Agricultural Water Management 189 (2017) 87–97

Contents lists available at ScienceDirect

Agricultural Water Management

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

Northwest Ohio crop yield benefits of water capture and subirrigation based on future climate change projections

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ARTICLE INFO

Article history:
Received 19 August 2016
Received in revised form 7 April 2017
Accepted 29 April 2017

Keywords:
Climate
Subirrigation
Crop-Yield
Evapotranspiration
Water–Capture

ABSTRACT

Climate change projections for the Midwest U.S. indicate a future with increased growing season dryness that will adversely impact crop production sustainability. Systems that capture water for later subirrigation use have potential as a climate adaptation strategy to mitigate this increased crop water stress. Three such systems were operated in northwest Ohio from 1996 to 2008, and they exhibited substantial crop yield benefits, especially in dry growing seasons, but also to a lesser extent in near normal or wet growing seasons. The goal of this research was to estimate the increase in crop yield benefits of water capture and subirrigation systems that can be expected under projcted 2041–2070 climate conditions in northwest Ohio. Historical subirrigated field crop yield differences with fields having free drainage only, relative to growing season dryness/wetness, were used to determine future northwest Ohio subirrigated field crop yield increases, based on the modeled climate for 2041–2070. Climate records for 2041–2070 were projected using three bias corrected model combinations, CRCM + CGCM3, RCM3 + GFDL, and MM5I + HadCM3. Growing season dryness/wetness was classified based on the difference between rainfall and the crop adjusted potential evapotranspiration using the 1984–2013 climate record at the three system locations. Projected 2041–2070 growing season precipitation varied substantially between the three model combinations; however, all three indicated increased growing season dryness due to rising temperature and solar radiation. The overall subirrigated field corn yield increase rose to an estimated 27.5%–30.0% in 2041–2070 from 20.5% in 1996–2008, while the subirrigated field soybean yield increase improved from 12.2% in 1996–2008 to 19.8%–21.5% for 2041–2070. Consequently, as growing season drought becomes more frequent, the crop yield benefits with water capture and subirrigation systems will improve, and these systems therefore provide a viable climate adaptation strategy for agricultural production.

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1. Introduction

The focus of water management for agriculture in the highly-productive eastern Corn Belt region of the U.S.A. has been on drainage to remove excess soil water early during wet periods. Subsurface drainage systems are extensively installed throughout the region to enable timely field operations and good soil aeration during the growing season. Although excess water is the most evident crop water stress in this humid region, crops also experience stress from lack of water during summer months at the peak of the growing season, when water need is typically highest due in part to poorly-timed precipitation (Andresen et al., 2001; Baker et al., 2012). Supplemental irrigation to provide additional water during the growing season could be beneficial for crop yields during dry years, but the investment needed for irrigation has not been considered cost-effective except in sandy soils or for high value crops. However, projected shifts in temperature and precipitation patterns towards warmer and wetter winters and springs, a greater

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http://dx.doi.org/10.1016/j.agwat.2017.04.019
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frequency of intense storms throughout the year, and more erratic precipitation including more frequent and longer droughts in the summer (Melillo et al., 2014; U.S. Global Change Research Program, 2009) could significantly impact productivity of corn and soybeans (Walthall et al., 2012). These changes collectively suggest that benefits of supplemental irrigation in this region will increase in the future (Baker et al., 2012; Hatfield et al., 2011).

Subirrigation, the practice of applying water through a subsurface drainage pipe system, has been proposed since the 1980s as an efficient management system that improves water quality and sustains agricultural productivity (Belcher and Protasiewicz, 1995; Drury et al., 2009, 1996; Fisher et al., 1999). In Ohio, Cooper et al. (1992, 1991) obtained yield increases from subirrigation up to 42% for soybean (*Glycine max*), and stable yields of corn (*Zea mays*) up to 12600 kg/ha. A two-year field study by Fisher et al. (1999) in southern Ohio found that average corn yield increased by 19% and soybean increased by 64% by sub irrigation over subsurface drained, non-irrigated plots. Corn yield increases of 64% were found by Ng et al. (2002) in southwestern Ontario, Canada, and up to 12.9% by Mejia et al. (2000) in eastern Ontario. The practice of subirrigation is attractive since millions of cropland acres have poorly drained and/or somewhat poorly drained soils that already require subsurface drainage systems, which are a part of subirrigation infrastructure. Therefore, a substantial portion of the cropland already having subsurface drainage may be easily retrofitted for subirrigation.

Capturing and storing runoff and drainage water on the farm, and recycling it for irrigation during summer when crops experience water deficit, is one practice likely to become more beneficial as the pattern of excess water at times and drought at other times is exacerbated by climate change. In addition to sustaining crop yields, such a system has the added benefit, due to less water released offsite, of reducing downstream nutrient loads, which will likely become an even greater concern as predicted wetter springs and a greater frequency of intense rainfall events mean that runoff/drainage intensity will increase. This approach would alleviate critical environmental concerns since nitrate losses through tile drains are the major source of hypoxia in the Gulf of Mexico (Alexander et al., 2008) and phosphorus losses add to harmful algae blooms in Lake Erie and other freshwater lakes (Ohio Environmental Protection Agency, 2010).

Limited studies have looked at the potential crop yield benefits of water capture and subirrigation. In southwest Ontario, Tan et al. (2007) found an overall 31% corn yield increase and a 38% soybean yield increase using subirrigation practices, as compared to free subsurface drainage, while Drury et al. (2009) found no yield increase under subirrigation. (Note: For this paper, “free subsurface drainage” refers to conventional subsurface drainage pipe systems where outflow is unrestricted.) In Missouri, corn grain yields increased up to 50% (Nelson and Smoot, 2012), while soybean yields increased up to 29% (Nelson et al., 2012). In Ohio, researchers developed a system that included runoff/drainage water capture and storage in both a constructed wetland and a deeper reservoir, which they called the Wetland Reservoir Subirrigation System (WRSIS). Runoff and subsurface drainage from cropland were collected in the wetland for partial treatment of nutrients and sediment and additional ecological benefits (Allred et al., 2014a; Luckeydoo et al., 2002; Smiley and Allred, 2011) before being routed to a reservoir and stored until needed to irrigate the crops through drainage pipes during dry parts of the growing season. The system benefited both crop yield and water quality (Allred et al., 2014a, 2014b, 2003), but due to the economic considerations (Richards et al., 1999), the system has not been widely adopted to date.

However, the need for increasing resilience due to projected future climate change, especially warmer temperatures and more frequent growing season dry periods, will likely increase the economic benefits of this type of system. This study examines the potential yield increases that could be achieved by on-farm runoff and drainage water capture and subirrigation under projected future climate conditions. Studies on future needs and benefits of irrigation are usually addressed through crop modeling studies (i.e., Bonfante et al., 2015; Finger et al., 2011), while this study instead links observed subirrigation yield increases during a 13-year field study to growing season dryness/wetness, and proposes a method to use that relationship in estimating future subirrigation yield increases based on model-based climate projections. Consequently, the overall goal of this research was to quantify crop yield benefits of water capture and subirrigation systems given predicted future climate conditions. The specific project objectives related to this goal were: (1) describe and quantify projected changes in growing season dryness/wetness and related climatic variables in this region using three model-based climate projections, and (2) use the climate projections together with measured historical yield data to estimate the increase in subirrigation crop yield that would be expected in the future.

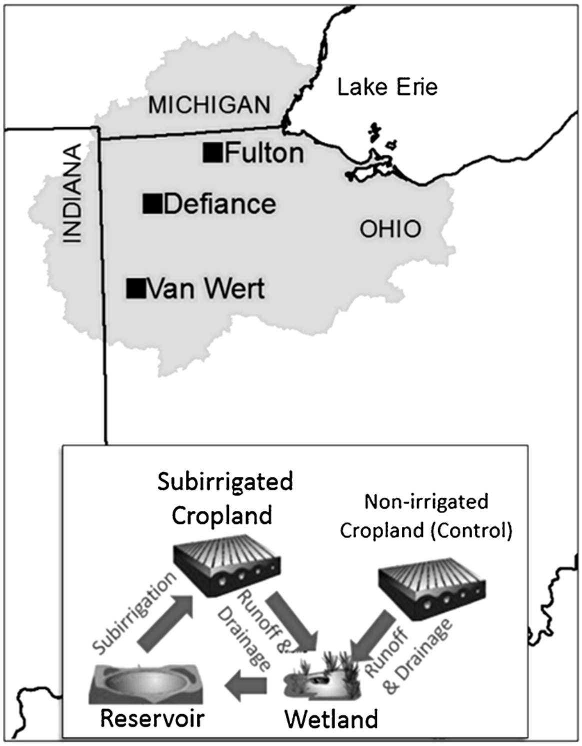

Fig. 1. Each WRSIS site included a wetland and a reservoir to capture and store runoff along with subsurface drainage capable fields. Control, non-irrigated field(s) with free drainage were also a component of the three WRSIS sites located in the Western Lake Erie Basin (shaded area).

2. Methods

2.1. Northwest Ohio wetland reservoir subirrigation systems

The three agricultural water recycling systems referred to as Wetland Reservoir Subirrigation Systems (WRSIS) were operated in the Western Lake Erie Basin in northwest Ohio from 1996 to 2008 (Fig. 1; Table 1). The three systems are described in detail by Allred et al. (2003; 2014a; 2014b). At each WRSIS site, a non-irrigated, free drained field served as a control for comparison to subirrigated field crop yield. Subirrigated fields typically have a spacing between drain lines that is 33% to 50% of what is commonly used in fields having free drainage. This reduced drain line spacing in subirrigated fields allows better uniformity of water table depth across a field

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