic situation in agriculture, however, is bound to be the frequency of the occurrence of extreme weather conditions, such as in 2003, for instance (summer drought) or 2002 (flooding caused by precipitation). The accumulation of such extreme years could become the real problem for agricultural plant production. An additional computation of yields (Table 3) without back coupling to the water balance confirms the slight reduction in yield. For Scenario 2050, yields remain 7% below the Initial Situation 2000 (mainly due to increased extreme events, as assumed in the scenario). The spatial distribution of the yield decline is shown in Figure 12. The lowest losses (up

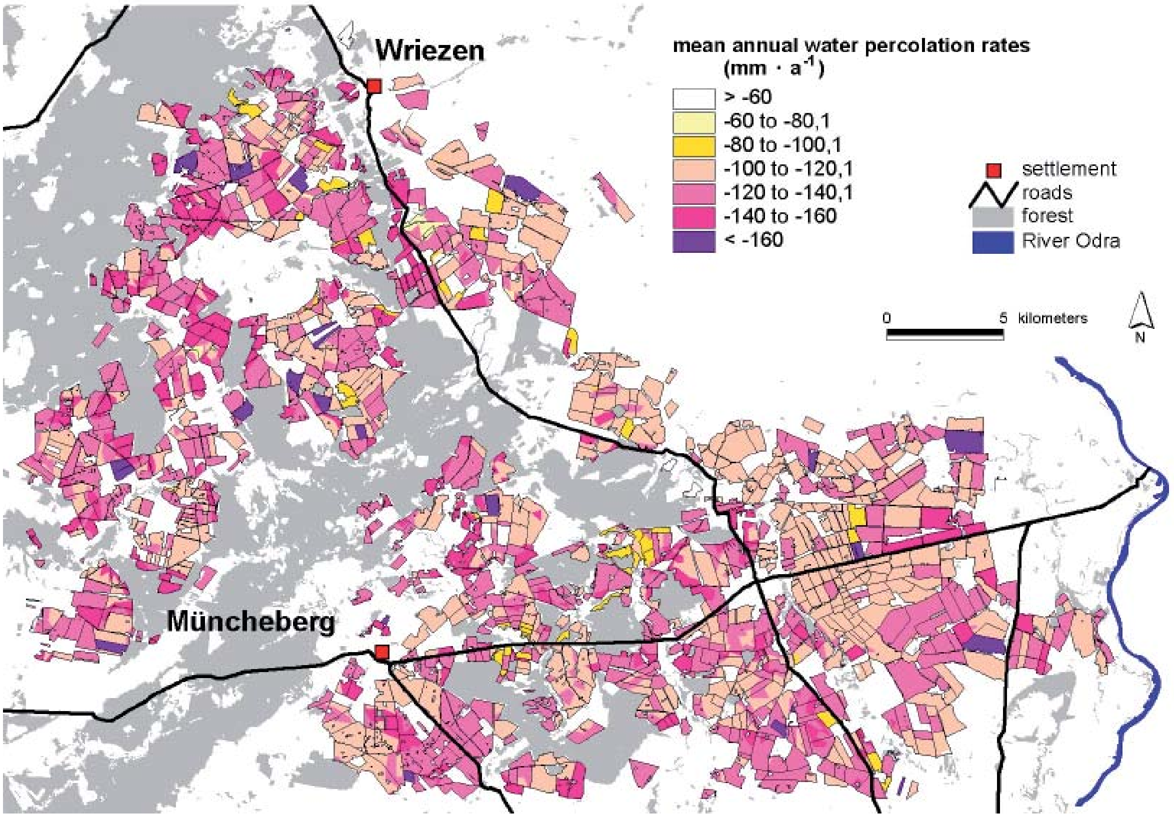


Figure 10. Difference between mean annual water percolation rates of Scenario 2050 and Initial Situation 2000.

Table 3. Cropping shares, change of average yields differentiated by effects of CO_2 on the research area.

Crop	Cropping share (%)	Mean change of yield Scenario 2050 vs. Initial Situation 2000 (%)	
		at ambient CO_2 concentration of 370 ppmv	at expected CO_2 concentration of 465 ppmv
Winter rye	17	-6	-0.3
Winter wheat	16	-5	0.5
Silo maize	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
Spring barley	2	-5	0.3
Spring rape	1	-7	-2
Spring wheat	1	-4	0.9
Clover gras	1	-13	-8
Oat	1	-5	0.2
Potatoes	1	-14	-9
Grassland and others	25		

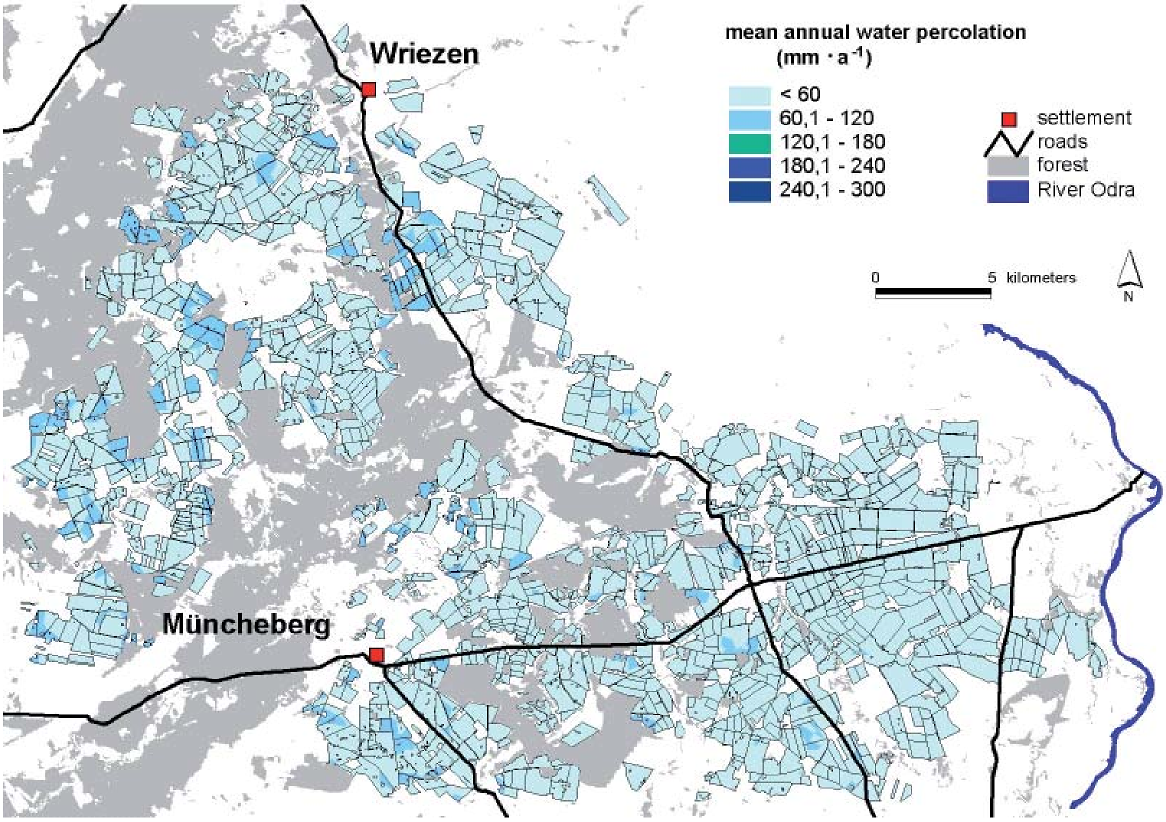


Figure 11. Mean annual water percolation of Scenario 2050.

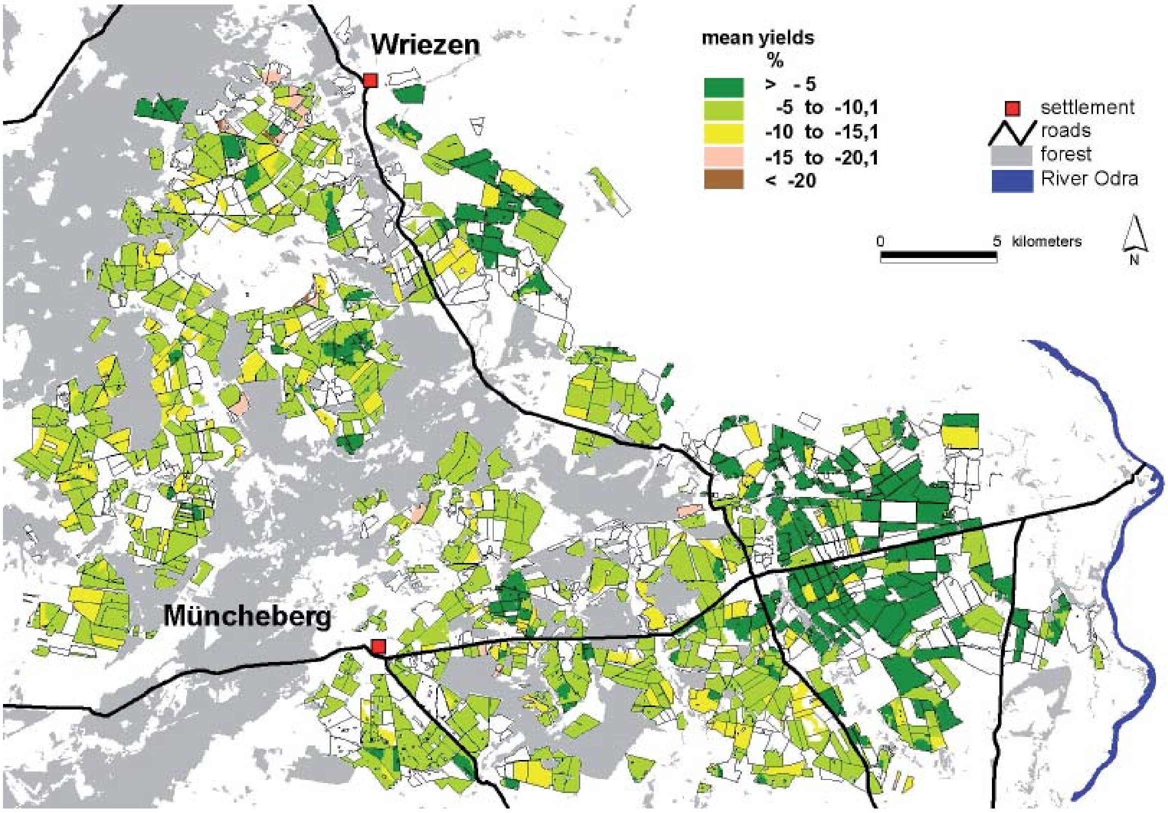


Figure 12. Difference between mean yields of Scenario 2050 and Initial Situation 2000 (excluding the effect of increased atmospheric CO_2).

to 5%) occur in the Oderbruch region, which provides higher soil water storage. The average yield decline broken down by crops ranges from 4% for summer wheat to 14% for potatoes (main cereals: 5%).

Due to the reduced water consumption resulting from plant physiology in the event of the increased concentration of CO_2, effects on the landscape water balance are to be expected (Ainsworth and Long 2005). Although Gedney et al. (2006) already interpret the increased global discharge as an indirect proof of the effect of CO_2 on the continental water balance, this still needs to be verified, according to Baldocchi and Wong (2006). Against this backdrop, it was refrained from modelling a CO_2-induced modification of the water balance. However, to refrain from omitting the CO_2 increase with respect to its more solid effect on yield (Long et al. 2006, Schimel 2006), Table 3 also lists yield changes under the assumption of a increase in CO_2 in the atmosphere to 465 ppmv in Scenario 2050.

6.3 Differences between Scenario 2050 and the Initial Situation 2000

The conducted sensitivity analysis reveals dramatic changes to the water balance (Figure 10) if current land use practices are maintained until 2050, while yields decrease only slightly, or virtually not all if the CO_2 fertilizing effect is taken into account. The increase in real evapotranspiration by 20 mm a^{-1} only results from the warmer winter periods, due to an insufficient soil water supply in summer. Decreased precipitation and increased real evapotranspiration reduce ground-water recharge in agricultural land to 12 mm a^{-1} on average. Due to the variability of site and weather conditions, years without local ground-water recharge may occur. If, when, and how strongly these small amounts of highly eutrophic percolation water impact the ground water and neighbouring ecosystems depends primarily on the occurrence of high rainfall weather extremes, a general unpredictability of this study.

7 Resilience of Current Approaches

Although modelling is based on highly detailed cropping sampling and site data for large areas as well as an acknowledged, regionally specific climate scenario, the values are potential values. The climate-induced yield decline and its compensation to a large extent through the CO_2 fertilizing effect are based on the unlikely assumption of unchanging managements, unchanging crop distribution and the absence of breeding progress on drought resistance. The potential respiration decrease of the crops in the event of an increase in CO_2 concentration is not taken into account either. Finally, a change of the frequency and amplitude of extreme meteorological conditions would restrict the accuracy of the statement considerably. Statements relevant to the entire landscape can only be deduced if the non-agrarian land (about 30% of East Brandenburg is forested) is included.

8 Conclusion

Since climate change-induced yield changes up to 2050 do not pose an existential threat to the agricultural production of a landscape characteristic of Northeast Central Europe, climate-adaptive management would only have to make up a small yield deficit to guarantee present yields. Further compensation effects, such as CO_2 fertilization (with simultaneous potential reduced respiration) and breeding progress, however, do not lead to any further site advantages, due to their supraregional character. Since, according to yield expectation, it is safe to assume that the fertilizing regime will not change considerably, it is hardly possible to reduce the surplus even further, which is low by cropping standards (good specialist practice of agricultural production).

It is not only the anthropogenic water supply that would be affected but also the ecologically valuable wetland areas fed by ground water that may disappear as a result of water deficiency and eutrophication. Whether the extensive conifer forested areas adjacent to the arable land provide compensation for ground water shortage is an issue to be answered in future research. Moreover, an increase in weather extremes higher than those assumed in Scenario 2050 would restrict the adaptability of agriculture (Eulenstein et al. 2005).

9 Outlook

If the climate changes as anticipated by the established scenarios, Northeast Central Europe will virtually maintain its present agricultural productivity, at least in the examined period up to 2050. If the results gained from real FACE experiments at the Braunschweig site are included in the calculation, the negative effects are reduced even further. The ground water recharge in agricultural land, on the other hand, will decrease dramatically, causing, among other things, the supply of neighbouring wetland habitats to decrease considerably, or even cease. In addition, low ground water recharge is associated with the problem of critically high nutrient concentrations from agricultural production, which are difficult to avoid and also have negative effects on anthropogenic water supply and neighbouring ecosystems. Extreme weather events surpassing the moderate weather variability modelled may result in the mean values mentioned being occasionally considerably exceeded with respect to water deficiency and yield reductions, which would necessitate new landscape-ecological assessments.

Since also potential agricultural adaptation strategies to changed climate conditions, such as types of crop rotation, fruit species and variety choice, reduced soil cultivation, extra-irrigation, changes to the fertilising regime as well as the use of culm stabilisators and plant protection agents, have not yet been taken into consideration, this assessment is relativised yet again. The crucial factor will be the frequency and extent of extreme weather conditions. However, it is extremely difficult to forecast this factor, which means that it continues to be associated with a high degree of uncertainty. Further uncertainties lie in the estimation of the probable plant physiological and ecological feedback effects of increased atmospheric CO_2 concentrations on the soil and plant water balance as well as the formation and conversion of substances. Great importance is therefore attached to the future continuation of FACE field experiments.

It can be derived from long-term data and findings that the expected climate changes can be counteracted by the following adjustment measures:

- safeguarding of the retention of precipitation by the soil all year round,
- increased transition to conservatory soil cultivation and direct drilling using new technologies,
- site-adjusted optimisation of the production systems from the perspective of the most effective water utilisation, preservation of the organic substance in the soil and reduction of pest infestation,
- optimisation of area of location and depth of sowing,
- ensure the optimum supply of nutrients,
- control of N fertilisation according to development of stock and water supply,
- caution in the use of growth regulators,
- culm base diseases must be combated in good time,
- increased use of irrigation and sprinkler irrigation, in particular for vegetables, potatoes and other special crops,
- establishing hedgerow and agro-forestry systems to protect against erosion and evaporation in landscapes that have been cleared.

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