Science of the Total Environment 541 (2016) 329–340

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Modelling regional variability of irrigation requirements due to climate change in Northern Germany

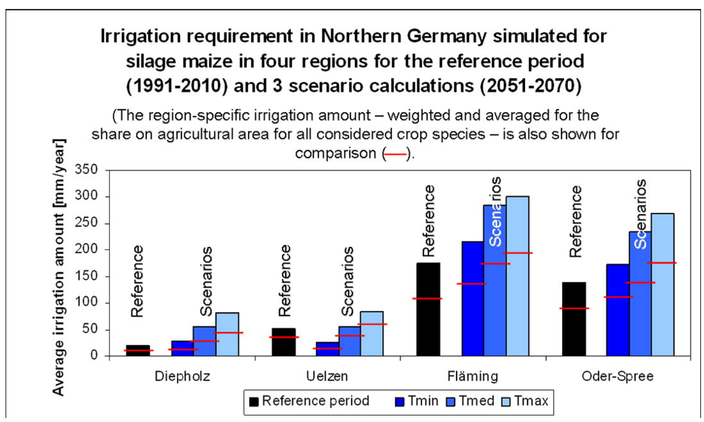
Jan Riediger [a,*], Broder Breckling [a], Nikolai Svoboda [b], Winfried Schröder [a]

[a] Landscape Ecology, University of Vechta, POB 15 53, 49377 Vechta, Germany
[b] Leibniz Centre for Agricultural Landscape Research, Eberswalder Straße 84, 15374 Müncheberg, Germany

HIGHLIGHTS

- We model crop water demand and derive changing irrigation requirements.
- Study areas are four model regions in central Europe (i.e., Northern German Plain).
- Results show a generally increasing water demand with increasing temperatures.
- Results show a heterogeneity between the model regions along an East–West gradient.
- Irrigation requirement depends on climate, soil and economic conditions.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 31 July 2015
Received in revised form 9 September 2015
Accepted 9 September 2015
Available online xxxx

Editor: D. Barcelo

Keywords:
Irrigation
Climate change
Field water capacity
Soil moisture
Water availability
North German Plain

ABSTRACT

The question whether global climate change invalidates the efficiency of established land use practice cannot be answered without systemic considerations on a region specific basis. In this context plant water availability and irrigation requirements, respectively, were investigated in Northern Germany. The regions under investigation – Diepholz, Uelzen, Fläming and Oder-Spree – represent a climatic gradient with increasing continentality from West to East. Besides regional climatic variation and climate change, soil conditions and crop management differ on the regional scale. In the model regions, temporal seasonal droughts influence crop success already today, but on different levels of intensity depending mainly on climate conditions. By linking soil water holding capacities, crop management data and calculations of evapotranspiration and precipitation from the climate change scenario RCP 8.5 irrigation requirements for maintaining crop productivity were estimated for the years 1991 to 2070. Results suggest that water requirement for crop irrigation is likely to increase with considerable regional variation. For some of the regions, irrigation requirements might increase to such an extent that the established regional agricultural practice might be hard to retain. Where water availability is limited, agricultural practice, like management and cultivated crop spectrum, has to be changed to deal with the new challenges.

* Corresponding author.
E-mail addresses: jan.riediger@uni-vechta.de (J. Riediger), bbreckling@iuw.uni-vechta.de (B. Breckling), Nikolai.Svoboda@zalf.de (N. Svoboda), wschroeder@iuw.uni-vechta.de (W. Schröder).

http://dx.doi.org/10.1016/j.scitotenv.2015.09.043
0048-9697/

1. Introduction

1.1. Background

Global climatic change models suggest and meteorological measurements confirm temperature increase including variation of precipitation patterns at the global and regional scale (IPCC, 2007, 2013; Leemans and Eickhout, 2004). Depending on the soil coverage and associated physical characteristics such as the water holding capacity of soils the necessity of land use adaptations might arise to cope with climate change (Adams et al., 1998). Increasing temperature will lead to higher evapotranspiration and could lead to soil moisture deficits followed by a growing risk of vegetation desiccation and decreasing plant development (Rind et al., 1990; Goyal, 2004). Persistent drought may even lead to complete crop failure. Soil moisture deficits can arise in times when evapotranspiration is higher than precipitation (Land Brandenburg, 2005) and soil water storage is not sufficient to maintain plant provision. Depending on the temporal and spatial extent of such climate change impacts, ecological and economic consequences for agriculture in large parts of Europe may emerge (Bindi and Olesen, 2011; Ciscar, 2012; Iglesias et al., 2012). One consequence could be an increasing irrigation requirement caused by soil moisture deficits (Adams et al., 1990; NLWKN, 2008, 2012). In Germany, an area of about 516,000 ha is equipped for irrigation to cope with shorter periods of rainfall deficits that occur from time to time (Frenken and Gillet, 2015). In 2013, about 235,000 ha was actually irrigated, and half of this area is located in the federal state of Lower Saxony in Northwest Germany (FAO, 2013).

The required amount of irrigation water depends on how much water the cultivation of a particular crop species requires and how much water is available from local sources. Climate change could exacerbate water availability and the demand for water (Döll, 2002). Adams et al. (1990) calculated a general increase in water use for crop irrigation and an according decrease in water availability for several regions in the United States. Barthel et al. (2012) modelled an increasing water demand for irrigation in the Upper Danube Catchment. An increasing irrigation requirement is also expected in the East and South of Britain (Arnell, 1998). Thus, it is a current research task to assess whether for specific regions and crops adaptation requirements will emerge under climate change (NLWKN, 2008, 2012; Weichselgartner, 2013). This is the basis for developing and consolidating decisions on adaptation strategies.

The *research questions of this investigation* are whether ongoing climate change may lead to increasing irrigation requirement in four model regions in the North German Plain and thereby, to a situation where the current crop cultivation without irrigation could be a risk to suffer from seasonal drought and whether there is a regional variability to be expected between the different regions.

1.2. Current situation in the model regions

This investigation concentrates on four model regions in the Northern German Plain: Diepholz and Uelzen in the federal state of Lower Saxony in West Germany, the region Fläming on the border of the federal states Saxony–Anhalt and Brandenburg in East Germany and the county of Oder-Spree, located in the East of Brandenburg (Fig. 1, Section 2.2).

In the county of Diepholz, the distinctive maritime climate and the frequent occurrence of moor soils (soil type *histosol*, according to the World Reference Base for Soil Resources (IUSS Working Group WRB, 2014)) with a high water holding capacity contribute to a high water availability and therefore, to a low irrigation requirement. Nevertheless, farmers locally expand irrigation equipment to be safe from successively increasing occasional dry periods (Agrarheute, 2013).

Because of a low annual precipitation amount of approximately 680 mm per year (DWD, 2010) and sandy soils with a low water holding capacity and temporarily occurring soil water deficits (Sutmöller et al., 2008), the county of *Uelzen* is one of the regions where irrigation is needed in agriculture (NLWKN, 2012). In Uelzen, groundwater use for irrigation is currently set to a maximum by legal regulations of 79 mm m^{-2} per year with a moving average over seven years in order to avoid depletion (Battermann and Theuvsen, 2007–2009). On average, 73 mm m^{-2} per year, i.e., 92.4% of the permitted amount was used for irrigation from groundwater extraction during the time period 1997–2004. In the low-rainfall year 2003, it was even 125% of the permitted amount. The intensity of irrigation has an additional economic background: Because of a local agro-industrial capacity for sugar beet processing, large amounts of this crop are grown and require high amounts of water (NLWKN, 2008).

In Brandenburg, where parts of the region *Fläming* and the county of *Oder-Spree* are located, the annual precipitation amount is even lower (approximately 570 mm; DWD, 2010; Lischeid, 2010) and evapotranspiration seasonally can exceed precipitation. In 1999, new negative records for the climatic water balance – precipitation minus potential evapotranspiration and runoff (Baumgartner and Liebscher, 1990) – of −400 mm during the vegetation period were reported (Land Brandenburg, 2000). The average water deficit was estimated to be 120–140 mm per year from April to September (Land Brandenburg, 2005). Even in years without such extreme conditions, fruits and crop species such as maize and potato can only be cultivated in an economically profitable way with irrigation (Land Brandenburg, 2000). This is the reason why crops with a high water demand like sugar beet and potato are usually not cultivated in Brandenburg (Table 3).

Irrigation was well-established before the German unification with 120,000 ha equipped in the federal state of Brandenburg (Land Brandenburg, 2000; Lischeid, 2010). In 2000 only 20,000 ha of them were still in operation. In 2009, the agricultural area equipped for irrigation increased to 38,960 ha again, 21,082 ha of them were actually irrigated (Land Brandenburg, 2011). The extension of irrigation systems in Brandenburg was subsidized by the government in the time period 2000–2010 with over 30 million € to maintain competitiveness in agriculture, horticulture and permanent cultures (Land Brandenburg, 2011).

Comparing the four regions under investigation, irrigation is most significant in the county of Uelzen, where 58,000 ha are equipped for irrigation and 90% of the agricultural land is currently irrigated (Fricke, 2005; Schaller and Weigel, 2007; Battermann and Theuvsen, 2007–2009; Heidt, 2009; FAO, 2013). Currently, irrigation is not conducted to a large extent in the other regions investigated.

2. Material and methods

2.1. Study design

To estimate irrigation requirement we developed the soil water model *BewUe* (*Bew*ässerung *Ue*lzen, translated: irrigation Uelzen; Section 2.4). The amount of soil water required to keep water content above a given threshold to prevent crop growth decrease was defined as irrigation requirement. Missing irrigation would not necessarily cause crop failure but yield reductions would be probable.

In agricultural practice, irrigation is applied if soil water content falls beneath 30–80% of the available field capacity (Land Brandenburg, 2005). To estimate minimum requirements, we use a lower level of 20% that still allows growth but does not provide safety margins

Fig. 1. Soil coverage patterns in the regions investigated (BGR, 2007). Climate data (DWD, 2010) refer to grids indicated representing areas with minimal difference to the average climatic conditions in the respective region. The assignment of the occurring soils refers to level 1 of the World Reference Base for Soil Resources (IUSS Working Group WRB, 2014). The small map on the upper left shows the location of the model regions within the federal states of Germany. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)