Europ. J. Agronomy 81 (2016) 117–128

Contents lists available at ScienceDirect

European Journal of Agronomy

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

Effects of irrigation and nitrogen fertilization on the greenhouse gas emissions of a cropping system on a sandy soil in northeast Germany

Benjamin Trost[a,*], Annette Prochnow[a,b], Andreas Meyer-Aurich[a], Katrin Drastig[a], Michael Baumecker[c], Frank Ellmer[d]

[a] Leibniz-Institute for Agricultural Engineering and Bioeconomy (ATB), Max-Eyth-Allee 100, 14469 Potsdam, Germany
[b] Humboldt-Universität zu Berlin, Faculty of Life Sciences, Chair Utilization Strategies for Bioresources, Hinter der Reinhardtstr. 8-18, 10115 Berlin, Germany,
[c] Humboldt-Universität zu Berlin, Faculty of Life Sciences, Field Study and Research Station, Dorfstraße 9, 14974 Thyrow, Germany,
[d] Humboldt-Universität zu Berlin, Faculty of Life Sciences, Division of Agronomy and Crop Science, Albrecht-Thaer-Weg 5, 14195 Berlin, Germany,

ARTICLE INFO

Article history:
Received 25 January 2016
Received in revised form 1 September 2016
Accepted 12 September 2016
Available online 17 September 2016

Keywords:
Greenhouse gas emissions
Cropping systems
Irrigation
N fertilization

ABSTRACT

Irrigation induces processes that may either decrease or increase greenhouse gas emissions from cropping systems. To estimate the net effect of irrigation on the greenhouse gas emissions, it is necessary to consider changes in the crop yields, the content of soil organic carbon and nitrous oxide emissions, as well as in emissions from the use and production of machinery and auxiliary materials. In this study the net greenhouse gas emissions of a cropping system on a sandy soil in northeast Germany were calculated based on a long-term field experiment coupled with two-year N_2O flux measurements on selected plots. The cropping system comprised a rotation of potato, winter wheat, winter oil seed rape, winter rye and cocksfoot each under three nitrogen (N) fertilization intensities with and without irrigation. Total greenhouse gas emissions ranged from 452 to 3503 kg CO_2-eq ha^{-1} and 0.09 to 1.81 kg CO_2-eq kg^{-1} yield. Application of an adequate amount of N fertilizer led to a decrease in greenhouse gas emissions compared to zero N fertilization whereas excessive N fertilization did not result in a further decrease. Under N fertilization there were no significant differences between irrigation and non-irrigation. Increases in greenhouse gas emissions from the operation, production and maintenance of irrigation equipment were mainly offset by increases in crop yield and soil organic carbon contents. Thus, on a sandy soil under climatic conditions of north-east Germany it is possible to produce higher yields under irrigation without an increase in the yield-related greenhouse gas emissions.

1. Introduction

Climate change may strongly affect global agricultural production (Calzadilla et al., 2013). Changes in climate are also expected in Europe which will influence crop production (Olesen and Bindi, 2002; Trnka et al., 2011). Especially changes in precipitation are projected that may seriously affect the productivity of crop production. On the one hand, higher amounts of precipitation are possible mainly in northern Europe. On the other hand, a decrease in precipitation endangers crop production in southern regions. However, even in regions with sufficient precipitation, weather extremes can be expected that will raise the risk of yield losses caused by drought periods (Trnka et al., 2011). Some regions exist in Germany where drought periods are problematic for crop production (Schindler et al., 2007). Especially in the federal state of Brandenburg in north-east Germany, a region with increasing pre-summer-droughts in combination with a low water holding capacity of the predominant sandy soils, water scarcity may result in high yield losses (Schindler et al., 2007; Drastig et al., 2011). Supplemental irrigation is an option to stabilize and increase yields in this region (Trost et al., 2014a). Thus an extended use of irrigation in this region is expected in the future (Simon et al., 2009).

Irrigation induces processes that may either increase or decrease greenhouse gas emissions (Trost et al., 2013). To estimate the net effect of irrigation on the greenhouse gas emissions of cropping systems, it is necessary to consider changes in the yields and in the content of soil organic carbon, in nitrous oxide emissions, as

* Corresponding author.
E-mail addresses: btrost@atb-potsdam.de (B. Trost), aprochnow@atb-potsdam.de, annette.prochnow@agrar.hu-berlin.de (A. Prochnow), ameyer@atb-potsdam.de (A. Meyer-Aurich), kdrastig@atb-potsdam.de (K. Drastig), michael.baumecker@agrar.hu-berlin.de (M. Baumecker), frank.ellmer@agrar.hu-berlin.de (F. Ellmer).

http://dx.doi.org/10.1016/j.eja.2016.09.008

well as in emissions from the use and production of machinery and auxiliary materials. Irrigation may increase or decrease CO_2 emissions by influencing the soil organic carbon contents, depending on climate and initial soil organic carbon contents (Trost et al., 2013). In dry regions and on soils with low initial carbon contents, irrigation can increase soil organic carbon contents (Entry et al., 2004; Gillabel et al., 2007; Denef et al., 2008), whereas a decrease is possible in regions with a humid climate and soils with high initial soil organic carbon contents (Dersch and Böhm, 2001; Getaneh et al., 2007). Irrigation as well as nitrogen fertilization influences N_2O emissions. Some studies have shown that irrigation, especially at high availability of N, may lead to increased N_2O emissions (Simojoki and Jaakkola, 2000; Livesley et al., 2010; Rochette et al., 2010; Trost et al., 2014b). However, other results indicate only a small influence of irrigation on the amount of N_2O emissions (Trost et al., 2014c). Additional greenhouse gas emissions associated with irrigation originate from the use and production of the irrigation machinery itself, particularly from the consumption of fossil fuels. By increasing yields, irrigation affects greenhouse gas emissions normalized for yield. Another relevant production factor, which also affects the yield-related greenhouse gas emissions, is N fertilization (Clayton et al., 1997; Hao et al., 2001; Liu and Greaver, 2009). It can potentially increase yield and soil-borne N_2O emissions as well as greenhouse gas emissions from the pre-chain, since the production of mineral N fertilizer is an energy and greenhouse gas intensive process (Lal, 2004).

Until now, there are many gaps in knowledge about the effects of specific agronomic management options on the greenhouse gas emissions (Sainju et al., 2014b). Especially the effect of irrigation on the greenhouse gas emissions of cropping systems is not well investigated (Mosier et al., 2006). No investigations are available on the greenhouse gas emissions of irrigated cropping systems under different N fertilizer intensities under the climatic conditions of central Europe.

The objective of this paper is to determine the net greenhouse gas emissions of a cropping system on a sandy soil in northeast Germany based on a long-term field experiment under three N fertilization intensities with and without irrigation coupled with two-year N_2O flux measurements on selected plots.

2. Material und methods

2.1. Cropping system, data base and functional unit

The cropping system is based on a long-term field experiment on a sandy soil in northeast Germany and consists of a five-year rotation of potato (*Solanum tuberosum* L.), winter wheat (*Triticum aestivum* L.), oil seed rape (*Brassica napus* L.), winter rye (*Secale cereale* L.) and cocksfoot (*Dactylis glomerata* L.). All crops are grown with and without irrigation and with three N fertilizer intensities (zero, normal, excessive). The amounts of fertilizer, seeds and the mean annual amounts of irrigation water are given in Table 1. The long-term field trial of the Field Study and Research Station of the Humboldt-University of Berlin in Thyrow is located south of Berlin in the federal state of Brandenburg. The site is characterised by a low fertility level because of the low water holding capacity and the limited cation exchange capacity. The primary kinds of soil substrate in the topsoil are low to average silty sand. The long term average annual precipitation is 495.3 mm and the mean annual temperature is 8.9 °C (Ellmer and Baumecker, 2008). Additional information on the long-term field trial is given in Trost et al. (2014a).

The greenhouse gas emissions of the cropping system were calculated based on a life cycle assessment approach according to ISO 14040 (2006) and ISO 14044 (2006). The system includes the mining and production of raw materials, the production of machines, fertilizers, pesticides and seed (pre-chains), the emissions from diesel consumption of agronomic activities for crop production and the transport of the harvest product to the farmyard. Soil borne N_2O emissions and emissions from changes in soil organic carbon contents were included as well (Fig. 1).

Data on yields and soil organic carbon contents were taken from results of the long-term field trial. N_2O-emission factors were estimated from results of field measurements carried out on selected plots of the field trial. Greenhouse gas emissions from the production of machinery and auxiliaries were taken from the database ecoinvent (2010) (V 2.2.) of the Swiss Centre for Life Cycle Inventories. Performance data, diesel consumption and working hours were taken from KTBL (2009) and KTBL database (2014). Greenhouse gas emissions were related to the functional units hectare (ha) for the land used and kilogram (kg) for the yield.

2.2. Calculation of greenhouse gas emissions

2.2.1. Greenhouse gas emissions from changes in soil organic carbon content

Detailed information on the development of yields, C inputs and SOC stocks is given in Trost et al. (2014a). The annual change in soil organic carbon contents was calculated with the values from the period of 2000–2013. This period was chosen to minimize the effect of a change in fertilizer management in 1995. Before 1995 N was applied in all three N fertilizer levels. In 1995 the N fertilization in one level was abandoned (fertilizer level “zero”) and reduced in the other two levels (fertilizer levels “normal” and “excessive”). This led to decreasing soil organic carbon amounts in the following years until a new equilibrium was reached in 2000 (Trost et al., 2014a).

The annual changes in soil organic carbon amounts ΔSOC (t C ha^{-1}) in all fertilizer levels were calculated from the soil organic carbon content in a soil depth of 0 to 20 cm in 2000 (SOC_{2000}) and in 2013 (SOC_{2013}). This soil layer represents the AP horizon of this field trial, which contains the main content of soil organic carbon and roots.

$$\Delta SOC = \frac{(SOC_{2013}\text{-}SOC_{2000})}{13\text{years}} \quad (1)$$

The average soil organic carbon contents in the treatments in 2000 and 2013 are shown in Table 2.

2.2.2. Soil-borne N_2O emissions

N_2O emissions were calculated according to IPCC (2006) using site-specific data from the long-term field trial. The calculated average N inputs by mineral fertilizer, crop residues and decomposition of soil organic matter are shown in Table 3. Crop and straw yields are shown in Table 4. For winter wheat and winter rye, the straw yields were determined every year. For potato and oil seed rape, the aboveground residues were calculated using the grain/straw ratio of 1:0.2 and 1:1.7 respectively (DüV, 2012). For cocksfoot, no data on the aboveground harvest residues was available due to the complete removal of aboveground biomass. Belowground residues were calculated by the ratio of aboveground biomass to belowground biomass according to IPCC (2006). The ratio was 1:0.23 for winter wheat, 1:0.22 for winter rye and 1:0.20 for potato. For oil seed rape and cocksfoot, a specific ratio was not available, thus for oil seed rape the ratio of 1:0.22 for cereals and for cocksfoot the ratio of 1:0.54 for non-legume hay was used. To calculate the N input from decomposition of soil organic matter, the values of ΔSOC were multiplied by the factor of 0.1, representing the mean ratio of carbon to N in soil organic matter (IPCC, 2006).

Direct N_2O emissions from N inputs were calculated with a site-specific N_2O emission factor derived from the long-term field