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Research Paper

Assessing explanatory factors for variation in on-farm irrigation in US maize-soybean systems

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ABSTRACT

Irrigation exhibits large variation across producer fields, even within same region and year. A knowledge gap exists relative to factors that explain this variation, in part due to lack of availability of high-quality irrigation data from multiple field-years. This study assessed sources of variation in irrigation using a large database collected during 9 years (2005–2013) from *ca.* 1400 maize and soybean producer fields in Nebraska, central USA (total of 12,750 field-year observations). The study area is representative of *ca.* 4.5 million ha of irrigated land sown with maize and soybean. Influence of biophysical (weather, soil, and crop type) and behavioral (producer skills, risk aversion) factors on irrigation was investigated. Field irrigation distributions showed a substantial number of fields received irrigation amounts that were well above average irrigation for same region-year. Variation in irrigation across fields, within the same region, was as large as year-to-year variation. Seasonal water deficit (defined as total reference evapotranspiration minus precipitation), soil available water holding capacity, and crop type explained about half of observed variation in field irrigation, indicating that producers adjusted irrigation depending upon site-year variation in these parameters. However, half of the variation in irrigation remained unexplained, indicating that producer behavior and skills play also an important role. There was evidence of a "neighbor" effect as fields that received large irrigation were surrounded by other fields with similarly large irrigation. Likewise, fields with above- or below-average irrigation in one year remained consistently above and below regional average irrigation, respectively, in other years despite similarity in weather and soil among fields. These findings indicate that irrigation decisions are influenced by both biophysical and behavioral factors, making predictions of field and regional irrigation extremely difficult. This study highlights the value of collecting on-farm irrigation data to understand producer decision-making and find opportunities to improve current water management in irrigated crop systems.

1. Introduction

Irrigated crop systems account for only 20% of arable land, producing *ca.* 40% of global food production (Schultz et al., 2005; Molden, 2007). Irrigation increases and stabilizes crop yields in areas where precipitation is not sufficient to satisfy crop water requirements (Grassini et al., 2014a). However, there is evidence of water withdrawals exceeding recharge and deterioration of water quality in many important irrigated areas of the world (Scanlon et al., 2012; Siebert et al., 2010). Exploring trade-offs in the nexus between food production and water resources is important for identifying pathways for sustainable intensification of irrigated crop systems in order to ensure current and future food production while protecting freshwater resources.

Availability of field-level irrigation data is essential to studies dealing with groundwater dynamics, land surface modelling, and environmental footprint. However, very few studies had access to actual field irrigation data (*e.g.*, Lorite et al., 2004; Grassini et al., 2011, 2014b; O'Keeffe et al., 2016). To our knowledge, there is no open-access source of field irrigation data that includes multiple years and regions, with companion biophysical data (soil, weather, and terrain parameters) that allow proper contextualization and quantitative analysis. To overcome this limitation, previous studies relied on irrigation data aggregated at large spatial scales (country

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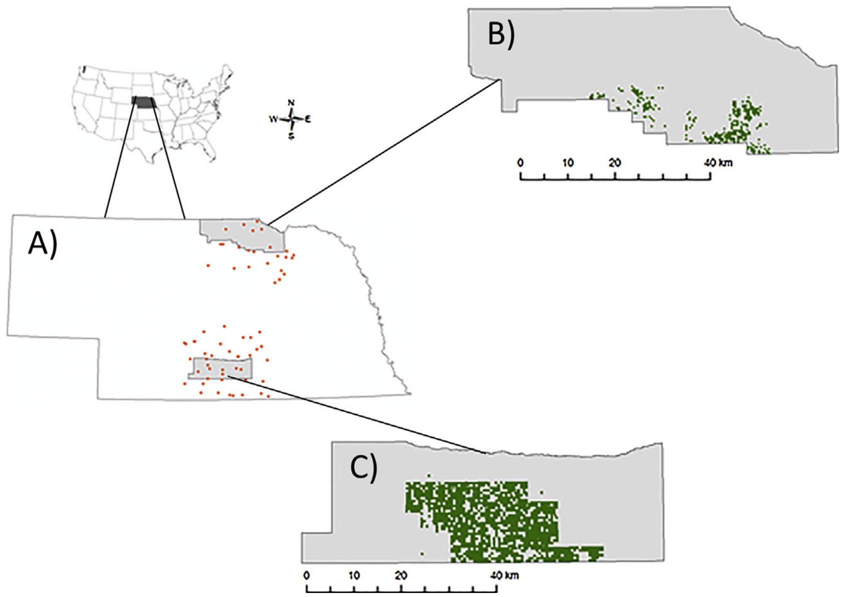

Fig. 1. A) Map showing the two study areas in Nebraska (shaded regions) as well as weather stations (red dots) used for weather interpolation in this study. Green squares indicate field location in north-central (B) and south-central (C) regions. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

or state), as those reported through AQUASTAT (http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en) and USDA-FRIS (https://www.agcensus.usda.gov/Publications/2012/Online_Resources/Farm_and_Ranch_Irrigation_Survey/fris13.pdf) databases (*e.g.*, Mullen et al., 2009; Siebert et al., 2010). Other studies attempted to estimate regional irrigation from secondary variables, such as groundwater dynamics, regional water balance, and weather (*e.g.*, Sharma and Irmak, 2012; Döll and Siebert, 2002; Droogers et al., 2010). While useful to detect regional or temporal trends, these sources of irrigation data cannot be used to benchmark water management in producer fields.

Understanding sources of variation in irrigation at field-level is important to identify opportunities for improving current water management. However, as indicated by Lorite et al. (2004), studies assessing the degree of variability in field-level irrigation are lacking. To our knowledge, no previous study explicitly assessed sources of field-to-field variation in irrigation across producer fields in the central US region. In an earlier study in Nebraska, Grassini et al. (2014b) found that field-to-field variation in irrigation was as important as (if not greater) variation across years and regions. And another study (Grassini et al., 2011) found that field-to-field variation in irrigation (coefficient of variation [CV] = 41%) was much larger than variation in yield (CV = 8%) and applied nitrogen fertilizer (CV = 17%). However, as we noted earlier, none of these previous studies looked into the causes for the observed variation in irrigation across producer fields. While field-to-field variation in irrigation may reflect differences in weather across field-years, as well as differences in soil type and topography, it may also reflect differences in producer skills and risk aversion as influenced by socio-economic variables (Andriyas, 2013). No previous study has attempted to dissect the relative contribution of biophysical *versus* behavioral factors to the observed field-to-field variation in irrigation amounts.

Understanding if producer decisions relative to input application (*e.g.*, irrigation, fertilizer) are consistent across years, and to which degree these decisions are influenced by manageable or non-manageable factors (*e.g.*, skill *versus* soil type), can help determine to what extent improvements in input-use efficiency are possible (Lobell et al., 2010; Farmaha et al., 2016). For example, if a producer consistently irrigates more than others in the same region, it implies that there is a persistent factor responsible for such behavior: a non-manageable factor such as soil type or a manageable factor such as irrigation system type or skill. In contrast, if a producer applies more irrigation in one year but a similar or smaller amount in another year, relative to the rest of the population of producers within the same region, it becomes more difficult to understand the factors driving irrigation decisions. To our knowledge, no previous studies have investigated the degree to which producer irrigation decisions are consistent across years.

In the present study, we used a unique database on total annual irrigation collected from *ca.* 1400 maize and soybean fields in Nebraska for 9 years (2005–2013). Our objective was to identify sources of variation in on-farm irrigation, including weather, soil properties, crop type, and producer behavior. Understanding the extent and underlying causes for field-to-field variation in irrigation is essential to benchmark current on-farm water management, identify opportunities for improvement, and better strategize research and extension programs to ensure sustainability of irrigated crop systems.

2. Material and methods

2.1. Study area and producer database

Annual irrigation data (*i.e.*, total amount of irrigation applied during the crop growing season) were available for maize and soybean fields over 9 years (2005–2013) in two regions of Nebraska: north-central (NC) and south-central (SC) (Fig. 1). Fields within these two regions are representative of the high-yield, high-input irrigated maize-soybean systems of the U.S central region, which accounts for *ca.* 4.5 million ha (USDA-NASS, 2014). Detailed description of these irrigated systems can be found elsewhere (Grassini et al., 2011; Farmaha et al., 2016).

Irrigation data were collected by the Tri-Basin (SC fields) and Lower Niobrara (NC fields) Natural Resources Districts (NRDs; https://www.nrdnet.org). The NRD data included field-specific information on sown crop, crop yield, crop rotation, irrigation system type, and total annual nitrogen fertilizer and irrigated water inputs. Previous studies have shown that the NRD producer-reported data aligned well with data reported by other independent