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**Final Report**

**PROJECT TITLE**: Agricultural production and the hydrologic cycle in the Upper Midwest

**PROJECT NUMBER**: MN CORN RES & PROMO COUNCIL/4101-15SP (no cost extension)

**PRINCIPAL INVESTIGATOR AND CO-INVESTIGATOR(S):** Tim Griffis, John Baker, Jeff Wood and John Nieber

**ABSTRACT**

This research project was designed to gain a better understanding of how agriculture fits within the regional water cycle in the Upper Midwest and to provide growers tools for estimating evapotranspiration (ET). We used a combination of isotope and eddy covariance measurements made at the field and regional scales, and will also used meso-scale modeling to determine agriculture’s contribution to regional ET and atmospheric water vapor. Further, we developed a tool called (ETool, https://www.biometeorology.umn.edu/research/etool) and provided weekly forecasts from 2014 to 2016 of precipitation and ET to assist growers in Minnesota with the aim of improving agricultural water use. We believe our research benefited farmers by: **(1)** improving our understanding of the impacts of weather and climate on ET; **(2)** quantifying the amount of water that agricultural crops use under a broad range of environmental conditions; **(3)** determining the role that agriculture plays in the regional hydrologic cycle; and **(4)** developinga state-of-the-art tool for supporting farm-level water management decision-making. We will continue to make ETool product available through 2017.

**INTRODUCTION**

Understanding the relationships between agriculture and the hydrologic cycle is of critical importance to enhancing agricultural productivity. Mean precipitation is projected to increase in wet continental areas, however, it is expected to fall as rain during intense convective storms—increasing the risks of runoff and flooding in spring, and susceptibility to periods of water deficit during summer. Indeed, there have been observations that increased precipitation has been matched or exceeded by increased runoff in watersheds dominated by corn-soybean agriculture.

Irrigation is most effective when used in humid climates, where water scarcity is not a significant impediment to crop growth, and there are substantial available water resources [Tanner and Sinclair, 1983]. Although irrigation rates in Minnesota are expected to be relatively modest owing to the humid climate [Baker et al. 2012], groundwater appropriation permit evaluation processes and mechanisms for altering existing permits are evolving to ensure long-term groundwater sustainability [DNR, 2013]. With the expansion of irrigation, a larger number of growers must share finite resources, which may have implications on the granting and sizes of permitted withdrawals. This underscores the need for a multi-faceted approach to agricultural water management. This approach could be viewed as an ‘insurance policy’ that mitigates risks by simultaneously implementing water conservation and irrigation, to make for a more robust production system. Our research is aimed at **(1)** determining agriculture’s current contribution to regional evapotranspiration (ET); and **(2)** assessing the effects of improved water management practices from both productivity and regional hydrologic perspectives.

**OBJECTIVE AND GOAL STATEMENTS**

The objectives of this research were to:

* Determine agriculture’s contribution to regional ET,
* Determine the water demands that would be exerted in order to accommodate increasing levels of irrigation, and
* Use the research capacity that is established to answer science questions to develop ETool, a resource to assist with farm-level irrigation water management decision-making.

**MATERIALS AND METHODS**

* Field and regional-scale measurements of ET using the eddy covariance approach
* Tall tower regional observations of the oxygen and hydrogen isotope composition of water vapor
* High performance computing through the Minnesota Supercomputing Institute (MSI)
* Application of the Weather Research and Forecasting Model to provide hourly forecasts of precipitation and ET

**RESULTS AND DISCUSSION**

The key findings from this research are as follows:

* Analysis of long-term (10 years) eddy covariance data from corn and soybean sites indicate that ET ranges from about 423 mm to 592 mm (an average of 522 +/- 52 mm)
* In general, ET from corn and soybean exceeds that of native prairie vegetation (i.e. 435 mm per year as observed in 2016).
* During years of notable drought such as 2003 and 2012, ET was 100 mm lower than the 10-year average. Thus, during these years the demand for water/irrigation can be significant and changes in climate are likely to exacerbate this situation. Most climate projections indicate warmer and wetter springs and warmer and drier summers.
* The mid-summer maximum ET rate from corn exceeds that of other crops and especially natural vegetation such as native prairie.
* The mid-summer maximum ET rate from corn also exceeds evaporation from large lakes within the region (Xiao et al., 2017), although annual lake evaporation is larger (i.e. White Bear Lake evaporation ranged from 550 to 780 mm from 2014 to 2016. Crops act to intensive the hydrologic cycle. They transpire significant quantities of water over a much shorter period of time compared to natural systems.
* Isotope observations and analyses show that agricultural crops contribute significantly to water vapor in the atmosphere. Tropical-like dew-point events that occur during the summer have a strong link to transpiration from crops. Our isotope and modeling studies show that agricultural crops can contribute to as much as 60% of that signal. This implies that agriculture can enhance convective precipitation and water recycling within the region.
* Our long-term observations of ET were used to validate the Weather Research and Forecasting (WRF) model and to help improve the ET forecasts for the region.
* We implemented near real-time satellite observations to obtain regional leaf area index, which helped to improve the ET forecast product.
* Weekly forecasts of hourly precipitation and ET (at 3 km resolution) were made available at our website for public access for the years 2014-2016.
* These forecasts have relatively high accuracy when compared to our tall tower observations. We believe these forecasts and can permit accurate forward calculations of water use and irrigation estimates. Thus, this tool has potential to help us better manage water within the region.
* These forecasts will be made available for the 2017 growing season with an improved graphical interface. Outside consulting firms have also expressed interest in using our approach for forecasting ET in other parts of the world.

**CONCLUSIONS**

Increasing atmospheric humidity and convective precipitation over land provide evidence of intensification of the hydrologic cycle – an expected response to surface warming. Climate observations and models indicate that the precipitation frequency and distribution is changing in Minnesota. We are getting more frequent and more extreme events with wetter springs and drier summers. These changing patterns require that we have monitoring and modeling systems that can be used to help us better manage our water resources. Through this project we made novel observations that provided information regarding evapotranspiration rates from crops over a broad range of environmental conditions and the isotope composition of water vapor in the atmosphere. We used this information to examine the importance of agricultural to the regional water balance. Further, we used this information to improve and validate a regional model that can be used to forecast precipitation and evapotranspiration for the region.

**EDUCATION, OUTREACH, AND PUBLICATIONS**

* This research supported the training of highly-qualified personnel including a postdoctoral researcher and a PhD student.
* Results from this research were presented at the 31st Conference on Agricultural and Forest Meteorology, American Meteorological Society, Portland OR, 12-15 May, 2014.
* Results from this research were presented at the 32nd Conference on Agricultural and Forest Meteorology, American Meteorological Society, Salt Lake City, Utah, 12-15 May, 2014.
* ETool has been made available online to provide farmers with easy access to data that supports irrigation water management.
* Results from this research were published in two of the top journals in atmospheric science including *Atmospheric Chemistry and Physics* and *Geophysical Research Letters* with a final manuscript in preparation for a special issue in *Agricultural and Forest Meteorology*
* Minnesota Public Radio featured a story related to this research <http://www.mprnews.org/story/2016/07/22/feeling-sweaty-minnesota-blame-corn-crops>
* Our paper published in *Atmospheric Chemistry and Physics* has received considerable attention and, to date, has been accessed over 1300 times

**REFERENCES and PUBLISHED WORK**

Research support from the Minnesota Corn Growers Association helped us published the following papers:

"Investigating the source, transport, and isotope composition of water vapor in the planetary boundary layer", T.J. Griffis, J.D. Wood, J.M. Baker, X. Lee, K. Xiao, Z. Chen, L.R. Welp, N. Schultz, G. Gorski, M. Chen, and J. Nieber ([Atmospheric Chemistry and Physics, 2016, 16, 5139-5157, doi:10.5194/acp-16-5139-2016](https://www.biometeorology.umn.edu/sites/biometeorology.umn.edu/files/griffis_2016_acp.pdf)) [ACP Discussion](http://www.atmos-chem-phys.net/16/5139/2016/) [Minnesota Public Radio](http://www.mprnews.org/story/2016/07/22/feeling-sweaty-minnesota-blame-corn-crops)

"Multi-scale analyses of solar induced fluorescence and gross primary production", J.D. Wood, T.J. Griffis, J.M. Baker, C. Frankenberg, M. Verma, and K. Yuen ([Geophysical Research Letters, 2017, 44, 533-541, doi: 10.1002/2016GL070775](https://www.biometeorology.umn.edu/sites/biometeorology.umn.edu/files/wood2017grl.pdf))

“Evaporation from a temperate closed-basin lake and its impact on present, past, and future water level”, K. Xiao, **T.J. Griffis**, J.M. Baker, P. Bolstad, M. Erickson, X. Lee, J.D. Wood, and C. Hu (*Water Resources Research*, submitted)

“An evapotranspiration forecasting system for improving irrigation water management in a humid continental climate”, K. Xiao, T.J. Griffis, J.M. Baker, and J.D. Wood (in preparation for Agricultural and Forest Meteorology special issue)