Water availability, root depths and 2017 crop yields

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Introduction

During 2016 and 2017, June-July precipitation was below normal in many parts of Iowa creating mid-season concerns about potential yield loss due to water stress. However, these concerns were not realized. In contrast, 2016 and 2017 crop yields over-performed yields obtained in many years with average or above average June-July precipitation. In Iowa, deep root systems, high soil water storage capacity, and shallow water tables are common explanations for high yields in years with below normal precipitation. How deep can roots grow? How much does groundwater contribute to the yields? To answer these questions and more, the Forecast and Assessment of Cropping sysTemS (FACTS) project was established in 2015 (Archontoulis and Licht, 2016). The FACTS project takes a systems approach to explain factors and mechanisms behind high or low yields while collecting ground-truth measurements from many trials around Iowa. Process-based modeling is used to integrate and extrapolate knowledge beyond study factors and weather-year (forecasts and scenario analysis). In this article, we report FACTS measured corn and soybean yield, root depth and shallow water tables across the state in 2017. Then, we use modeling to explain how root depth and shallow water table interacted to protect 2017 crop yields from mid-season drought.

Materials and methods

Experimental locations and treatments

In 2017, the FACTS project had 11 experimental locations with corn and soybean crops across Iowa. In these locations, 12 soybean and 33 corn treatments were studied. Treatments included different planting dates, drainage systems, nitrogen rates and row spacing x plant populations. Each treatment was replicated three times. All plots were fertilized with P, K and S according to ISU recommendations. Nitrogen application rates followed MRTN recommendations for continuous corn and corn-soybean rotation systems. Planting dates and cultivars were selected to represent common practices at each site.

Field measurements

Field measurements were specifically designed to facilitate a systems level understanding – that is an understanding of how multiple system components interact to produce outcomes – and calibrate cropping systems models. Soil, crop and atmospheric measurements were made at high resolution (from 1 hour to 15 days). Soil nitrate and ammonium were sampled every two weeks at 0-30 cm depth and once per month at 30-60 cm depth from March to November. Volumetric soil moisture and temperature were measured hourly at 15 cm and 45 cm depth in each plot. Groundwater sensors measured depth to water table on an hourly basis at every site (n = 34 wells).

Crops were sampled every 15 days destructively. In soybean, plants we measured the following parameters: plant height, number of plants, node number, pod number, leaf area, dry weights and carbon and nitrogen concentration of different plant tissues including green leaves, senesced leaves, stems, pods, seeds and seed number. In corn plants, we measured the following parameters: plant height, leaf area, dry weights and concentrations of plant tissues that is green leaves, senesced leaves, stems, kernel, cob, husk and shank, and kernel number per ear. From these data, crop growth and N uptake rates were calculated. In addition, we measured root growth velocity in each harvest at two row positions per plot using soil cores (in row and between two rows; see Ordonez et al., 2018). When roots reached maximum depth, deep soil cores with a hydraulic probe were taken from each plot during the growing season (in-row and between rows; approx. end of July to mid of August). The depth of each core was 2.2 meter. From these cores, we calculated root dry mass, root length, specific root length, root N and C concentrations per soil layer.

Finally combine yield estimates were taken from the center four or six rows per plot. Corn yield were normalized to 15% moisture and soybean yields to 13% moisture. Hourly weather data were recorded from automated weather stations located at the borders of every fields (IEM Mesonet). A 35-yr historical weather data per location was used to calculate 2017 deviations from climatology.

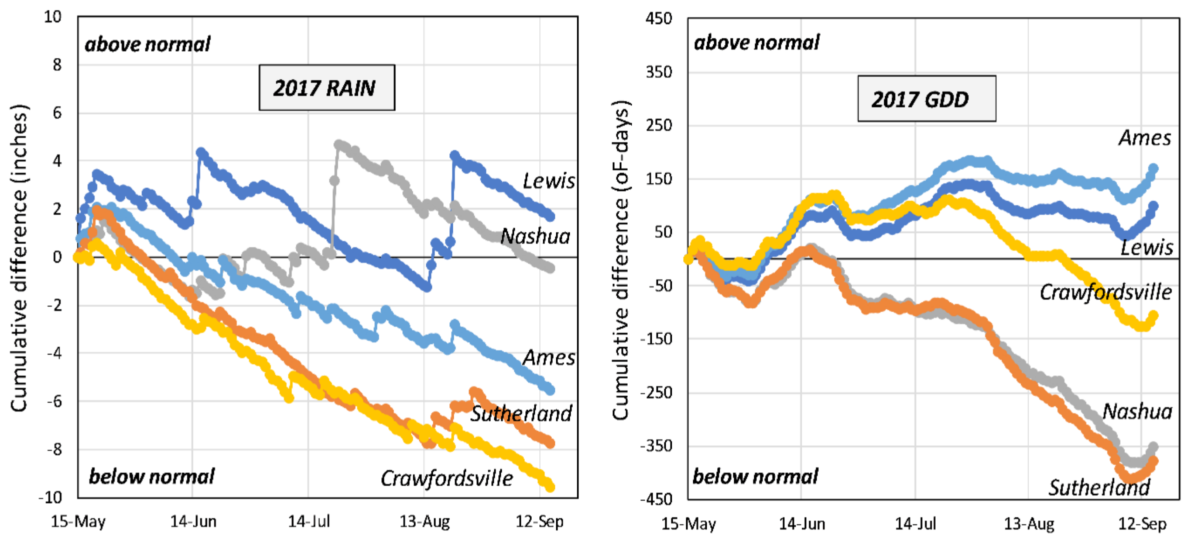

Figure 1. Cumulative difference between 2017 rain and GDD from long-term average climatology (35 year average).

Modeling

We used the APSIM software platform, version 7.8 (Holzworth et al., 2014). Inputs to the model were: management, weather, soil profile information and cultivar characteristics. The majority of model inputs were derived from the above measurements and the model simulated crop yields, soil nitrate, soil water by layer with good accuracy (see https://crops.extension.iastate.edu/facts/). For more details about APSIM performance in Iowa we refer to recent publications (Martinezt-Feria et al., 2016; Puntel et al., 2016; Togliatti et al., 2017).

Results and discussion

Weather conditions

Crawfordsville was the driest site with up to a 10 inch water deficit from May 15th to September 15th 2017 (Figure 1). Sutherland was the second driest location followed by Ames. Northern locations were much cooler than central and southern locations (Figure 1). Until the middle of July, thermal time accumulation was +/- 50 GDD from the 35-year average at all locations. After that period, GDD accumulation slowed in the northern locations, which resulted in delays in crop maturity and harvest in

2017. From May 15th to September 15th, the central and southern locations accumulated approximately 150 MJ/m2 more radiation than average while the northern location accumulated approximately 50 MJ/m2 less radiation compared to the 35-year average (data not shown).

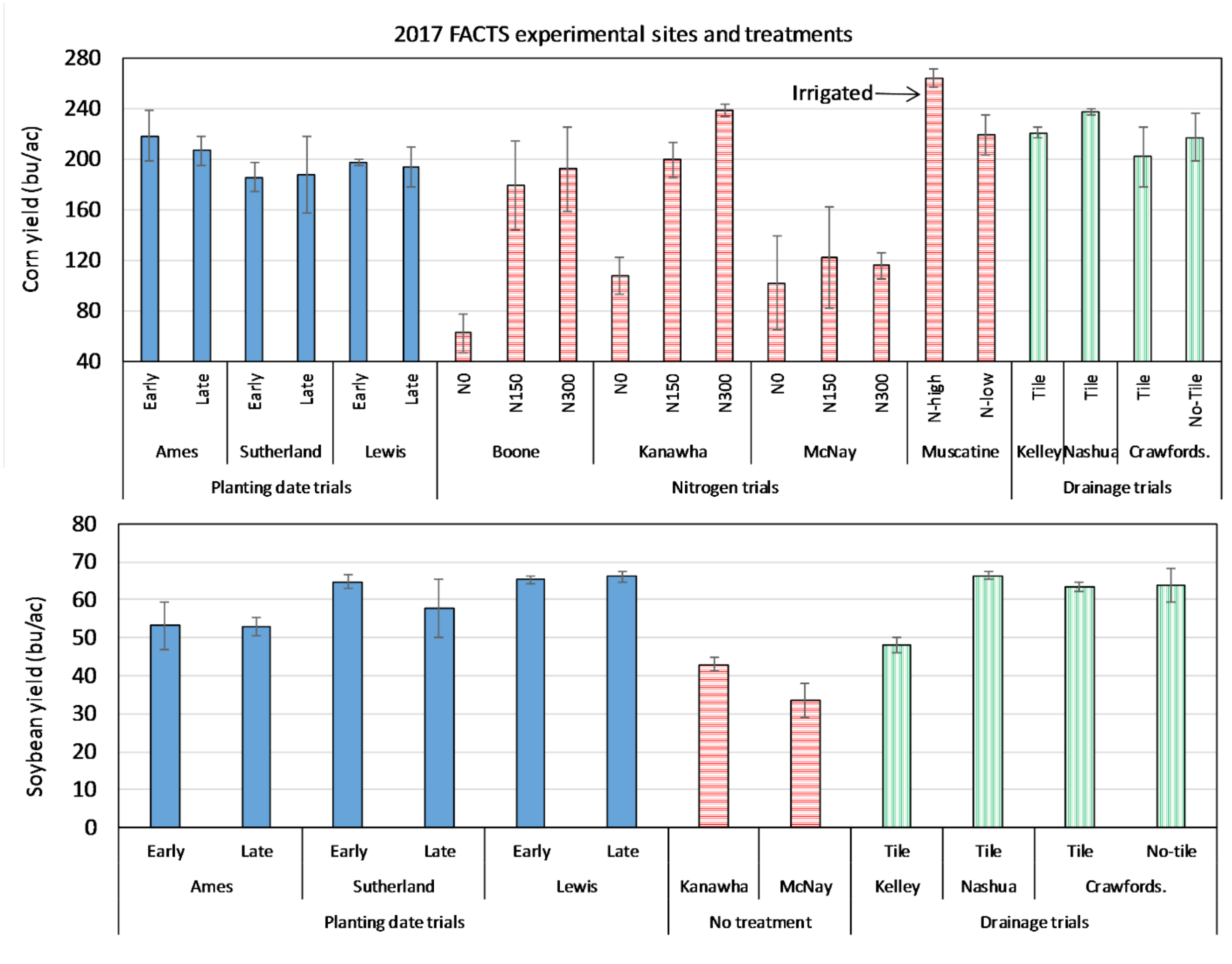

Figure 2. Combine harvested crop yields at FACTS experimental sites. N0, N150 and N300 indicate 0, 150 and 350 lbs N/ac treatments. N-high and N-low indicate low and high N inputs (no zero due to irrigation). All other locations received the ISU recommended N rate (http://cnrc.agron.iastate.edu/).

Crop yields

Despite the 10 inch water deficit in Sutherland and Crawfordsville, corn and soybean yields were approximately 200 and 60 bu/ac, respectively (Figure 2). Planting date had a minor impact on corn and soybean yields. Nitrogen application rate had a significant effect on corn yields, with an economical optimum N rate between around 160 and 240 lbs/acre in Ames and Kanawha, respectively. The McNay site was unresponsive to nitrogen fertilization and in general that site scored the lowest yield because of soil constraints. Muscatine, a sandy soil with low water holding capacity scored the highest yield (268 bu/ac). However, that was the only irrigated FACTS site (10 inches of irrigation water across 14 applications). From rainfed sites, Nashua scored the highest corn yield (240 bu/ac) and soybean yield (65 bu/ac). Interestingly, the no tile drainage treatment at the Crawfordsville site yielded 15 bu/ac more corn yield than the tile drained treatment in 2017. Historically the tile drainage plots yield more than the no-tile drainage plots in this site (1 to 15%; Helmers et al., 2012; Schott et al., 2017). No differences were found in soybean yield between tile and no tile drainage in that site. Corn yield at the Lewis site was slightly below 200 bu/ac. We expected more than 250 bu/ac at that site given excellent weather conditions (Figure 1). Model analysis revealed that relatively low corn yield at that site cannot be attributed to biophysical factors, leaving management as a potential cause.

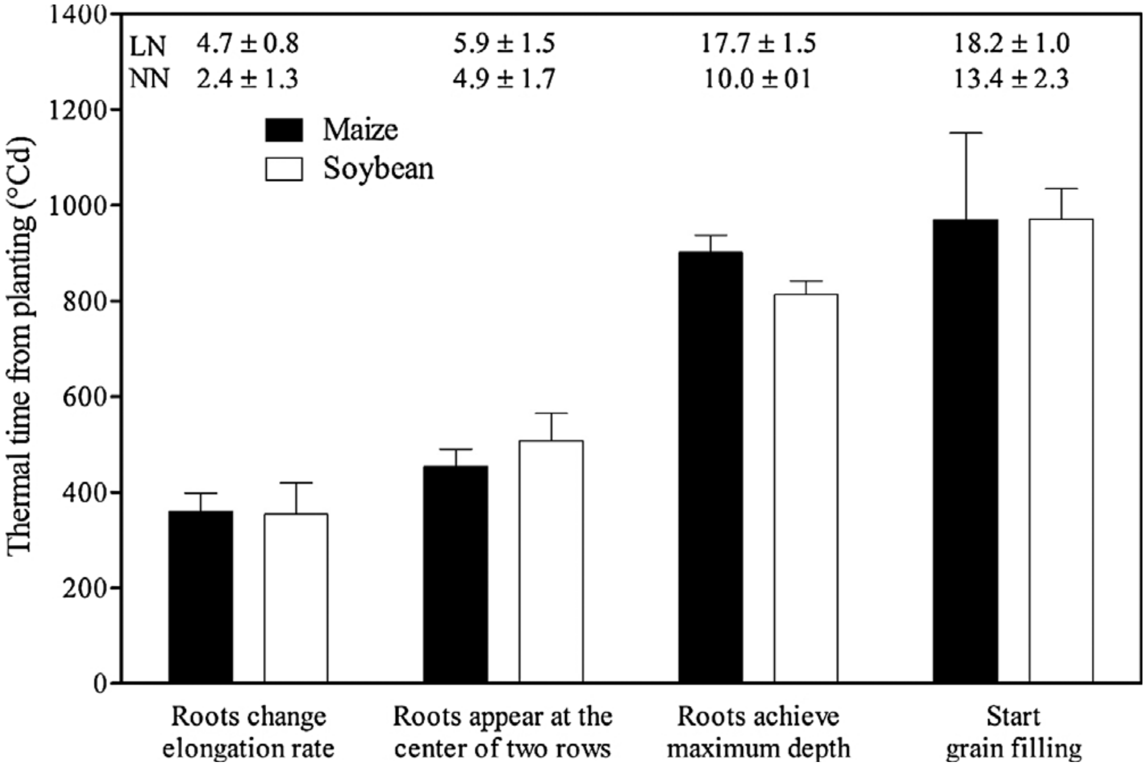

Figure 3. Thermal requirements for key root phenological events. LN = leaf number (corn) and NN = node number (soybean). Data recorded in 2016 across six sites and 20 treatments in Iowa (Ordonez et al. 2017).

Root depth

Across all sites, the 2017 root front measurements revealed similar rates of growth (depth) as in 2016 (Ordonez et al., 2018). Both corn and soybean roots increased at about the same rate (0.3 inch/day until 4.7 corn leaf number and 2.4 soybean node number and about 1.1 inch/day thereafter). Corn and soybean roots reached the center of 30 inches rows at 6th corn leaf and 5th soybean node, respectively (Figure 3). The maximum depth was determined by cultivar maturity and depth to water table. Across 20 trials, the maximum root depth recorded in 2016 was 6 feet and was similar for both corn and soybean. In most cases, the maximum root depth was about 4.5 to 5.5 feet (Figure 4). Shallow water tables limited root growth to these depths; roots cannot grow in anaerobic conditions due to lack of oxygen.

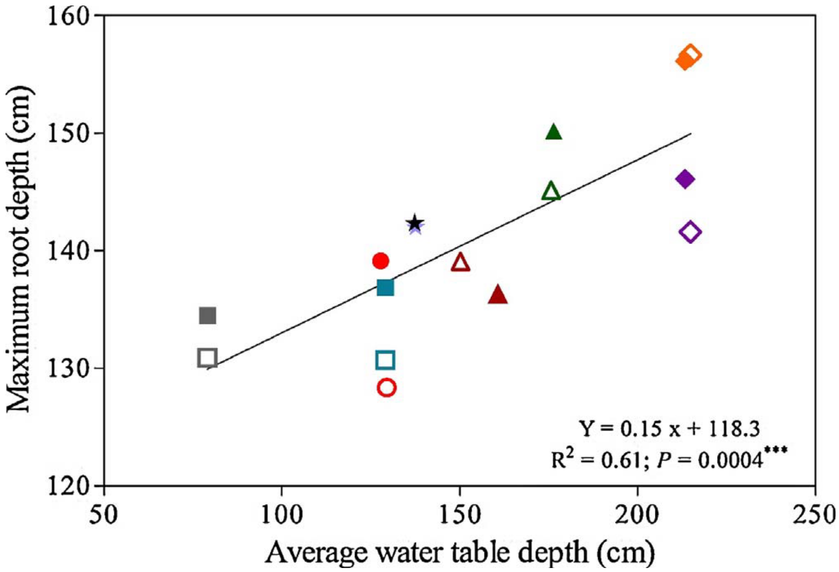

Figure 4. Maximum root depth versus average water table in July (Ordonez et al., 2017).

For corn we also developed a simple regression model that can be used for rapid assessment of root growth in the field (for every new corn leaf, the root increases by 2.7 inches, Figure 5)

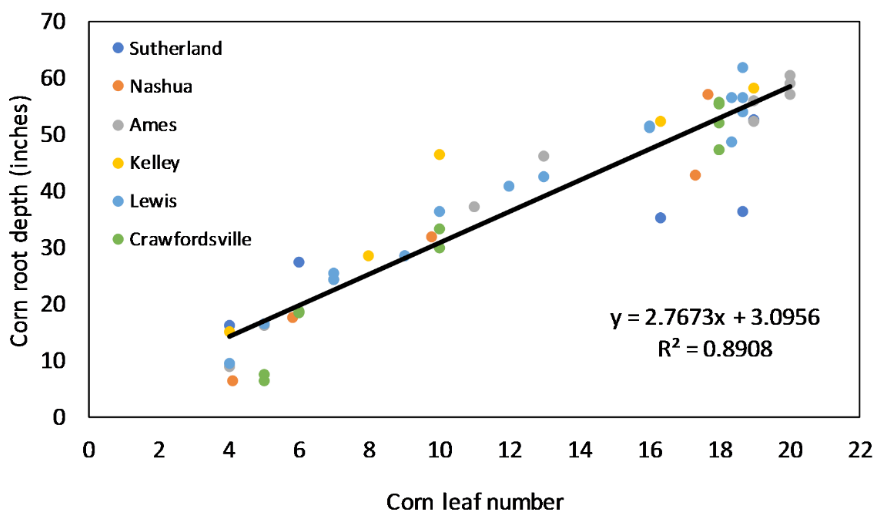

Figure 5. Corn root depth versus leaf number

Water table depth

Figure 6 illustrates water table levels for three time periods in 2017: June 1st, July 15th and August 15th. In June, the water table was about 3.5 feet in central and northern locations and dropped to 7-8 feet by mid-August in northwest and central Iowa. Crop roots in central and northwest Iowa compensated for the 2017 precipitation deficit by taking up water from deep soil layers (Figure 1). In northeast and central sites (Figure 6) the contribution of groundwater to crop transpiration and crop yields was less compared to the central and northwest sites due to adequate precipitation (Figure 1). The contribution of water table in southwest and southern sites was little as the depth to water table was consistently at 7 to 8 feet. In the southeast Iowa water table data are still in analysis but preliminary results indicated that the depth to water table was about 2.5 feet in June 1st, dropped to 4.6 feet by July 15th and to 7.6 feet by August 15th.

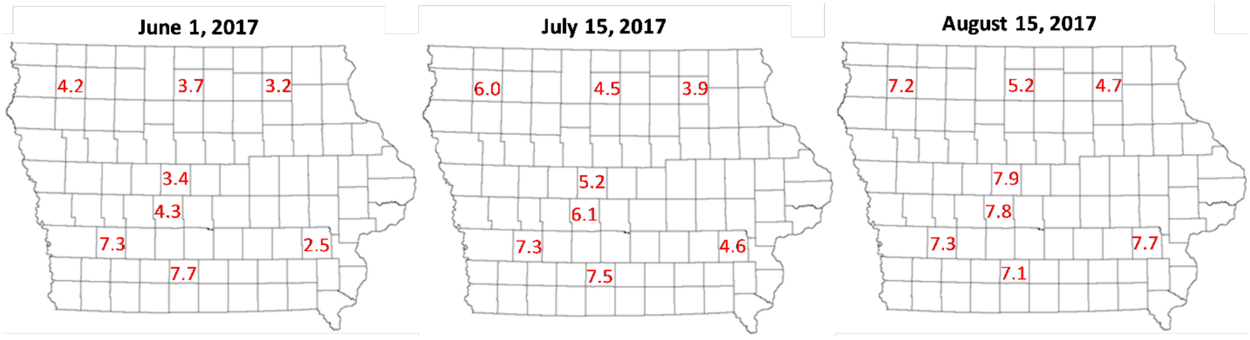

Figure 6. Measured depth in feet to groundwater table in different sites.

The impact of ground water table depth on crop yields has not received the appropriate attention over the past years. Our systems analysis via the FACTS project has showed that the depth to groundwater is a critical factor that explains a large amount of the inter-annual yield variability (see below). The water table determines the maximum root depth (Figure 4) as well as the distribution of the roots along the soil profile (data not shown). June is the critical month for root development in Iowa. Below average precipitation in June promotes the development of a deep root system to supply both water and nutrient to the crop. However, there is a limit on how much water can be supplied by groundwater per site. If the dry conditions continue during grain filling period (August) there will be a decline in yield potential.

Quantifying yield credits from shallow water tables

According to the literature groundwater table can supply up to 75% of the evapotranspiration (Gao et al., 2017) and there is an optimum water table depth for maximizing yields per location (Florio et al., 2014). Because of the dynamic nature of water table and interactions with soil topography, precipitation and vegetation, quantitative assessments of water table contribution to grain yields are missing from the literature. We used the APSIM model and data from the FACTS project to provide a first assessment for Iowa. To do that we simulated crop yields with and without shallow water tables and calculated yield credits and penalties caused by shallow water tables. Figure 7 illustrates the preliminary results.

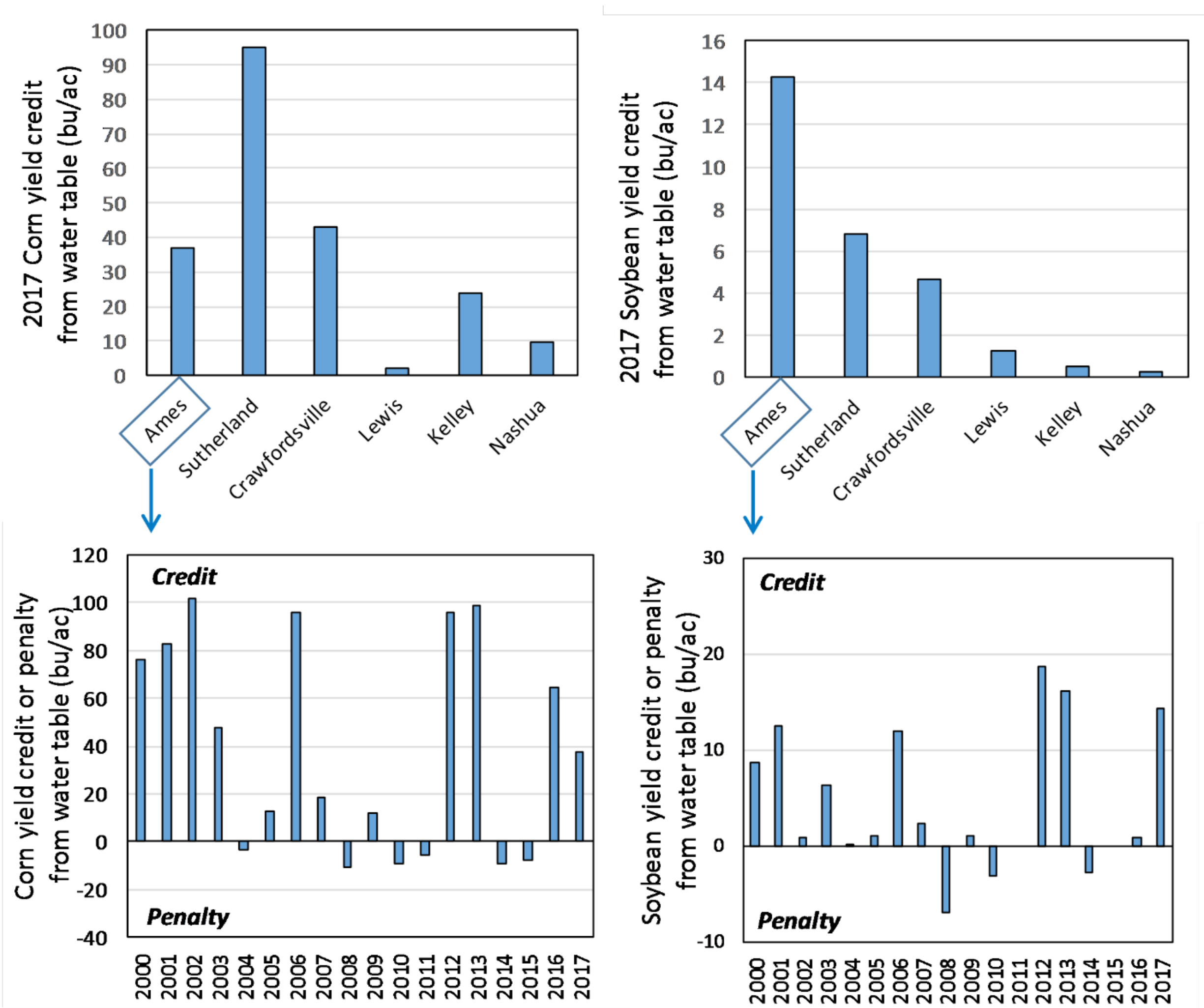

Figure 7. Model analysis of groundwater table yield credit and penalty in 2017 across six location (top panel) and long term impacts for Ames (bottom panels).

According to the model analysis, the water table contributed 90 bu/ac to corn yield in Sutherland, about 40 bu/ac corn yield in Ames and Crawfordsville, 25 bu/ac in Kelley (central Iowa) and 2 to 10 bu/ac in Lewis and Nashua respectively. In terms of percent values, the contribution of water table to the final observed 2017 corn yields ranged from 1 to 75% and it was site specific. The contribution of water table in soybean yields in 2017 was less compared to corn. It ranged from 1 to 14 bu/ac (Figure 7) or 0 to 21% of the final yields.

In the long term (2000 to 2017; 18 years) the contribution of water table to grain yields was variable (Figure 7). In particular, for central Iowa, the contribution ranged from -15 bu/ac to + 100 bu/ac for corn and from -7 bu/ac to +19 bu/ac in soybean. On average across 18 years, 40 bu/ac/year of the obtained corn yield was due to water table credit and 5 bu/ac/yr of the obtained soybean yields was due to water table credit (Figure 7). In 12 out of the 18 years in central Iowa, the water table had a positive effect on yield and in the remaining six years had a neutral or a negative effect. In Sutherland the long term benefit of groundwater for corn was 65 bu/ac/yr (14 out of the 18 years showed a positive response) and in Crawfordsville the long term benefit of groundwater for corn was 13 bu/ac/yr (11 out of the 19 years showed a positive response).

The above model analysis was specifically designed to quantify yield penalties and credits associated with presence or not of shallow water tables in Iowa. Additional model analysis (data not shown) indicated that drainage systems eliminated the yield penalties caused by shallow water tables while maintained or further increased the yield credits. In the long term (18 years), the simulation analysis has shown that tile drainage systems provided a yield benefit and stability as compared to the undrained plots in most of the years with few exceptions like 2012 and 2017 years in which the undrained plots scored higher yields than the drainage plots. Overall, the modeling work suggests that the impact of groundwater table on crop yields is significant and more research should be directed towards managing groundwater tables to maximize yields and environmental impacts.

Conclusions

- Deep roots and shallow water tables compensated for much of the precipitation deficit occurred in summer of 2017 in parts of Iowa.
- The contribution of water table to final corn yields in 2017 ranged from 2 (southwest) to 90 bu/ac (northwest) in 2017.
- A below normal precipitation in June is favorable for Iowa conditions for two reasons: a) rapid and unconstrained root growth (1.1 inch per day); b) soil inorganic nitrogen is at highest levels during that period and excess of water will stimulate N loss.
- Quantifying water table dynamics across the state will greatly assist management decisions and predictability of crop yields and N losses

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