Northwest Ohio Crop Yield Benefits of Water Capture and Subirrigation Based on Future Climate Change Projections

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Highlights:

1) Projected increases in temperature and insolation in NW Ohio will increase crop PET.

2) Evapotranspiration is projected to increase faster than precipitation by mid-century.

3) Dry and very dry growing seasons will double in 2041-2070 as compared to 1984-2013.

4) Subirrigation crop yield benefits will improve further by 2041-2070.

5) Versus free drainage only, subirrigation increases crop yield by 20-30% in 2041-2070.

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 1996-2008, 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.

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 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 Protasiewcz, 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 (Richard 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.

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 (Figure 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 during irrigation and provides more efficient drainage when excess water needs to be quickly removed from the soil.

The WRSIS subirrigated fields could be operated in three modes: free drainage, controlled drainage, and subirrigation. The general strategy was to subirrigate when there was a rainfall deficit, use controlled drainage when there was sufficient rainfall with no irrigation needed, and use free drainage when quick removal of excess soil water was required due to heavy rainfall (Allred et al., 2014b). The targeted water table depth under subirrigation was 25 cm beneath the ground surface at the drain line, which resulted in water table depths of 46 to 51 cm at the midpoint between drain lines. Depending on site conditions, water was supplied either continuously over long periods of the growing season, or intermittently, for just short intervals if there was critical crop water stress and limited water availability.

All sites followed a two-year rotation of corn and soybeans. At each WRSIS site, the same corn hybrids and soybeans varieties were grown using the same standard farming practices (tillage, fertilizer/pesticide application, planting date, harvest date, etc.) in both subirrigated fields and non-irrigated control fields (Allred et al., 2014b). In the earlier years, both corn and soybeans were grown on fields at each site, but in some of the later years, only one crop (either corn or soybeans) was grown each year.

2.2 Historical Climate Data

2.2.1 Development of a Representative Historical Climate Series

Historical climate data were examined to understand the climatic characteristics of the study area and to give a baseline for comparison with modeled climate data (Table 2). As measurements of solar radiation are not collected in most monitoring networks in the United States, solar radiation values were obtained from the gridded NASA POWER product (Wilks, 1999, Hoell et al., 2005; White et al., 2011) Both GHCN-D and NASA POWER contained acceptable levels of data completeness (at least 95% temporal coverage) for this period.

A complete historical data series was constructed from the GHCN-D observed data using the Defiance station as the base series, which had the most complete data series of the three sites, and filling in missing values through the nearest available station). Missing values in the solar data were filled by linear interpolation between valid data points.

2.2.2 Priestly-Taylor Evapotranspiration

Values of potential evapotranspiration were calculated and examined to understand the amount of water needed for agricultural production and potential need for irrigation of corn and soybeans in northwest Ohio. Daily values of potential evapotranspiration for the 1984-2013 period were estimated using the Priestly-Taylor methodology (Priestly and Taylor, 1972). The general form of the Priestly-Taylor equation is:

$$PET = \frac{1}{\lambda} * \frac{s(R_n - G)}{s+\gamma} * \alpha \qquad [1]$$

where *PET* is the potential evapotranspiration (mm day^{-1}), λ is the latent heat of vaporization (MJ kg^{-1}), s is the slope of the saturation vapor pressure-temperature relationship (kPa $°C^{-1}$), R_n is net radiation (MJ m^{-2} day^{-1}), G is the soil heat flux (MJ m^{-2} day^{-1}), γ is the psychrometric constant (kPa $°C^{-1}$), and α is the Priestly-Taylor Coefficient (a standard value of 1.26 was used in this study). Methods for estimating the total radiation term followed the procedure defined by Allen *et al.* 1998. Radiation based potential evapotranspiration methods such as Priestly-Taylor have been found to perform well in data-limited situations and generally provide acceptable comparisons to more sophisticated methods such as Penman Monteith while not requiring relative humidity and wind speed which were not available historically or well predicted by future climate models (Weiβ and Menzl, 2008). Radiation is more influential than temperature in predicting evapotranspiration, and therefore, temperature based methods are less appropriate.

Daily PET values were adjusted for soybeans and corn through the use of crop coefficients (K_c).

$$PET_c = K_c * PET \qquad [2]$$

where PET_c is the crop potential evapotranspiration (mm day^{-1}), K_c is the crop coefficient, and *PET* from Equation [1]. Crop PET values are useful for determining the potential vegetative water needs of a crop in lieu of direct field level measurements. K_c values were determined following the methods outlined in Allen et al. (1998). In this method, crop progress/development data are needed to scale the reference

PET value to the crops' phenological stage. Following Allen et al. (1998), length of each stage was determined for initial, mid-season, and end-season based on key stages in plant development. The key stages for corn are: planting, silking, maturity, and harvest; for soybeans the key stages are: planting, podding, shedding of leaves, and harvest.

Representative dates were obtained from Crop Reporting District (CRD)-level data from the National Agricultural Statistics Service (NASS). These data were obtained from two sources: for more recent years 1997-2013, 1984, and 1988 data were obtained from the Indiana NASS Indiana State Office Website. Several years were not provided online and were obtained through the NASS State Statistician for Indiana (Table 2). The date on which 50% of acres were reported to be at a particular stage in a growing season was used for defining the points between periods, following the initial stage length after planting, which was taken from Allen et al. (1998). Planting date was determined in a similar fashion; the date on which 50% of the acres in the CRD were reported to be planted was used as the representative planting date for that growing season. Linear interpolation was used to determine the 50% dates if the reported date fell between reporting periods. The change points and final K_c curves were based on mean period lengths from 1984-2013 and are shown in Figure 2.

2.2.3. Dryness/Wetness Classification

The observed climate records for the three GHCN-D weather stations were employed to group northwest Ohio growing seasons from 1984 to 2013 into quintiles based on overall dryness/wetness. Classification of growing season dryness/wetness was based on the dryness/wetness index (DWI), computed separately for corn and soybeans, calculated as shown in Equation [3] by subtracting total growing season crop potential evapotranspiration (PET_c - via Equation[2]) from the total growing season precipitation,

$$DWI = Precipitation - PET_c \ . \qquad [3]$$

The growing season (May through September) dryness/wetness quintiles, each containing 20% of the total 1984 to 2013 growing seasons, were designated very dry (VD), dry (D), near normal (NN), wet (W), and very wet (VW). The division of water-related variables into quintiles has previously been found to be a useful approach to categorizing the characteristics of seasonal precipitation (i.e. Tennant and Hewiston, 2002). An additional method was also used to classify growing season dryness/wetness based on the departure from average precipitation (*DAP*), similar to the method employed by Allred et al. (2014b). The described *DWI* approach is far more rigorous for characterizing crop water stress than *DAP*, and since the results of both the *DWI* and *DAP* analysis were found to be quite similar; only the *DWI* results are presented in this paper. Furthermore, this *DWI* approach was the most robust means possible (given available climate data) for categorizing growing season dryness/wetness in manner that accounts not only for precipitation, but also temperature, solar radiation, and crop (corn or soybeans).

2.3 Climate-Model-Derived Projections

Climate model-derived projections were obtained from the North American Regional Climate Change Assessment Program (NARCCAP) (Mearns et al., 2009) (Table 2). Three distinct model combinations were implemented to evaluate the projected future climate over Northwest Ohio for the period from 2041-2070 and the potential effects of subirrigation on crop yields under projected conditions. NARCCAP data have previously been found to be more representative of North American regional climate than direct output from Global Climate Models (e.g. coarser spatial resolution) (Sobolowski and Pavelsky, 2012). NARCCAP data are typically available for two time periods, one historical period from 1971-2000 and one future period from 2041-2070 forced using the Intergovernmental Panel on Climate Change (IPCC) SRES A2 scenario, which projects increasing global population and greenhouse gas emissions into the future (Intergovernmental Panel on Climate Change, 2000). The three model combinations (Global Climate Model + Regional Climate Model) selected for this study were CRCM+CGCM3, RCM3+GFDL, and MM5I+HadCM3. These choices were informed by past and ongoing research focused on the evaluation of the representation of precipitation processes in the Great Lakes region and consultation with experts on the climate of the Great Lakes region of North America (Basile et al*.,* 2014).

2.3.1 Bias Correction/Representativeness of Model-Derived Data

Comparisons of the model-derived historical outputs to the historical GHCN-D observations were conducted to look for bias in the model-derived data. This was done to examine how close the model-derived data represent historically observed conditions. The NARCCAP "current contemporary" model runs (1971-2000) were bias corrected to the filled Defiance data series over the same period and the available NASA POWER data for 1984-2013 for all available data points. Although these two periods are slightly different, the comparison was deemed suitable as the NARCCAP data are initialized with historical climate conditions but not continuously altered with observations, and NASA POWER provides a realistic approximation of intra-annual and inter-annual variability in solar radiation. A unique correction factor was determined for each model combination and each variable by taking all available daily model values, comparing the average of all model-derived data points to the average of all historical data points from the filled historical series, and adjusting the daily model-derived output accordingly. Temperature values were adjusted by an offset method, applying the difference in the long-term mean of the model-derived data and the historical observations to each daily value in the model-derived data. Precipitation and solar radiation were adjusted using a ratio scaling method, in which the ratio between the model-derived dataset and the historical observations was applied to each daily value in the model-derived data (Maraun et al., 2010). The same adjustments were then applied to the modeled data from 2041-2070 to get estimates for the change in seasonal temperature, precipitation, and potential evapotranspiration (PET and PET_c). The distributions of high/low precipitation accumulation during growing seasons in the three projection-derived historical data series were also compared to the filled historical Defiance series using the quintile classification (Very Low, Low, Near-

Normal, High, Very High), similar to the method described in Section 2.2.3 to see if the projection-derived historical data represent the extremes of the seasonal distribution.

2.3.2 Quantifying Future Changes in Dryness/Wetness Crop Conditions

Once the bias correction of the model-derived historical and projection data was complete, the results were used to quantify the changes in dryness/wetness index (*DWI*) between the model-derived historical climate (1971-2000) and the projected future climate (2041-2070) conditions. Differences were calculated for the growing season means of solar radiation, average, maximum, and minimum temperature and totals of growing season precipitation, *PET*, and PET_c. To examine potential changes in the distribution of dry/wet growing seasons in northwest Ohio, dryness/wetness classifications were calculated for projected future climate; these model-derived quintiles were then compared to the quintiles derived from the historical observations.

2.4 Analysis of Subirrigated Field Crop Yield Increase: Historical and Future

The subirrigated crop yield increase (compared to non-irrigated control fields) for each growing season dryness/wetness classification ("X" - very dry, dry, etc.) was calculated across all three WRSIS sites during their period of operation (1996 to 2008). The equation used for this calculation was:

$$\%CYI_X = \left[\frac{ACYdifference_X}{ACYcontrol_X}\right] \times 100 \qquad [4]$$

where $\%CYI_X$ is the percent crop yield increase (corn or soybeans) in the subirrigated fields compared to the control fields for a particular growing season dryness/wetness classification "X", $ACYdifference_X$ is the average difference between subirrigated field crop yields and corresponding control field crop yields for a growing season classified as "X", and $ACYcontrol_X$ is the average of the non-irrigated control field crop yields during an "X" classified growing season. As an example, to calculate the corn yield increase in very dry (VD) growing seasons, the average corn yield difference, $ACYdifference_{VD}$, was computed between corresponding subirrigated fields and control fields across all three sites and this average difference in turn divided by the average non-irrigated control field corn yield in very dry growing seasons, $ACYcontrol_{VD}$, with this fractional quantity then multiplied by 100 to obtain a percent value.

The overall subirrigated field percent crop yield increase ($\%CYI_{Overall}$), combining the increase from all dryness/wetness classifications (VD, D, NN, W, VW), was determined with a weighted average using the following equation:

$$\%CYI_{Overall} = \left(\frac{\%VD}{100} \times \%CYI_{VD}\right) + \left(\frac{\%D}{100} \times \%CYI_{D}\right) + \left(\frac{\%NN}{100} \times \%CYI_{NA}\right) + \left(\frac{\%W}{100} \times \%CYI_{W}\right) + \left(\frac{\%VW}{100} \times \%CYI_{VW}\right) \text{ , [5]}$$

where, for example, $\%VD$ is the percent of growing seasons classified as very dry, and $\%CYI_{VD}$ is the subirrigated field percent crop yield increase over all “very dry” growing seasons. Overall percent crop yield increases were calculated separately for corn and soybeans. The $\%CYI_{Overall}$ was computed for the historic 1996 to 2008 WRSIS operational period, and also for the future period of 2041 to 2070 for each of the three model combinations. For each model combination, the observed $\%CYI_{X}$ data (see Equation [4]) from 1996 to 2008 and the percentages of VD, D, NN, W, and VW growing seasons in 2041 to 2070 were input into Equation [5] to compute the overall subirrigated field percent corn or soybean yield increase ($\%CYI_{Overall}$) for 2041 to 2070. The analysis of the 2041 to 2070 $\%CYI_{Overall}$ values for corn or soybeans is contingent upon two assumptions; (1) corn and soybean varieties/cultivars commonly grown today will also be those commonly grown in the future, and (2) water capture and subirrigation operational practices used today that are based on growing season dryness/wetness will also be the same operational practices employed in the future. Note: Both $\%CYI_{X}$ and $\%CYI_{Overall}$ refer to a "percent crop yield increase" instead of a "percent crop yield difference" because in this study, it was found that these values were always positive and therefore "increase" seemed more appropriate than "difference".

2.5 Note on Historical Climate Records Utilized in Study

Three historical climate records were used in this research; 1971 to 2000, 1984 to 2013, and 1996 to 2008. To avoid possible confusion, it is useful to restate the purpose for each of these three historical climate records. The northwest Ohio 1971 to 2000 climate record was employed to bias correct the 2041 to 2070 northwest Ohio climate records projected by the three model combinations; CRCM+CGCM3, RCM3+GFDL, and MM5I+HadCM3. The 1984 to 2013 climate records from NOAA weather stations (GHCN-D) near each WRSIS site were combined to determine quintile value limits for growing season dryness/wetness classification (VD, D, NN, W, VW). The 1984-2013 years were also the earliest thirty-year period available in the NASA POWER solar data. The 1996 to 2008 climate record, corresponding with the period of WRSIS operation, was utilized to associate a growing season's dryness/wetness classification with that same growing season's subirrigated field versus control field crop yield difference (corn and/or soybean).

3. Results and Discussion

3.1 Historical Climate Conditions

The climate at the three locations was found to be similar in most aspects(Table 3), which strengthens the validity of implementing the gridded model output and the filled Defiance series to encompass the three locations with only one value. The coolest month on average was May and the warmest was July, while precipitation was spread evenly throughout the growing season. Interannually and climatologically, growing season total precipitation amounts were more variable than temperature. Solar radiation and PET were both highest in July and lowest in September. PET_c for corn is typically less than the reference PET, while PET_c for soybean is less than PET_c for corn. When the magnitude of the growing season PET_c totals are taken into account, the variability is similar to reference PET.

3.2 Evaluating Model-Derived Historical Data

The model-derived historical temperature data typically contained a cool bias (Table 4). For average temperature, this ranged from 1.1°C to 3.3°C colder than the station observations. Minimum and maximum daily temperatures also displayed a cold bias. Precipitation is typically considered more difficult to model than temperature. This is due to the scale at which the processes that govern its formation occur (Dai, 2006). All three model combinations displayed a positive bias in daily precipitation values of up to 1 mm day^{-1}.

Another important consideration in model-derived precipitation is the over-dispersion and under-accumulation of precipitation, meaning that models precipitate too often and too little when they do (i.e. Katz and Parlange 1998). At Defiance, the measured percentage of “wet” days (>0.2 of precipitation) was found to be 35.8% in the gauge observations. In the model-derived historical data, the occurrence of “wet” days was found to be much higher across the three models (MMI5+HadCM3: 46.16%, CRCM+CGCM3: 65.8%, and RCM3+GFDL: 59.1%). Examining precipitation on longer timescales (e.g. growing season or annual) negates this shortcoming to an extent, as precipitation totals over an entire season are close to what is observed from historical station data.

The models were found to have a positive bias in solar radiation at this location, ranging from. 0.82 MJ m^{-2} day^{-1} to 0.98 MJ m^{-2} day^{-1} higher than the observations from NASA POWER. Following the bias correction of temperature, precipitation, and solar radiation, reference and crop-adjusted PET values were calculated using the bias-corrected information (Table 5). Growing season values for temperature, accumulated precipitation, solar radiation, and calculated PET values from the models were found to be in better agreement with the historical in-situ observations (Table 3), though notable difference still exist following correction.

Quintiles of the historical observations were used to define quintiles of precipitation ranging from very low to very high. Even with the bias correction, model-derived historical data did not accurately capture the distribution of high and low precipitation accumulation seasons. Very few growing seasons in the modeled historical values fall in the tails of the distribution, resulting in fewer very high or very low growing season than the observations show. This is consistent with previous research on representation of precipitation in climate models, with the models underestimating heavy precipitation events and over representing light precipitation events, leading to more seasonal accumulations near the middle of the observed distribution (Dai, 2006). Therefore, future precipitation projections are compared to the bias corrected modeled historical precipitation distributions to show the relative change in growing season precipitation distribution in each model, rather than comparing to the distribution from direct stations observations.

3.3 Projected Future versus Historical Conditions

All three model-derived projections incorporated in this study display substantial changes in several of the variables important when examining PET and, subsequently, on-farm water management. The numbers presented here are 30-year averages (Table 3) comparing the periods from 1971-2000 to the projections for the period from 2041-2070.

Total growing season projections for precipitation were more mixed between the three model-derived projections, with three distinct projected results (Table 3). One model projects a decrease of 29 mm, another projects that growing season precipitation will remain similar to the modeled historical values, while the third (projects an increase of 37 mm. This range in precipitation is typical of climate models, as the uncertainty surrounding precipitation projections is generally greater than those for temperature (Knutti and Sedláček, 2012) , and the range in projected precipitation change allows us to evaluate three potentially different futures as indicated by the projections.

The distribution of the projected future precipitation, using quintiles from the historical period (1971-2000), indicate a shift towards the tails of the distribution (Figure 3). Two of the models show increases in the number of low and very low seasons and one model showed a substantial increase in the number of dry and very dry growing seasons in terms of precipitation.

3.4 Historical Growing Season Dryness/Wetness Classification and Subirrigated Field Crop Yield Increase

The growing season dryness/wetness index quintile value limits, calculated for the 30-year period from 1984 to 2013, were substantially lower for corn than soybeans, due to corn water needs being greater than soybean water needs (Table 6). These limits are shown together with crop yield differences calculated by subtracting the non-irrigated control field crop yields from the corresponding crop yields of fields subirrigated with captured runoff/drainage in Figure 4. In the large majority of years, the subirrigated field crop yields were greater than the control field crop yields. However, there were a minority of growing seasons (14 out of 61 total), especially at the Defiance County WRSIS and the Van Wert County WRSIS, that had subirrigated field crop yields that were less than the control field crop yields. These few negative crop yield differences do not seem to be related to growing season dryness/wetness as they occurred across the entire range of VD to VW years (Figure 4).

There were 30 observed site years of corn and 31 site years of soybeans over the 13 years of WRSIS field study (1996-2008) at the three sites. This period had substantially wetter growing seasons than the 30-year record (1984-2013) employed to determine the dryness/wetness quintile value limits. The amount of growing season rainfall was on average approximately 39 mm greater for 1996-2008 than 1984-2013. During actual WRSIS operation, there were a much greater number of W or VW growing seasons combined than there were D and VD growing seasons combined (Table 7).

Subirrigated field percent corn or soybean crop yield increase ($\%CYI_X$ - Equation [4]) ranged from 3.7% to 35.1% (Table 7). On average, subirrigated field crop yield increased (relative to control fields) for all growing season dryness/wetness categories (Table 6), with the most substantial percent yield increases (24.4% to 32.4%) occurring in D and VD growing seasons as expected. The average $\%CYI_X$ for corn and soybeans was generally much less in NN, W, and VW growing seasons, with the exception of corn for W years, which had the highest $\%CYI_{X\ \mathrm{value}}$ of 35.1% (Table 7). This high $\%CYI_{X\ \mathrm{value}}$ was influenced greatly by a single wet growing season (2001) at the Fulton County WRSIS, where the subirrigated field corn yield was 12063 kg/ha and the corresponding control field corn yield was only 4570 kg/ha (difference of 7493 kg/ha - largest shown in Figure 4).

One explanation for the increased crop yields with the subirrigation capable fields during NN, W, and VW growing seasons in 1996 to 2008 is that the subirrigated fields drained more quickly than the non-irrigated control fields, because the drain line spacing distance in the subirrigated fields is much less than the drain line spacing in the control fields. Once the crops had become well established, the capacity for quicker drainage in subirrigated fields reduced the chance of root zone flooding conditions due to periods of excessive rainfall, which damage crops by disrupting respiration processes or promoting diseases. Figure 5 provides an example showing quicker drainage in a subirrigation capable field as compared to a field with only free drainage. This aerial photo of the Fulton County WRSIS shows both the subirrigation capable field, labeled "S", and the adjacent free drainage control field, labeled "D". The photo was obtained on March 19, 2006 when the surface was bare (no vegetation) and six days after a 36 mm rainfall event. Lighter shades of grey (i.e. greater reflected light) indicate a drier soil surface, while darker shades (i.e. less reflected light) indicate a wetter surface. The ground surface in the free drainage control field was dry directly over the drain lines but was still wet between the drain lines, while for the subirrigation capable field, the entire ground surface overtop and between drain lines was dry, thus confirming that the subirrigated field drained more quickly than the free drainage control field.

Two additional explanations for the increased crop yields with the subirrigation capable fields during NN, W, and VW growing seasons are highlighted by Figure 6, which compares monthly *DWI* to the overall growing season *DWI*. First, on average, larger May and June *DWI* values occurred in overall growing seasons that were W or VW (compare Quadrant II to Quadrant I in Figure 6a). These larger *DWI* values for May and June, due to greater rainfalls; (1) could potentially reduce field trafficability, which can postpone corn and soybean planting, and (2) also decrease soil aeration, thereby delaying seed germination and crop emergence. However, the narrower drain line spacing in subirrigated fields promoted quicker drainage that mitigated these adverse impacts of excessive rainfalls in May and June that tended to occur more frequently in W and VW growing seasons. Second, even during W, and VW growing seasons during 1996 to 2008, there were still dry periods in the critical July, August, and September months of the growing season (Quadrant IV in Figure 6b). Subirrigation, by providing water to the crops, therefore helped alleviate corn and soybean dry period stress that occurred during critical parts of an otherwise W or VW growing seasons.

Monthly differences were further explored by conducting a statistical correlation analysis between monthly values of *DWI* versus *CYdifference* (subirrigated field crop yield minus control field crop yield using WRSIS data from 1996-2008. This analysis provided insight on which growing season months subirrigation had the most impact on crop yield (Table 8). With respect to *DWI* versus *CYdifference*, the strongest correlations were obtained for July, August, and September with soybeans and July and September with corn. These moderate negative "r" values imply that, regarding the best months for subirrigation, mitigating crop water stress (negative *DWI*) in July, August, and September for soybeans and July and September for corn is most important. A forward selection stepwise regression analysis was also carried out with monthly *DWI* as independent variables and *CYdifference* as the dependent variable. The multiple linear regression equation for soybeans was:

$$\mathit{CYdifference} = -159.07 + 3.41(\mathit{DWI}_{May}) - 1.16(\mathit{DWI}_{June}) - 3.72(\mathit{DWI}_{July}) - 2.37(\mathit{DWI}_{August}) - 6.43(\mathit{DWI}_{September}), \quad [6]$$

with an R^2 value of 0.47, statistical significance p of 0.005, and an order for independent variable importance of $DWI_{July} > DWI_{September} > DWI_{August} > DWI_{July} > DWI_{May} > DWI_{June}$. The stepwise regression analysis confirms implications from Table 8 that subirrigation of soybeans in July, August, and September is crucial for mitigating crop water stress and thereby sustaining crop yields. The multiple linear regression equation for corn was:

$$CYdifference = -148.94 + 9.54(DWI_{May}) - 5.34(DWI_{June}) - 9.46(DWI_{July}) - 6.60(DWI_{August}) - 20.84(DWI_{September}), \quad [7]$$

with an R^2 value of 0.21, statistical significance p of 0.31, and an order for independent variable importance of $DWI_{September} > DWI_{August} > DWI_{July} > DWI_{May} > DWI_{June}$. This stepwise linear regression analysis indicates that, with respect to subirrigation of corn, mitigating crop water stress in August is also important, in addition to mitigating dryness/wetness indexs in July and September.

Typically, subirrigation was ceased late August or early September, and although the water table was not maintained at previous levels, there was supplemental soil water available in the root zone to meet crop needs, possibly into mid-or late September. This observation is supported for soybeans by Fausey and Cooper (1995). The correlation and stepwise regression analyses show that to sustain crop yields, July, August, and September are the most critical months to subirrigate, although the case for this conclusion is much more persuasive with soybeans than corn. The consequence of this conclusion with regard to management of water capture and subirrigation systems is that, where supply is limited, water should be conserved early in the growing season for later subirrigation use in the critical months of July, August, and September.

3.5 Future 2041 to 2070 Growing Season Dryness/Wetness Classification and Subirrigated Field Crop Yield Increase

Although projected precipitation changes differed between the three models, growing seasons are projected to become on average much drier for 2041 to 2070 regardless of the climate modeling combination, due to higher potential evapotranspiration caused by increased temperatures and solar radiation. The percentage of D and VD growing seasons will increase from 40% in 1984-2013 to between 70% - 80% in 2041-2070 (Table 9).

The months of May and June in northwest Ohio, as projected for 2041-2070, and depending on the model combination employed, will on average have minor decreases to moderate increases in *DWI* as compared to the 1984-2013 historical period (Figure 7). Two of the three model combinations (CRCM+CGCM3 and MM5I+HadCM3) indicate significantly wetter May field conditions that will result in more trafficability and soil aeration problems, causing delays in corn/soybean planting, seed germination, and crop emergence, which can be better alleviated in subirrigation capable fields that have quicker drainage. The months of July, August, and September in northwest Ohio, as projected for 2041-2070, and depending on the model combination employed, will on average have moderate to substantial decreases in *DWI* as compared to the 1984-2013 historical period (Figure 7). When evaluated cumulatively over the course of the growing season, *DWI* deficit conditions for corn begin in July, in the three models, averaging 123 mm less than the historic *DWI* by the end of the growing season (Figure 7). The same pattern is observed when soybeans are considered, though the overall magnitude of the cumulative *DWI* deficit is less, due to lower $PET_{c,}$ particularly in August and September.

Since these most critical months of the growing season will become much drier, sustaining present crop yield levels in northwest Ohio will be difficult unless a supplemental water supply is available. With growing season crop water needs expected to increase going forward, water capture and subirrigation systems will become increasingly valuable. As previously suggested, subirrigation might be best managed, if there is limited water storage/supply, through conserving water by subirrigating only in the most critical part of the growing season (middle July to middle September).

3.6 Further Research Needs

This study used daily rainfall projections that have been primarily aggregated to monthly and seasonal value, and therefore does not explicitly consider the projected increased frequency of intense rainfall events at daily timescales (U.S. Global Change Research Program, 2009). Additionally, the climate projections implemented in this study are of insufficient spatial resolution to resolve the convective processes responsible for most intense/heavy precipitation events in the Midwest U.S. Intense rainfall, particularly when it occurs during the latter half of the growing season after deep vertical soil crack preferential flow pathways have formed, is often immediately lost offsite via subsurface drainage, but could potentially be captured and used with water management systems such as those described here. However, future research to estimate these benefits would require projected and downscaled precipitation intensity, of sufficient spatial and temporal resolution, which is not yet available, and a hydrologic modeling approach capable of capturing this process. Additional research is needed to determine the water storage capacity required to meet future crop water needs using subirrigation, as well as the most economical designs and load reduction benefits under future climate change conditions.

4. Summary and Conclusions

Historical crop yield data from subirrigated and control fields, together with historical climate data and model-derived climate projections by three model combinations from the North American Regional Climate Change Assessment Program (NARCCAP) were used to estimate the increasing crop yield benefits of subirrigation under future climate conditions. Bias-corrected climate projections for Northwest Ohio using the three models with the A2 emissions scenario suggest that by mid-century (2041-2070) average daily temperatures will increase by 2.9°C-3.6°C, with little change in the diurnal temperature range for this location. Solar radiation was projected to increase by approximately 0.5 MJ meter^{-2} day^{-1} on average during the growing season by all three models, and together with the rising temperature will drive a substantial increase in growing season PET for both corn and soybeans. Precipitation projections showed substantially more uncertainty among the three models, with one model projecting an increase and two a decrease in average growing season precipitation. Whether precipitation increases or decreases, occurrences of a dry and very dry growing seasons were projected to be more common and more intense in all three models.

Five dryness/wetness categories based on quintiles of growing season dryness/wetness index for each crop (corn and soybeans) during 1984 to 2013 were used to substantiate the benefit of subirrigation under various climate conditions. In the future (2041 to 2070), the percentage of dry or very dry growing seasons is expected to essentially double. The historical crop yield benefit observed at all three sites can be expected to increase even more under future climate conditions. For corn, the observed yield increase of 20.5% from 1996-2008 was projected to rise in mid-century to a yield increase of 27.5 to 30.0% due to subirrigation. For soybeans, the observed 1996-2008 subirrigated yield increase of 12.7% was projected to exapnd to a yield increase of 19.8 to 21.5% in the 2041-2070 period. The increased yield benefits predicted using all three model combinations, even one in which precipitation was projected to increase, shows the importance of PET projections which were calculated using Priestly Taylor which takes into account both solar radiation and temperature.

These results imply that given the predicted greater frequency of drier growing seasons for northwest Ohio in 2041-2070, agricultural systems combining water capture, storage, and subirrigation reuse, can in coming years potentially have a very positive impact on sustaining agricultural production in northwest Ohio and other regions within the Midwest U.S., and should be studied more widely as a climate change adaptation strategy.

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Figure 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).

Figure 2. Derived crop coefficient curves are shown for Corn (solid line) and Soybeans (dashed line) for northeast Indiana, 1984-2013. The average growing season length for corn was 171 days and 146 days for soybeans. Average planting date for corn was May 10th and May 21st for soybeans.

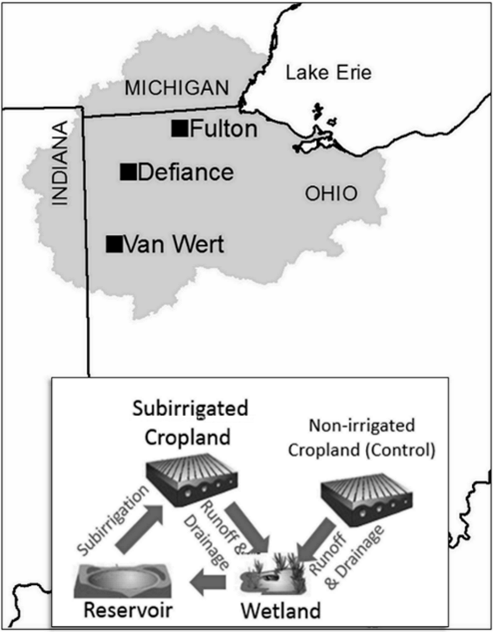
Figure 3. Histogram showing projected (2041-2070) shifts in the categorical distribution (Very Low to Very High) of growing season precipitation in the three climate projections when compared to the projection derived historical data (1971-2000). Historically, each category would have 6 growing seasons.

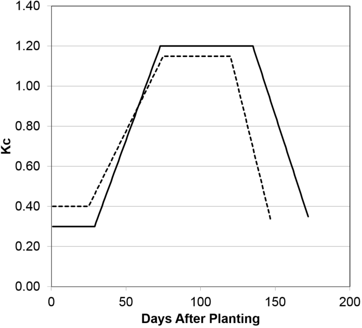
Figure 4. Observed annual crop yield differences (bars) between subirrigated fields minus control fields and dryness/wetness indexs (symbols) for the WRSIS sites in Defiance, Fulton and Van Wert Counties. Corn (a) and soybean (b) were calculated separately. Dashed lines are the boundaries of the growing season dryness/wetness index quintile value limits based on the 30-year period 1984-2013, with quintile categories: VD = Very Dry; D = Dry; NN = Near Normal; W = Wet; and VW = Very Wet.

Figure 5. Drier soil in the subirrigated (S) compared to the free drainage (D) field is evident in this aerial photo of the Fulton County WRSIS obtained by the Ohio Geographically Referenced Information Program (http://ogrip.oit.ohio.gov/) six days after a 36 mm rainfall event. The wetland is labeled "W", and the storage reservoir is labeled "R". The two fields were bare of vegetation and lighter shades of grey indicate a dry soil surface, while darker shades of grey indicate a wetter soil surface.

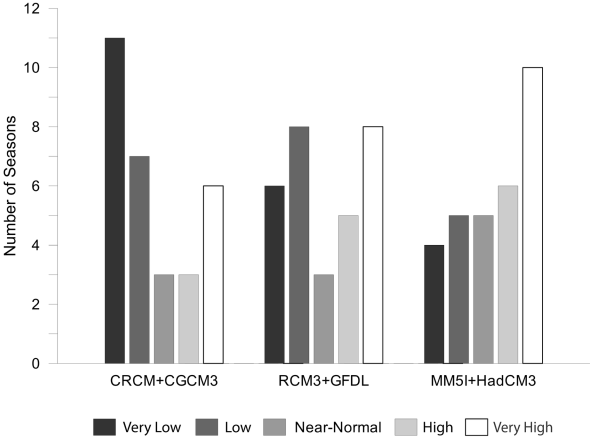
Figure 6. Monthly *DWI* versus overall growing season *DWI*; (a) early growing season (May/June) and (b) later growing season (July/August/September).

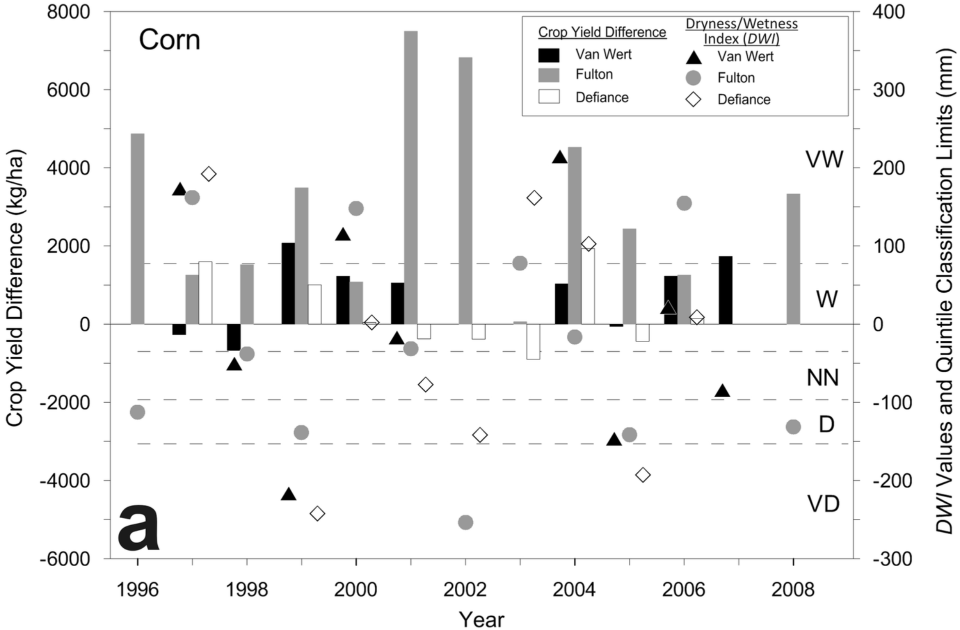
Figure 7. Average monthly and total growing season *DWI* for corn and soybeans for the historical period (1984-2013) and projected future (2041-2070).


Lake Erie
MICHIGAN
INDIANA
Fulton
Defiance
OHIO
Van Wert
Subirrigated Cropland
Non-irrigated Cropland (Control)
Subirrigation
Runoff & Drainage
Runoff & Drainage
Reservoir
Wetland

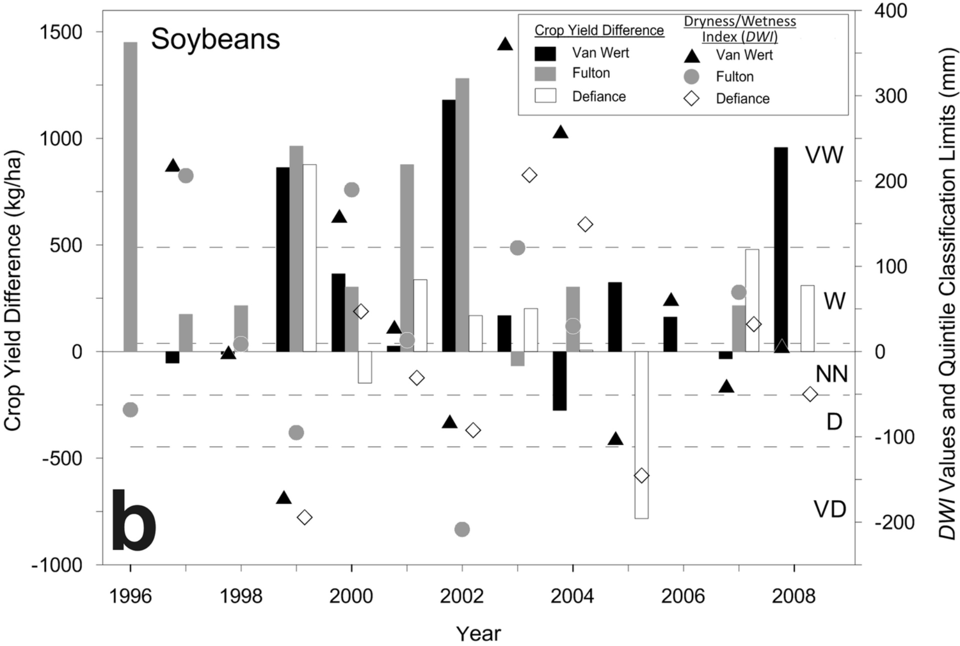


1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
Kc
0
50
100
150
200
Days After Planting

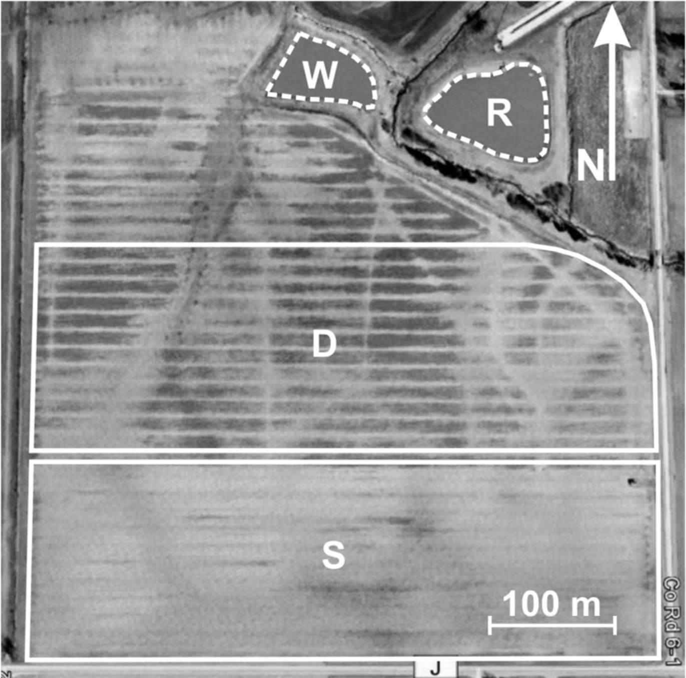

12
10
8
6
4
2
0
Number of Seasons
CRCM+CGCM3
RCM3+GFDL
MM5I+HadCM3
Very Low
Low
Near-Normal
High
Very High



Corn
a
Crop Yield Difference
Van Wert
Fulton
Defiance
Dryness/Wetness Index (DWI)
Van Wert
Fulton
Defiance
VW
W
NN
D
VD
8000
6000
4000
2000
0
-2000
-4000
-6000
400
300
200
100
0
-100
-200
-300
Crop Yield Difference (kg/ha)
DWI Values and Quintile Classification Limits (mm)
1996
1998
2000
2002
2004
2006
2008
Year



Soybeans
b
Crop Yield Difference
Van Wert
Fulton
Defiance
Dryness/Wetness Index (DWI)
Van Wert
Fulton
Defiance
VW
W
NN
D
VD
1500
1000
500
0
-500
-1000
400
300
200
100
0
-100
-200
Crop Yield Difference (kg/ha)
DWI Values and Quintile Classification Limits (mm)
1996
1998
2000
2002
2004
2006
2008
Year


W
R
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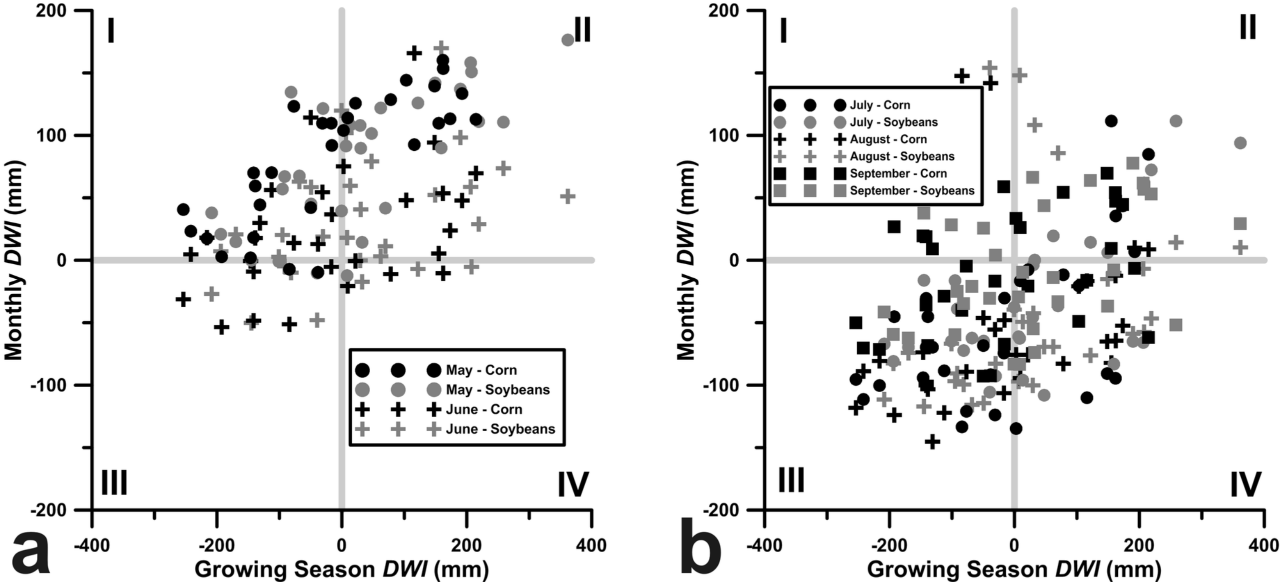
200
100
0
-100
-200
Monthly DWI (mm)
-400
-200
0
200
400
Growing Season DWI (mm)
I
II
III
IV
May - Corn
May - Soybeans
June - Corn
June - Soybeans
a
200
100
0
-100
-200
Monthly DWI (mm)
-400
-200
0
200
400
Growing Season DWI (mm)
I
II
III
IV
July - Corn
July - Soybeans
August - Corn
August - Soybeans
September - Corn
September - Soybeans
b

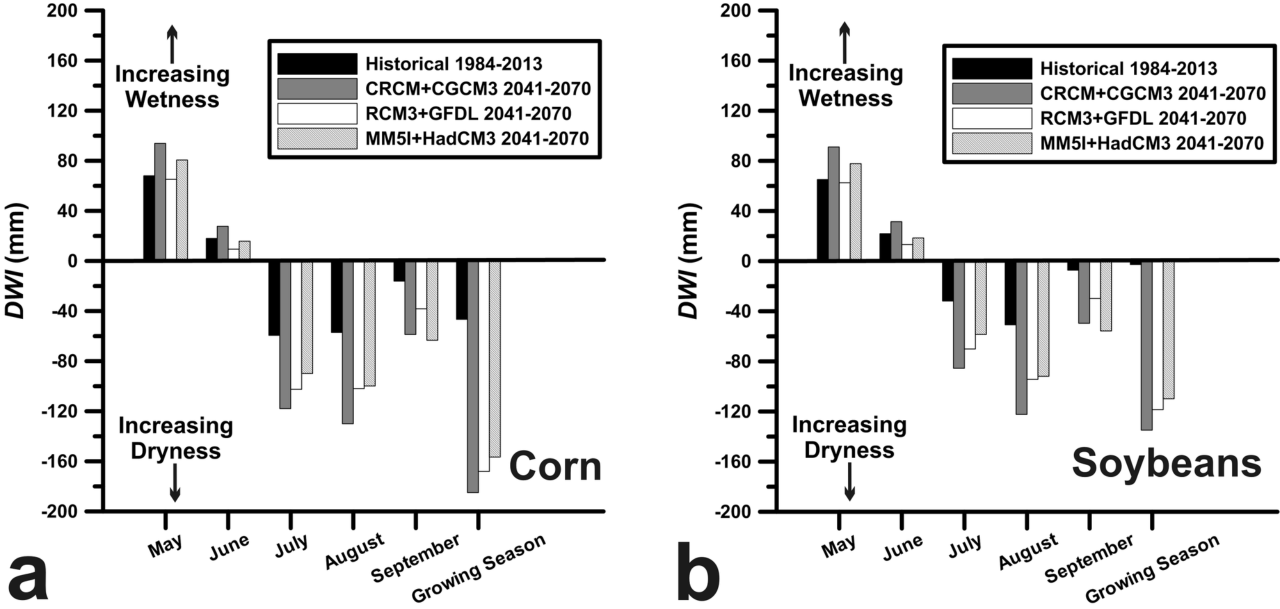
a
DWI (mm)
200
160
120
80
40
0
-40
-80
-120
-160
-200
Increasing Wetness
Increasing Dryness
Historical 1984-2013
CRCM+CGCM3 2041-2070
RCM3+GFDL 2041-2070
MM5I+HadCM3 2041-2070
May
June
July
August
September
Growing Season
Corn
b
DWI (mm)
200
160
120
80
40
0
-40
-80
-120
-160
-200
Increasing Wetness
Increasing Dryness
Historical 1984-2013
CRCM+CGCM3 2041-2070
RCM3+GFDL 2041-2070
MM5I+HadCM3 2041-2070
May
June
July
August
September
Growing Season
Soybeans

Table 1: Site information for the three WRSIS sites used in this study (Allred et al., 2014a; 2014b; 2003)

Site	Location	Subirrigated field area (ha)	Non-irrigated field area (control) (ha)	Volume of wetland + reservoir (m^3)	*Dominant soil* (Avg Ksat in cm/s)	Drain spacing of subirrigated field(s) (m)	Drain spacing of control field (m)
Defiance County	41.33 N, 84.43 W	2.2 ha	8.1	700 + 2950	*Paulding clay* (10^{-5} cm/s)	2.4, 4.9	6.1, 12.2
Fulton County	41.60 N, 83.98 W	8.1	8.1	3790 + 8706	*Nappanee loam* (10^{-4} cm/s)	4.6	13.8
Van Wert County	40.88 N, 84.56 W	12.2	6.1	8710 + 12870 (original) to 3680+28330	*Hoytville clay* (3×10^{-4} cm/s)	5.3	10.6

Table 2. External climate and agricultural data sources implemented in this study to evaluate the potential benefits of WRSIS systems under historical and projected climate conditions.

Dataset	Time Period	Variables	Type	Resolution (Temporal/ Spatial)	Source	Reference
Global Historical Climatology Network-Daily (GHCN-D)	1971-2013	Average Temperature, Precipitation	Point Data	Daily/-	Applied Climate Information System (ACIS)	Menne et al., 2011; www.rcc-acis.org
Prediction of Worldwide Energy Resource (POWER)	1984-2013	Solar Radiation	Gridded	Daily/1°x1°	National Aeronautics and Space Administration (NASA)	Hoell et al., 2005; White et al., 2011
Crop Progress and Condition Reports	1984-2013	Crop Development Stage for corn and soybeans	Spatial Average	Weekly/Multi-County Average	United States Department of Agriculture, National Agricultural Statistics Service (USDA/NASS)	https://www.nass.usda.gov/Statistics_by_State/Indiana/index.php; Greg Matli, personal communication, 8/27/2015
North American Regional Climate Change Assessment Program (NARCCAP)	1971-2000; 2041-2070	Maximum Temperature, Minimum Temperature, Average Temperature, Precipitation, Solar Radiation	Gridded	3 hour/50 km	North American Regional Climate Change Assessment Program (NARCCAP)	Mearns et al., 2009

Table 3. Growing season (May-September) mean values from the three historical climate sites and the filled Defiance series from 1984-2013 and relative changes between the modeled historical data (1971-2000) and the future projections (2041-2070) for each model, positive (negative) values indicate a future increase (decrease).

Climate data	Max Temp. (°C)	Min Temp. (°C)	Avg. Temp. (°C)	Precip. (mm)	Solar rad. (MJ m2 day-1)	PET_c Corn (mm)	PET_c Soybean (mm)
Mean values for 1984-2013							
Observed							
Defiance			20.1	449	19.4	515	472
Van Wert			20.4	502	19.4	519	476
Wauseon			19.6	448	19.4	507	464
Filled Defiance			20.1	450	19.4	515	470
Deviations of the future period (2041-2070) from the modeled historical data (1971-2000)							
Projections							
CRCM+CGCM3	3.9	3.3	3.56	-29	0.48	58	52
RCM3+GFDL	3.3	3	3.12	0	0.48	52	47
MM5I+HadCM3	2.8	3	2.91	37	0.59	53	48

Table 4. Observed bias in model-derived historical data bias for analyzed variables. Historical model period is 1971-2000.

Dataset	Daily Average Temperature (°C)	Daily Total Precipitation (mm)	Daily Solar Radiation (MJ m^{-2} day^{-1})	Daily Maximum Temperature (°C)	Daily Minimum Temperature (°C)
CRCM+CGCM3	-1.1	0.9	0.88	-0.60	-1.7
RCM3+GFDL	-3.3	0.8	0.99	-5.1	-1.5
MM5I+HadCM3	-2.0	1.0	0.98	-2.6	-1.3

Table 5. Bias-corrected historical modeled data and Observations (GHCN-D) for the growing season for the period from 1971-2000.

Dataset	Max Temp. (°C)	Min Temp. (°C)	Avg. Temp (°C)	Precip (mm)	Solar (MJ m^{-2} day^{-1})	PET (mm)	PET_c Corn (mm)	PET_c Soybean (mm)
Observations (GHCN-D)	26.1	13.9	20.0	450	19.34	619	515	470
CRCM+CGCM3	27.8	12.7	20.2	429	19.70	623	528	482
RCM3+GFDL	25.3	12.7	19.0	410	20.18	625	527	480
MM5I+HadCM3	27.0	13.2	20.1	450	20.62	645	525	481

Table 6. 1984 to 2013 quintile value limits[1] for northwestern Ohio growing season dryness/wetness classification based on dryness/wetness index.

Dryness/ Wetness Quintiles	Growing Season Crop Water Deficit Classification Limits	
	Corn (mm)	Soybeans (mm)
Very Wet	> 77.4	> 122.1
Wet	-34.9 to 77.4	9.6 to 122.1
Near Normal	-96.6 to -34.9	-51.0 to 9.6
Dry	-153.1 to -96.6	-111.6 to -51.6
Very Dry	< -153.1	< -111.6

[1] Data from NOAA weather stations in Defiance, OH; Van Wert, OH; and Wauseon, OH were used in determining these 1984 to 2013 growing season dryness/wetness quintile value limits.

Table 7. Number of site years and observed average crop yield increase in each dryness/wetness category[1] for the three sites from 1996-2008.

Crop		Very Dry (VD)	Dry (D)	Near Normal (NN)	Wet (W)	Very Wet (VW)	All Growing Seasons
Corn	Number of site years	4	6	4	6	10	30
	Percent of total (30) corn site years	13.3	20.0	13.3	20.0	33.3	100.0
	Average corn crop yield increase (%CYI) (%)	32.4	27.0	6.5	35.1	8.6	20.5
Soybeans	Number of site years	4	5	6	8	8	31
	Percent of total (31) soybean site years	12.9	16.1	19.4	25.8	25.8	100.0
	Average soybean crop yield increase (%CYI) (%)	24.4	25.6	10.4	7.8	3.7	12.2

[1] Growing season dryness/wetness categories based on analysis of climate record during the period from 1984 to 2013.

Table 8. Correlation between monthly dryness/wetness index/excess (*DWI*) and the crop yield difference (CYdifference) between subirrigated fields and control fields.

Crop	Pearson Correlation Coefficient (r): Monthly or Growing Season *DWI* vs CYdifference				
	May	June	July	August	September
Corn	-0.12	0.03	-0.23	-0.09	-0.33
Soybeans	-0.07	0.06	-0.38	-0.28	-0.38

Table 9. Growing season wetness/dryness and agricultural water recycling subirrigated field crop yield increase (versus free drainage) for northwest Ohio based on CRCM+CGCM3, RCM3+GFDL, or MM5I+HadCM3 modeled climate change projections for 2041 to 2070.

Model Combination	Crop	Very Dry % and (#)	Dry % and (#)	Near Normal % and (#)	Wet % and (#)	Very Wet % and (#)	Overall Crop Yield Increase %
CRCM+CGCM3	Corn	66.7 (20)	13.3 (4)	13.3 (4)	3.3 (1)	3.3 (1)	27.5
	Soybeans	63.3 (19)	16.7 (5)	13.3 (4)	3.3 (1)	3.3 (1)	21.5
RCM3+GFDL	Corn	50.0 (15)	23.3 (7)	6.7 (2)	20.0 (6)	0.0 (0)	30.0
	Soybeans	50.0 (15)	23.3 (7)	6.7 (2)	20.0 (6)	0.0 (0)	20.4
MM5I+HadCM3	Corn	60.0 (18)	13.3 (4)	10.0 (3)	13.3 (4)	3.3 (1)	28.7
	Soybeans	53.3 (16)	16.7 (5)	13.3 (4)	13.3 (4)	3.3 (1)	19.8