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Short communication

Risk efficiency of irrigation to cereals in northeast Germany with respect to nitrogen fertilizer

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ABSTRACT

The potential role of irrigation of cereals as a response to climate change is under debate. Especially under temperate continental conditions empirical evidence of crop yield response to irrigation in interaction with nitrogen fertilizer supply is rare. Besides mean yield effects, irrigation reduces yield variance, which may be an incentive for farmers to use irrigation. This paper investigates the risk-efficiency of irrigation in cereal production in a temperate continental climate, based on data from a long term field experiment on a sandy soil. Irrigation and no irrigation of winter rye (*Secale cereale*) and winter barley (*Hordeum vulgare*) were investigated in three different nitrogen (N) fertilizer levels. Crop yield response data (1995–2010) to irrigation and N fertilizer were used to calculate net returns, certainty equivalents (CE) for different levels of risk aversion and the conditional value at risk (CVaR) as a downside risk indicator in two price scenarios. The scenarios were calculated with a total cost and a partial budget approach. Irrigation was found to be profit-maximizing in all partial budget calculations, which sometimes required higher N input to be profit-maximizing. Irrigation and N fertilizer reduction were identified as risk mitigation strategies, even though their impact was limited. Irrigation reduced the downside risk only in the partial budget calculations. The analysis based on the CE did not show improved risk efficiency with irrigated management options. In contrast, reduced fertilizer input proved to be risk efficient at specific levels of risk aversion. The price expectations of winter rye and winter barley had a much higher impact on the ranking of the management options than risk aversion based on the crop yield variances. At low crop prices for all levels of risk aversion, irrigation of winter barley and winter rye was only economically justified if fixed costs for irrigation were not taken into account. At high crop prices, irrigation of winter barley was also justified based on the total cost calculation. However, this advantage was only given at a very low level of risk aversion. With increasing levels of risk aversion irrigation was not efficient based on the CE in the total cost accounting scenario. In conclusion, irrigation of cereals can contribute to downside risk mitigation and increased profits, if fixed costs for irrigation are covered. However, this conclusion holds only when irrigation is combined with an increased N intensity. If total costs need to be accounted for, irrigation in cereals is not an appropriate risk reduction strategy and a reduction of N input is more effective.

1. Introduction

As a response to climate change, irrigation of cereals in temperate regions of Europe is increasingly under debate (Olesen and Bindi, 2002; El Chami et al., 2015, Zhao et al., 2015). While under current conditions investments in irrigation systems are not likely to be profitable for cereals in temperate Europe, this could change with climate change or increased crop prices, which has been shown for English, Swiss and German conditions (El Chami et al., 2015; Münch et al., 2014; Finger and Schmid, 2008). Especially in northeastern Germany the future potential role of increased integration of irrigation in arable cropping systems has been highlighted (Münch et al., 2014). In this region, increasing pre-summer-droughts in combination with a low water holding capacity of predominant sandy soils often result in shortage of water available for plants, and lower yields (Schindler et al., 2007; Drastig et al., 2011).

Irrigation decisions should not be based solely on the expected profit, but should also consider uncertainties and farmers' attitudes to risk, since irrigation typically affects variance and skewness of profits and is often associated with an investment decision (Bosch et al., 1987; Finger, 2013). Lehmann et al. (2013) have presented a framework,

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Table 1
Soil physical and chemical properties of field research station of the Humboldt University of Berlin in Thyrow (according to Trost et al., 2014).

Soil attribute	Value
Soil pH	5.3–5.9
Field capacity (%)	16.1
Usable field capacity (%)	11.0
Wilting point (%)	4.5
Bulk density (cm^{-3})	1.67
Average Corg content	0.52
Sand (%)	83.10
Silt (%)	14.20
Clay (%)	2.70

which models the associated risks of fertilizer and irrigation decisions based on a bio-economic modelling approach with an integrated crop growth model and an economic decision model. Their study under Swiss conditions showed in all calculated climatic scenarios that for a moderately risk averse farmer irrigation of winter wheat did not result in a higher farmer's utility compared to not irrigated winter wheat. However, in contrast to winter wheat, irrigation was found to be the utility maximizing strategy for grain maize in several climatic scenarios.

Besides the use of irrigation water, nitrogen (N) fertilizer also has an impact on mean profitability and profit variability of farming. Literature suggests that high N rates are risk increasing (Rajsic et al., 2009; Finger, 2012). So from a risk mitigation point of view, irrigation and N fertilizer reduction may both be a potential risk mitigation strategy, which should be traded off appropriately.

The economic analysis of irrigation, especially with respect to risk, is mostly based on modelling approaches, which generate yield response to irrigation for specified climate scenarios. Different biophysical models have been suggested, which can generate the necessary data sets (for example Münch et al., 2014; El Chami et al., 2015; Finger et al., 2010). Typically irrigation is modelled as a function of weather-, and plant-induced soil water status. However, modelled yield response to irrigation may deviate from empirical yield response to irrigation derived from field trials because of various restrictions that appear in practice. Such limitations are for instance limited information on soil water status or time restrictions. However, economic and risk analyses from empirical data are rare. Foudi and Erdlenbruch (2012) showed with an econometric approach based on European Farm Accountancy Data that French farmers with irrigation have higher mean profits with lower profit variability compared to those without irrigating. To our best knowledge no studies have compared risk mitigation by irrigation accounting for interactions resulting from different N fertilizer rates based on empirical data.

Table 2
Annual amounts of irrigation water and the number of irrigation water applications.

	Winter rye		Winter barley	
Year	Annual irrigation water ($mm\ m^{-2}$)	Number of applications	Annual irrigation water ($mm\ m^{-2}$)	Number of applications
1995	No cultivation of winter rye		0	0
1996	0	0	47	2
1997	0	0	60	3
1998	0	0	60	3
1999	0	0	60	3
2000	20	1	100	5
2001	20	1	40	2
2002	21	1	43	2
2003	98	3	70	3
2004	30	2	30	2
2005	20	1	23	1
2006	77	3	142	5
2007	42	2	42	2
2008	134	7	127	6
2009	45	3	45	3
2010	14	1	No cultivation of winter barley	

We used data from a long term field experiment to model the implications of the variability of the expected net return, with respect to farmers' risk attitude. The study aims to contribute to the following questions: What is the potential impact of risk aversion on the utility of investments in irrigation of cereals on a poor soil, in a continental temperate climate? Is it economically justified to use existing irrigation equipment on poor soils in a temperate continental climate for cereal production? What are the implications of irrigation on the risk-efficiency of different N fertilizer applications?

2. Data and methods

2.1. Field experiment

Data on crop yield response to N fertilizer and irrigation were taken from a long-term field experiment located in Thyrow (52°15 N, 13°14 E) in the federal state of Brandenburg, Germany. The site is located 43 m above sea level with an annual average temperature of 8.9 °C and annual precipitation of 495 mm (Ellmer and Baumecker, 2008). According to the World Reference Base for Soil Resources 2006, the soil type is Cutanic Albic Luvisol (Abruptic Arenic) (Schweitzer and Hierath, 2010). The site is characterized by poor soil fertility because of limited water-holding capacity and cation exchange capacity. Sand is the primary particle size class in the topsoil. Further physical and chemical properties of the topsoil are listed in Table 1.

The long-term field trial with a rotation of five crops was established in 1969. Potato (*Solanum tuberosum* L.), winter barley (*Hordeum vulgare* L.), oil seed rape (*Brassica napus* L.), winter rye (*Secale cereale* L.), and cocksfoot (*Dactylis glomerata* L.) were grown in a five-year crop rotation until 2010, when some crops in the rotation changed. The rotation was replicated on five plots so that each crop of the rotation was planted in each year. The plots were split in irrigated and non-irrigated subplots with three N fertilizer intensities (0, 60, 120 kg N ha^{-1}), which were arranged with triple non-randomized replications within the subplots. The amounts of irrigation water were based on the water status of the soil, calculated with a soil hydrological model, taking into account water-holding capacity, plant growth stage and potential evapotranspiration (Table 2, further information in Trost et al., 2014).

In this study, a time period of 15 years (1995–2010) was used to collect data of crop yield response of winter rye and winter barley to irrigation in interaction with three different N fertilizer levels.[1] For the risk analysis crop yield data were trend-corrected applying a linear time trend model.

2.2. Economic analysis of the different management systems

The economic analysis in this paper is focused on the economics of irrigation with respect to N fertilizer application. A total cost accounting approach was selected to compare the net returns of the different management systems (Eq. (1)),

$$\pi = p_c \cdot y + DP - C_f - p_N \cdot N - C_{irrigation\ (fixed)} - C_{irrigation\ (variable)} \tag{1}$$

where π indicates the per hectare net return from growing a specific crop. p_c is the crop price, y is the crop yield, DP are the direct payments according to the Common Agricultural Policy of the EU, C_f are the total costs of farming, including land rents, but excluding N fertilizer and

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[1] Since the experimental design was repeated in five blocks, representing the crop rotation, each plot was planted three times during the considered 15 years. Due to changes in the crop rotation in 1995 and 2010 winter rye and winter barley were not both planted at the same time. All considered crop yield data are provided in the appendix.