Estimation of Aeration Stress Effects On Crop Yields in Midwest USA

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Introduction

Crop yields are closely related to soil moisture conditions during the growing season. Excess soil moisture results in a deficiency of oxygen and increase of carbon dioxide in the root zone, resulting in leaf chlorosis and reduced growth, especially in the early growing season. The potential for excess water can be widely found in the Midwestern US, where poorly drained soil contributes to a high water table. Subsurface drainage is commonly used to make such fields workable, however, the increasing precipitation and a move towards growing biofuel feedstock crops on marginal lands means that the potential adverse impacts of aeration stress on the crop yields need to be critically evaluated.

Objectives

1. Examine the capability of SWAT to capture soil moisture content at the field scale for two sites with 6-7 years of continuous and bias-corrected soil moisture data at different depths.
2. Explore the ability of the model to predict crop yields using extended historic climate data and NASS county level yield data (1941-2010)
3. Investigate the robustness of model on representing crop growth responses under climate variability.

Study Area

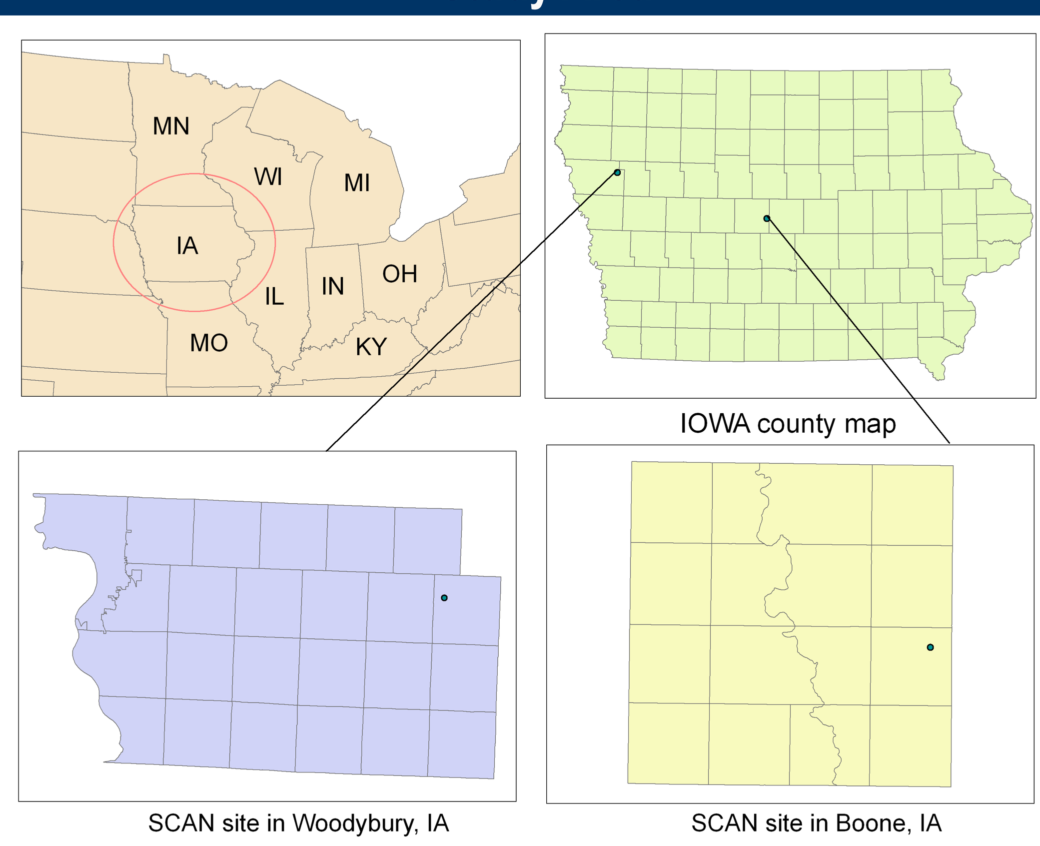


Fig.1 Relative locations of study areas

Data and Method

1. The Soil and Water Assessment Tool (SWAT): SWAT, which was developed by USDA-ARS, is one of the most popular models to assess the impact of climate variability on hydrologic process and crop productions. In SWAT, crop yields are mainly affected by temperature, drought, aeration and nutrient (N & P) stresses. Major hydrologic processes simulated by the model are simply shown on Fig. 2

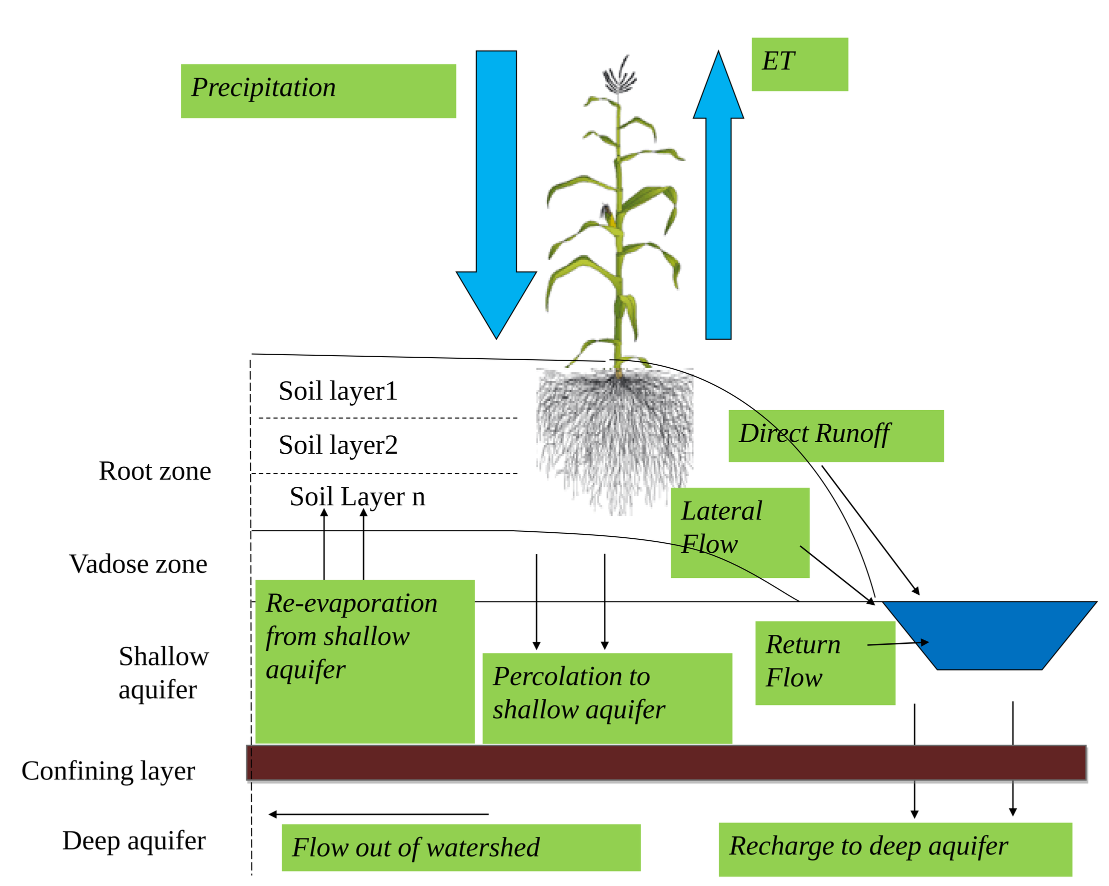


Fig.2 SWAT model structure

2. Soil moisture data: Layer specific soil moisture contents were obtained from the NRCS-Soil Climate Analysis Network (SCAN). The system focuses on agricultural areas of the U.S., monitoring soil moisture content at several depths that are collected by a dielectric constant measuring device. Typical measurements are at depths of 2, 4, 8, 20 and 40 inches.

3. Soil character data: Layer specific soil properties (bulk density, field capacity, etc) are provided by SCAN sites. Porosity is estimated by Van Genuchten method.

4. County level crop yield data: Annual corn and soybeans grain yields are collected from USDA-National Agricultural Statistics Service (NASS). Crop yield data was obtained for the county containing the SCAN site.

Model Improvement

1. Aeration stress algorithm: calculate aeration stress (AS) based on layers directly related to root depth.
2. Drought stress: introduce a response function in drought stress (DS) to reduce the variability of annual crop yields caused by drought factor.

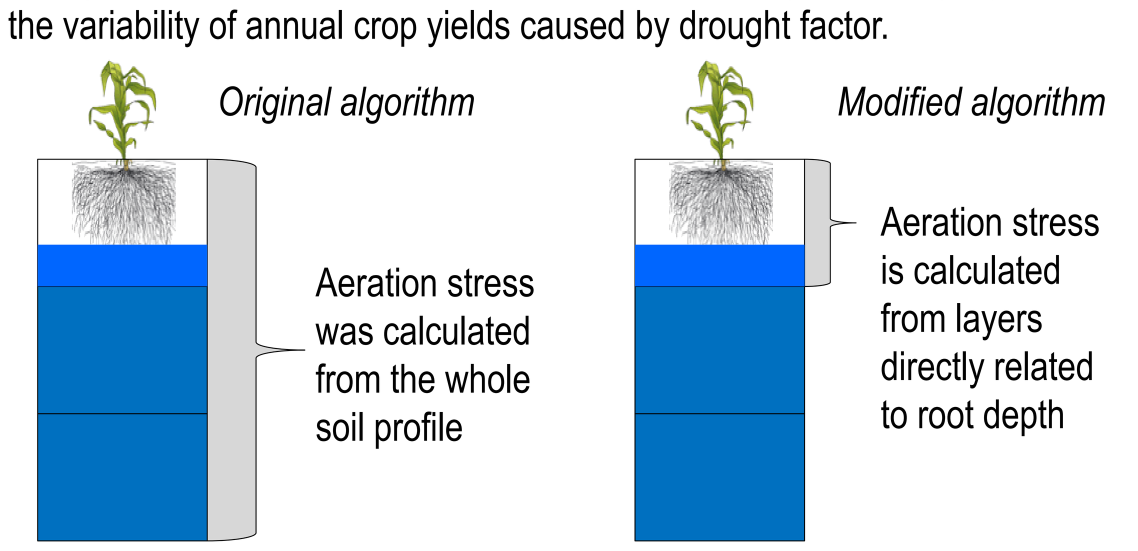


Fig. 3 Aeration stress algorithm modifications

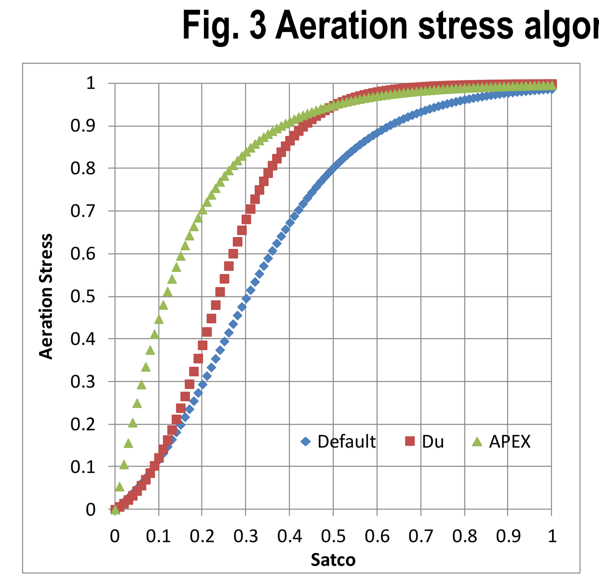


Fig. 4 Aeration stress calculation curves

> Satco is the fraction of saturation over the field capacity.

> SWAT calculates or scales aeration stresses based on satco through different methods.

> From Fig. 4, default and Du's (2005) method induced less variation in aeration stress when satco is low (0-0.2)

> We have introduced a similar scaling function for drought stress.

> Severe drought stress will not be significantly affected, but moderate and small drought stresses will be reduced based on transformation method 6 (DS6).

> Compared to other methods, DS6 causes less variability in annual crop yields. (See details in Fig. 7)

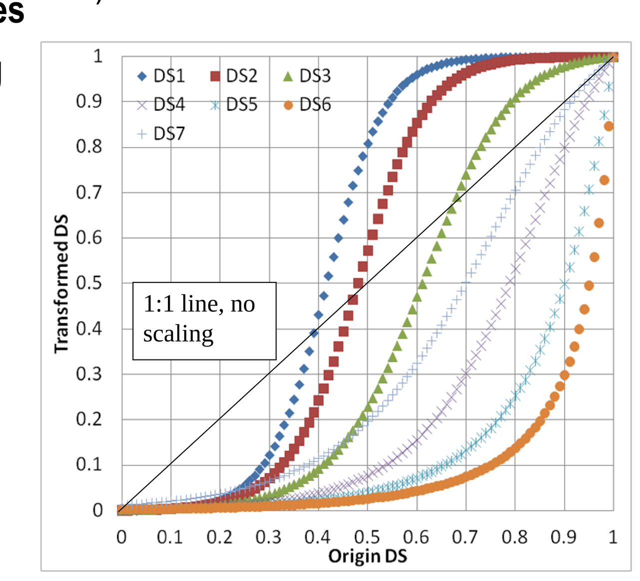


Fig. 5 Drought stress scaling curves

Results (Objective 1)

Soil moisture calibration

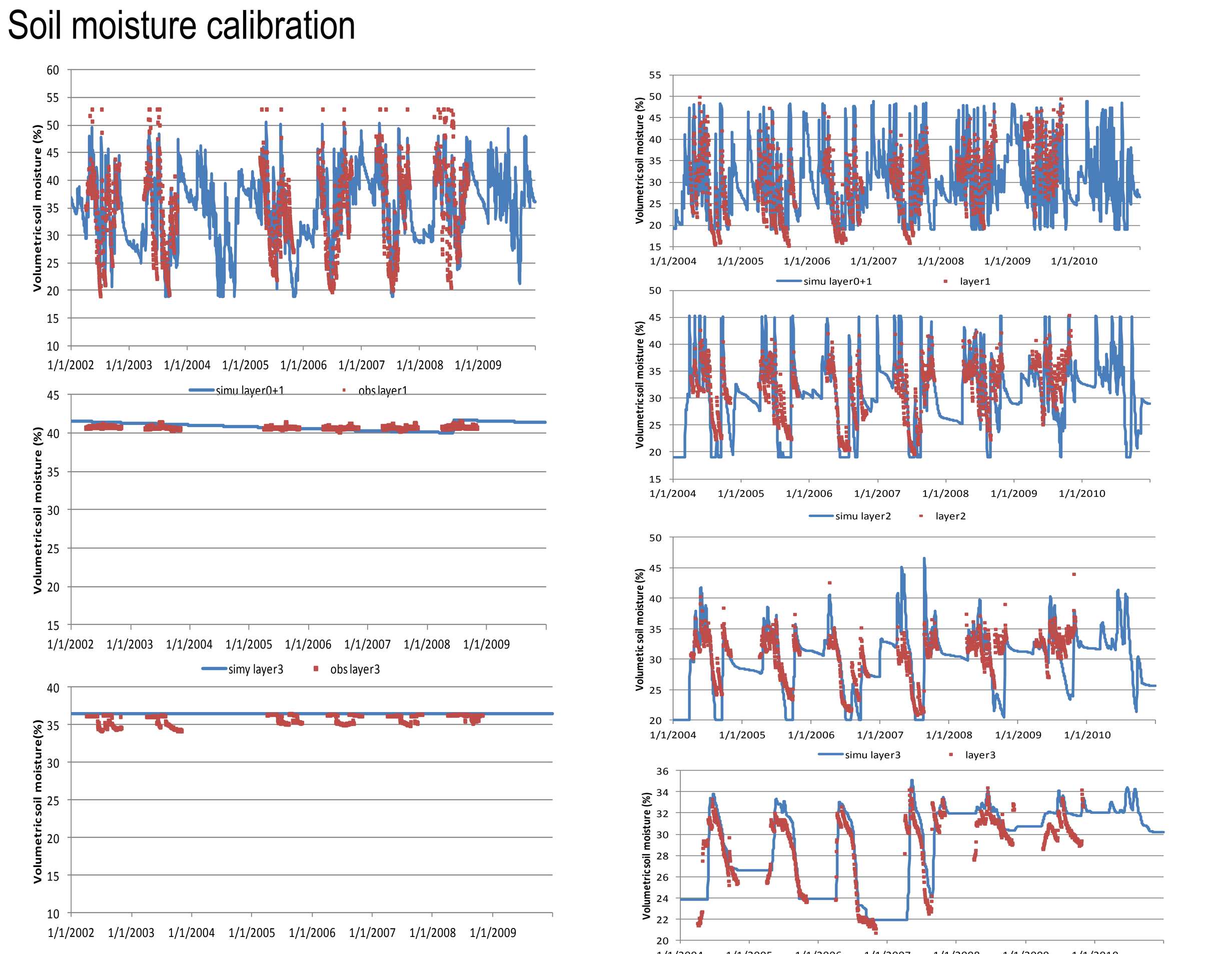


Fig. 6 Model performance vs. observed soil moisture at different depths. (Left: Boone, IA; Right: Woodbury, IA)

Model parameters that control different hydrological processes, such as: ET process (ESCO, EPCO, esd, rootmax); surface runoff (CN, surlag); groundwater (GW_delay, Indep_Bsn); soil properties (Ksat, pwp) were adjusted to calibrate soil moisture to observations.

Table 1 Model performance after calibration

	Mass Balance Error (%)						
Boone, IA	2002	2003	2005	2006	2007	2008	Mean
Layer1	2.59	-4.20	-0.36	8.17	1.09	0.75	1.33
Layer3	1.42	1.06	-0.14	-0.68	-1.33	0.71	0.17
Layer6	3.18	3.24	1.79	1.92	1.70	0.84	2.11
Woodbury, IA	2004	2005	2006	2007	2008	2009	Mean
Layer1	-0.21	4.08	-2.03	0.02	-8.00	-19.70	-5.28
Layer2	-2.30	-3.14	-1.56	1.77	-2.36	-8.69	-2.87
Layer3	-2.33	-2.24	-1.80	11.08	-5.90	-5.99	-1.42
Layer5	0.24	2.16	3.16	-0.61	3.06	5.82	2.33

Results (Objective 2)

Observed vs. simulated crop yield

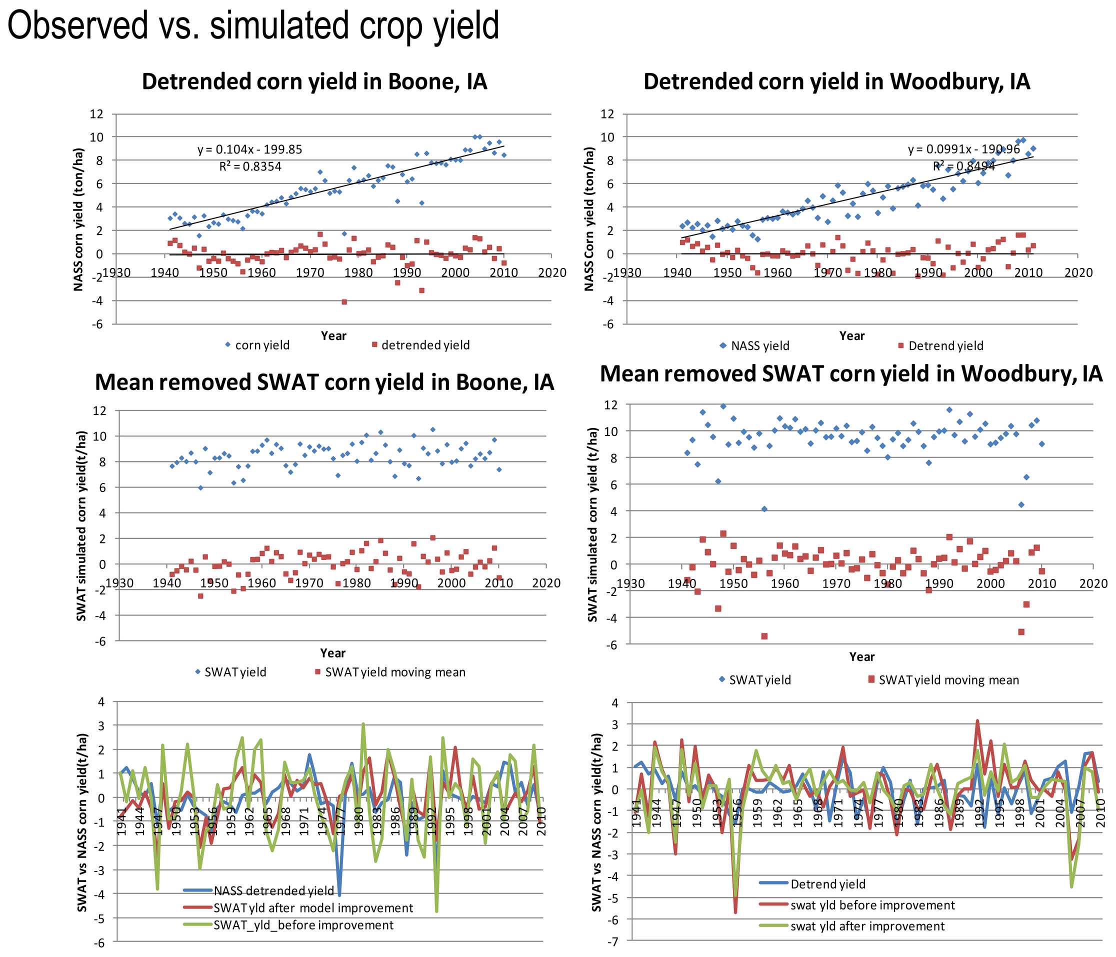
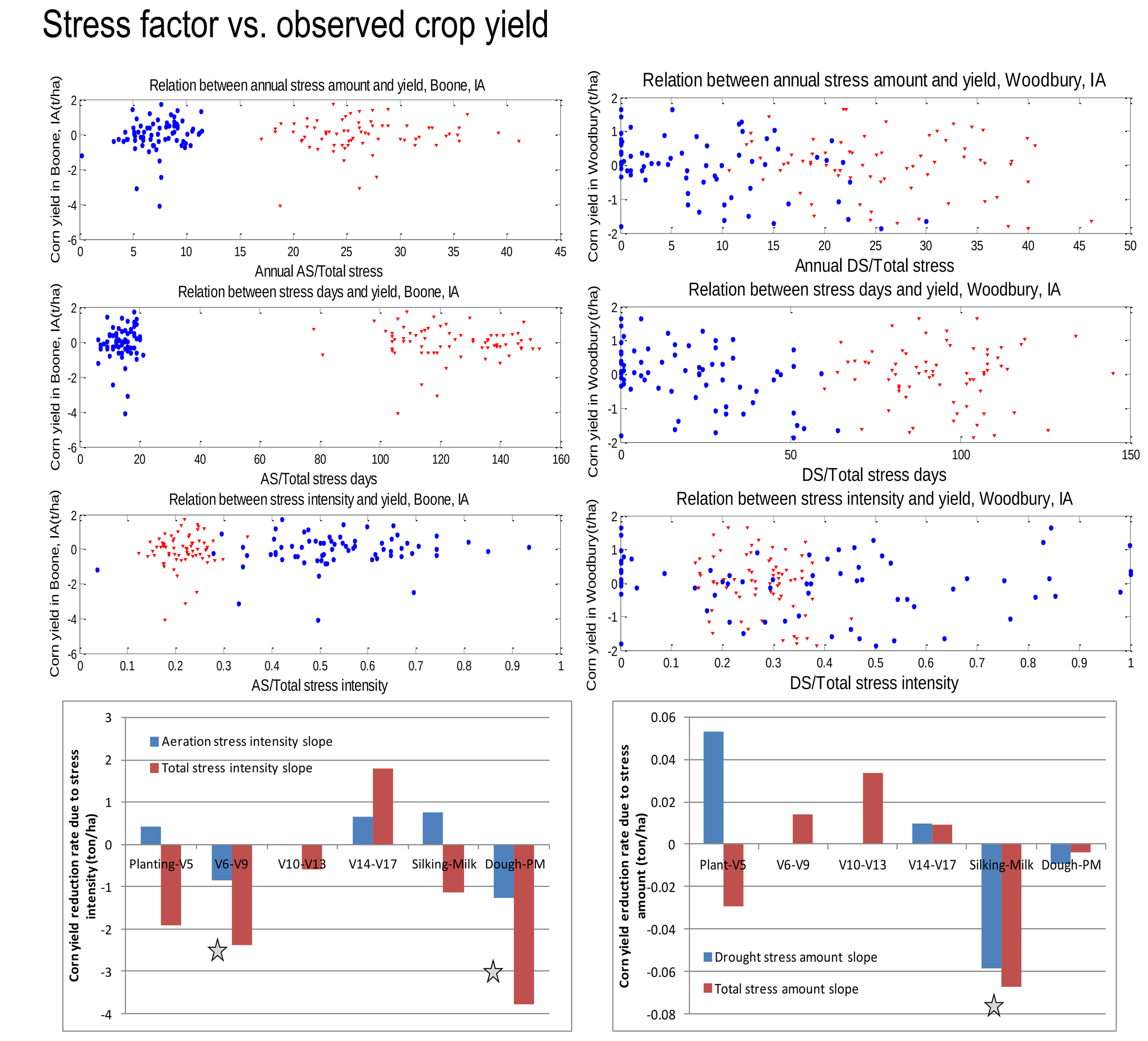


Fig. 7 Observed vs. SWAT crop yield for Boone (left), and Woodbury, IA (right)

> Modified model reduced simulated yield variability substantially in Boone, IA.
> Modified model had limited impact on variability in Woodbury, IA, which is dominated by two extreme points in 1956 and 2006.
> Model is over sensitive to stresses in rapid growth period as defined by heat units in SWAT (Outliers in 1956 and 2006 in Woodbury)
> Model only considers daily biomass reduction. Plant can always recover (Simulated crop recovered with late season rain in 1977 in Boone)

Results (Objective 3)

Stress factor vs. observed crop yield



☆ means the relationship between crop yield and stress index in each growth period is significant.

Fig. 8 The relationship between crop yield and stress indices

> Relationships of the three seasonal stress indices (total stress amount, stress days and stress intensity) with observed yield were evaluated. Annual correlations were found to be weak, so analysis focused on specific physiological stages.
> Seasonal total drought stress amount is correlated with crop yield in Woodbury, IA.
> Aeration and total stress intensity in V6-V9 and Dough-PM stages is significantly correlated with crop yield in Boone, IA.
> The relationship between total drought stress amount in Silking-milk stage and crop yield is significant in Woodbury, IA.

Conclusions

1. After appropriate parameter calibration, SWAT is an acceptable tool to simulate soil moisture conditions in Midwestern US.
2. Model modifications (Aeration stress calculation algorithm update and drought stress scaling) are helpful to reduce simulated yield variability, and in turn to enhance the model performance in crop yield prediction.
3. Crop yield is significantly correlated with growth stresses in some specific physiological stages. (V6-V9, Silking-Milk period)
4. SWAT still has trouble capturing yield for some years (1956, 1977, 2006), due to the structure of crop growth module (Biomass potential growth curve; daily biomass reduction due to stresses). The improvement of this module is our future work.

References

Du, B., J.G. Arnold, A. Saleh, and D.B. Jaynes. 2005. Development and application of SWAT to landscapes with tiles and potholes. *Trans. ASABE 48(3): 1121-1133.*