

Soybean yield increase due to artificial drainage in the North Central US region

Spyridon Mourtzinis, José F. Andrade, Patricio Grassini, Juan I. Rattalino Edreira, Hans Kandel, Seth Naeve, Kelly A. Nelson, Matthew Helmers, Shawn P. Conley

IN A BEAN POD

- ▶ Across the entire region, average yield in subsurface artificial drainage (AD) versus natural drainage (ND) was 8% higher (+4.1 bu/ac) and 4% higher (+2.3 bu/ac) based on analysis of experimental and producer data, respectively.
- ▶ Our analysis indicated that part of the AD-ND yield difference in producer fields can be attributed to a shift towards earlier sowing after AD adoption.
- ▶ Overall results highlight the important contribution of AD adoption to the historical soybean yield gain in the US-NC region.

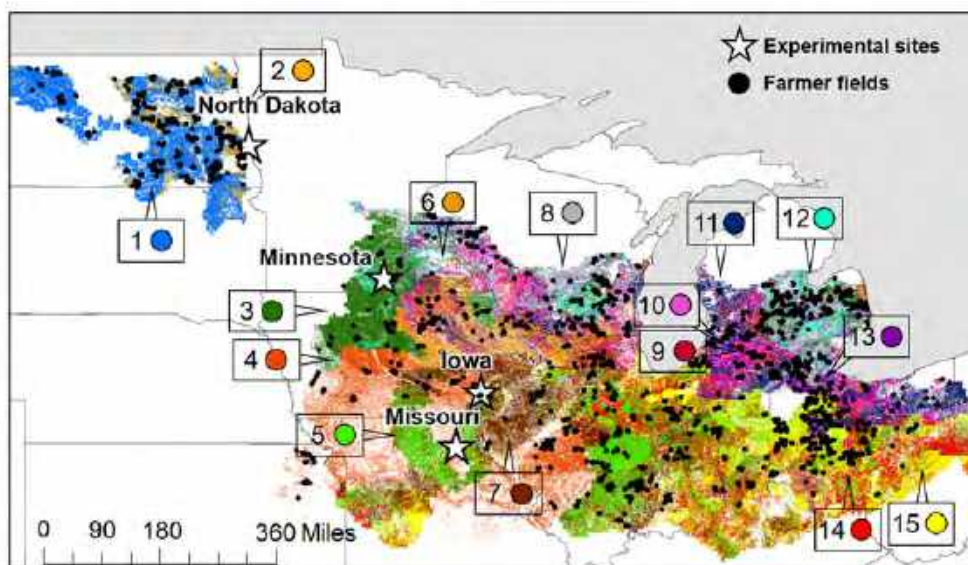
INTRODUCTION

Excess water early in the crop season may result in extended periods with saturated soil conditions, which affect soybean establishment and growth, leading to reduced dry matter accumulation and yield (Hatfield *et al.*, 2014; Bajgain *et al.*, 2015). Besides the direct effect of excess water through anoxia, stand losses, higher disease pressure, and reduction in N_2 fixation (Bacanamwo and Purcell, 1999), saturated soil conditions may also delay sowing and plant emergence. As it has been documented in previous studies, sowing delay can lead to additional yield penalty (Rowntree *et al.*, 2013; Rattalino Edreira *et al.*, 2017; Mourtzinis *et al.*, 2018). Hence, managing soil excess water early in the season is essential to avoid yield penalties across years.

The North Central US (NC-US) region includes *ca.* 82 million ac soybean sown annually (USDA-NASS, 2017). In its natural state, much of the fertile land in this region was either wetland or frequently too wet to allow profitable crop production (Beauchamp, 1987). Since the late 19th century, artificial drainage (AD) started to be adopted to allow cultivation, and field surveys conducted in the 1940s reported large maize yield increases due to AD adoption (Sutton, 1943; Uhland, 1944). Nowadays, *ca.*

one third of the cropland in the entire NC-US region and up to 70-90% in parts of the central and eastern areas of the region is artificially drained to reduce the risk associated with excess water early in the season (Castellano *et al.*, 2019).

Figure 1. Location of experiments (stars) and producer fields (solid circles) in the US North Central region. Colors are used to identify 15 technology extrapolation domains (TEDs); each TED corresponds to a unique climate-soil combination. Fields with surface AD are located in the north-western region (TEDs 1-2); rest of AD fields have subsurface drainage.





Subsurface tile drainage is the most common AD method in the region, except for the north-western region (North Dakota) where surface drainage prevails, although tile drainage has recently started to be adopted in eastern North Dakota (Wiersma *et al.*, 2010). The purpose of AD is to reduce excess water while improving workability and timely fieldwork in poorly drained soils (Zucker and Brown, 1998). The magnitude of yields derived from adoption of AD depends on topography, precipitation, water table depth, and their interactions (Kladivko *et al.*, 2004). For example, in wet years, fields that receive water from upland positions in the landscape (*i.e.*, through surface run-on) are prone to excess water; hence, these fields are expected to benefit from AD adoption. In contrast, the impact is expected to be smaller or nil in dry years and/or fields in upper positions of the landscape.

Most studies that have examined the effect of AD to increase crop yield in the NC-US region were conducted several decades ago (*e.g.*, Sipp *et al.*, 1986). These experiments were conducted at research stations across a limited number of years which results in limited ability to extrapolate results to a wide region. Similarly, management practices have changed drastically over time, which would likely influence the yield response to AD (*e.g.*, earlier sowing date, no-till adoption). Finally, the sites used in those previous studies have been selected based on their probability to favorably respond to AD installation, which can lead bias the evaluation of AD in terms of crop yield response. To summarize, an assessment of the soybean yield benefits derived from AD adoption in producer fields using current management practices across a wide range of environments is missing. We argue that an evaluation of interactions between AD, weather and management practices (using both experimental and producer data) would provide a better understanding of the yield benefit derived from AD adoption in producer fields.

The objective of this study was to examine the effect of AD on soybean yield as influenced by pre-sowing precipitation, topography, and management practices. To do so, we used experimental and producer field data collected in NC-US region, an area that accounts for a third of global soybean production and includes the largest area under soybean cultivation with AD in the world. The analysis of experimental and producer survey data, across a large number of sites and years, allowed us to understand the effect of AD on soybean yield across a wide range of environments.

MATERIALS AND METHODS

Experimental data

We compiled yield and management data from replicated field experiments conducted in Iowa, Missouri, Minnesota, and North Dakota during the past 20 years (2002-2019) (Figure 1). All experiments were rainfed, that is, they did not receive supplemental irrigation. Each trial included a side-by-side comparison of AD *versus* naturally drained (ND) treatments. Daily precipitation data were retrieved from meteorological stations located less than 18 miles from the experimental sites and 30-day cumulative precipitation before sowing (P-30) was calculated for each site-year. The P-30 was considered a reasonable indicator of excess water in the soil and workability of the field early in the season.

Producer data

Data on yield and management practices were collected from fields sown with soybean in 10 states located within the NC-US region (Iowa, Illinois, Indiana, Kansas, Michigan, Minnesota, North Dakota, Nebraska, Ohio, Wisconsin) over four (2014-2017) crop seasons (Figure 1). Soybean producers were requested to indicate type of drainage for each field by selecting among three options: ND, surface AD, and subsurface AD. We focused our assessment on rainfed fields. Producer fields were grouped based on similarity of climate and soil (Figure 1) using the technology extrapolation domain (TED) spatial framework (Rattalino Edreira *et al.*, 2018). Each TED corresponds to a specific combination of annual total growing degree-days, aridity index, temperature seasonality, and plant-available water holding capacity. Grouping the fields into TEDs



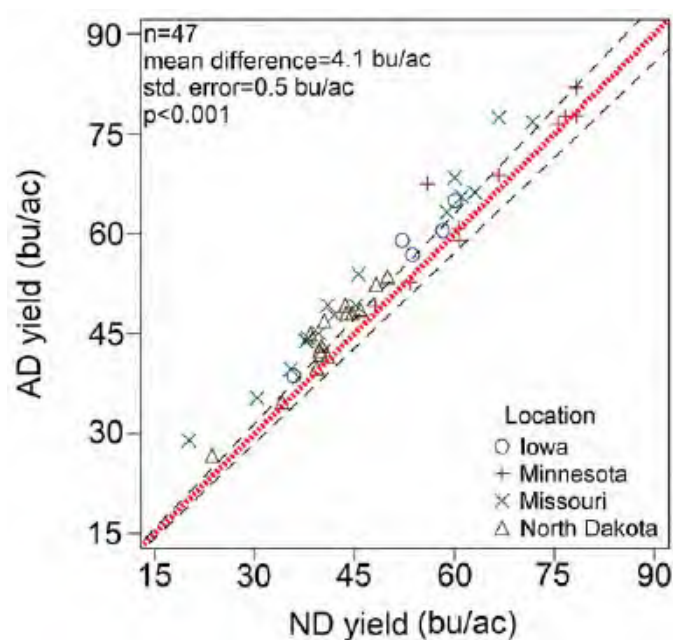
allowed us to account for climate-soil background differences across the region. Across the entire region, 15 TEDs were selected containing a total of 2,805 surveyed soybean fields. Weather data for each surveyed field were obtained from the DAYMET dataset (Thornton *et al.*, 2016), and P-30 cumulative precipitation for each field was calculated.

RESULTS

Soybean yield with artificial versus natural drainage based on experimental data

Across experimental site-years, average yield was 4.1 bu/ac (s.e. = 0.5 bu/ac) higher in AD versus ND treatments ($p < 0.001$), representing an 8% yield increase in relation to average ND yield (Figure 2). There was still variation in the magnitude of the yield difference, ranging from -1.7 to 11.5 bu/ac across site-years. In only 6% of the cases, yield difference between AD and ND response was *nil* or negative. There was no significant interaction between P-30 and AD across the experimental years ($p = 0.89$).

Figure 2. Comparison of soybean yield across 47 site-year experiments including subsurface artificial drainage (AD) and natural drainage (ND) treatments. The red and black dashed lines indicate $y=x$ and $\pm 5\%$ yield differences, respectively. Each datapoint corresponds to a side-by-side AD versus ND comparison for a given site-year with identical management background.



Effect of artificial drainage on producer soybean yield

Producer fields with subsurface AD were mostly distributed across the eastern and central portions of the NC-US region (Figure 3). It was remarkable the high frequency of AD soybean fields in many agricultural districts located in these regions, with greater than 90% of fields with AD in some districts (e.g., south-central Minnesota and northeast Illinois). As indicated previously, surface AD prevailed over subsurface AD in North Dakota (31% and 3%, respectively). In contrast, frequency of AD fields was nil or small in the western fringe (i.e., Nebraska, Kansas, western North Dakota) and Wisconsin.

Average producer yield was 2.1 bu/ac (s.e. = 0.5 bu/ac) higher in subsurface AD versus ND fields ($p < 0.001$), representing a 4% increase relative to average ND yield (Figure 4). Average yield difference between surface AD and ND fields in the TEDs located in the northwest region was not significant (+1.4 bu/ac; s.e. = 0.8 bu/ac). Similar to the findings from the experimental data analysis, there was variation in the magnitude of the AD-ND yield difference, ranging from -1.7 to 5.9 bu/ac across TED-years (Figure 4).

In 10% of the cases, yield difference between AD and ND response was *nil* or negative. Consistent with the results based on experimental data, TED-year specific AD-ND yield differences (expressed either as an absolute value or as a fraction of ND yield) were not correlated with P-30.

Figure 3. Frequency of fields with subsurface artificial drainage (AD) across the North Central US region. The map was derived from survey data collected from soybean producers during four crop seasons. Data were aggregated for visual purposes using USDA-NASS agricultural districts (https://www.nass.usda.gov/Charts_and_Maps/Crops_County/boundary_maps/indexgif.php). Inset shows the frequency of fields with surface AD, which are only present in the northwestern portion of region.

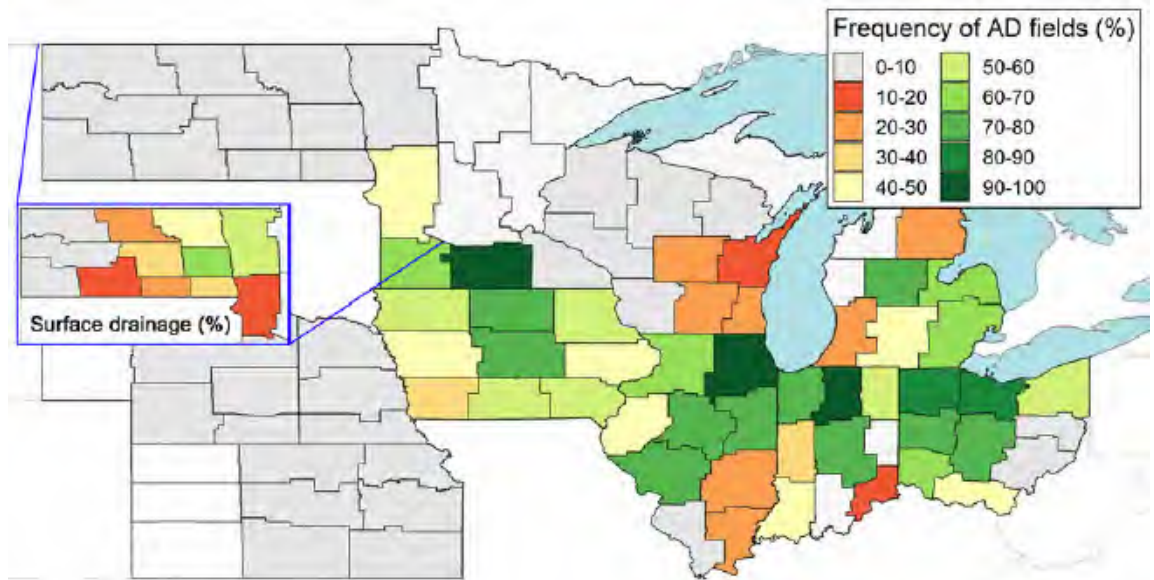


Figure 4. Comparison of soybean yield in producer fields with artificial drainage (AD) versus natural drainage (ND). AD corresponds to surface drainage (TED 1 and 2) or subsurface drainage (TEDs 3-15). Each symbol corresponds to a technology extrapolation domain (TEDs), with each datapoint showing average yield for AD and ND fields in a TED-year combination ($n=8$ and 52 for surface and subsurface AD, respectively). The TEDs are mapped in Figure 1. The red and black dashed lines indicate $y=x$ and $\pm 5\%$ yield differences, respectively.

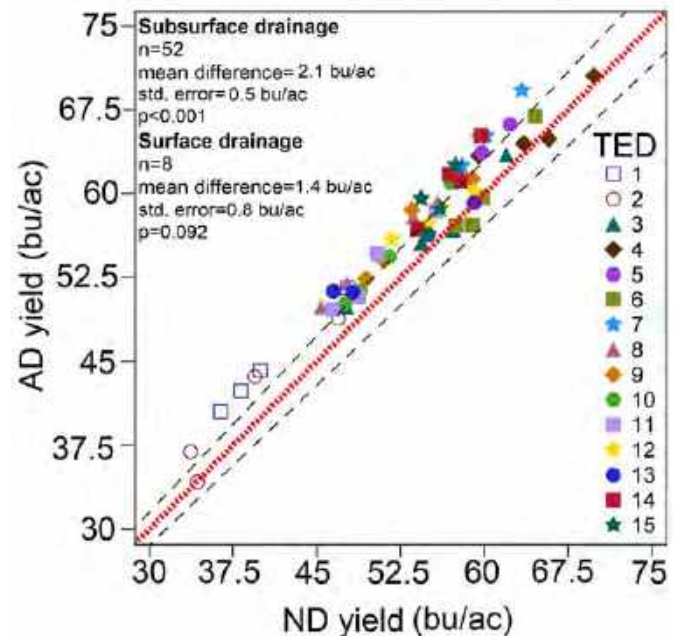
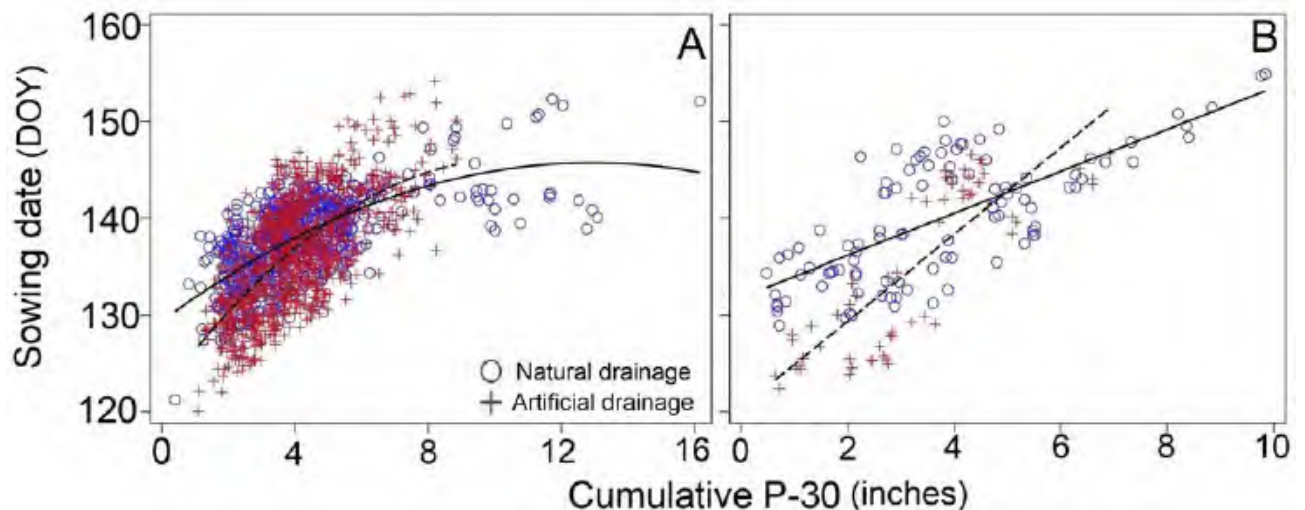
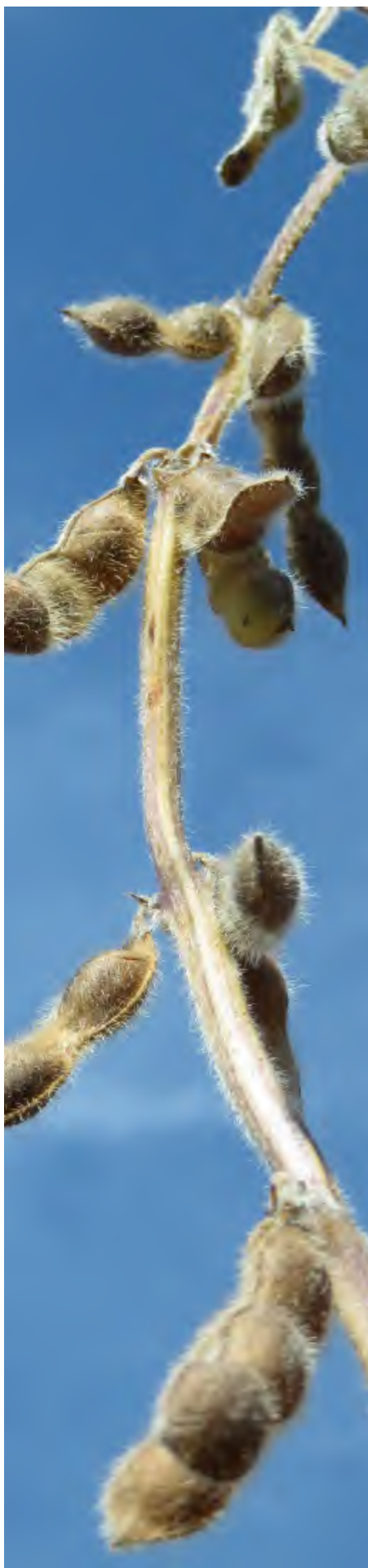


Figure 5. Relationship between sowing date (DOY, day of year) and cumulative pre-sowing precipitation (P-30) in fields with artificial drainage (AD) or naturally drained (ND). Separate panels are shown for subsurface (A) and surface AD fields (B). Each symbol represents a site-year. Data were pooled across the technology extrapolation domains (TEDs) shown in Figure 1. Solid and dashed lines show the fitted regression models to ND and AD fields, respectively ($p < 0.001$).





In connection to the previous point, one could also speculate that AD installation could have led to changes in management practices that are not reflected in TED-wide average differences between AD and ND fields. Across TEDs, on average, subsurface and surface AD fields were sown *ca.* 7 and 8 d earlier (s.e. = 1.6 and 2.3 d, respectively) than ND fields, respectively (Figure 5, $p < 0.001$). Additionally, there was an interactive effect between AD and P-30, with earlier sowing in AD *versus* ND fields only for P-30 values lower than 3 inches (subsurface AD) and 4 inches (surface AD), but no clear differences above these thresholds.

DISCUSSION

Observed pattern of AD adoption across the US-NC region followed the gradient in precipitation, increasing from west to east, and the spatial pattern of water table depth reported by Fan *et al.* (2013). The analysis from replicated experiments revealed an average yield increase of 8% in subsurface AD *versus* ND fields. Analysis of producer survey data helped to confirm that the AD-ND yield difference was also observed in producer fields.

Productivity and environmental performance of AD soybean-corn systems in the NC-US region have received increasing attention and a call for 'sustainable intensification' of AD cropping systems has been made recently (Castellano *et al.*, 2019). Our study makes a first contribution here by showing that subsurface AD is an effective management practice to increase crop yields in environments of the NC-US regions that have a high probability of excess water early in the season. Not surprisingly, AD has been adopted in 71% of the soybean area located in the eastern and central NC-US region, including Iowa, Illinois, Minnesota, Indiana, Ohio, Wisconsin, and Michigan (Figure 3).

At the farm level, our findings can be used to determine the long-term cumulative yield benefit and profit associated with AD installation in environments that are prone to excess water. Such an assessment would also require information about cost of AD installation, expected yield increase in other crops in the rotation, potential increase in land value, and other benefits to the farm operation (*e.g.*, high yield stability across years and improved field workability early and throughout the season). Similarly, results from our study can be used to determine the contribution of AD adoption to soybean yield gain over time.

CONCLUSIONS

We performed a combined analysis that includes both data from experimental plots as well as from producer fields to assess the yield benefit derived from AD compared with ND, using data collected over recent years and across a wide range of environments. Analysis of experimental and producer survey data revealed a 4–8% benefit of AD in soybean yield in environments of the NC-US region that are prone to excess water early in the season. Part of the yield benefit is likely driven by earlier sowing as a result of AD adoption. Our study also highlights the important contribution of AD adoption to the historical soybean yield gain in the US-NC region.

Adapted from: Spyridon Mourtzinis, José F. Andrade, Patricio Grassini, Juan I. Rattalino Edreira, Hans Kandel, Seth Naeve, Kelly Nelson, Matthew Helmers, Shawn P. Conley. 2020. *Assessing benefits of artificial drainage on soybean yield in the North Central US region*. Agricultural Water Management. <https://doi.org/10.1016/j.agwat.2020.106425>

ACKNOWLEDGEMENTS

Authors acknowledge the North-Central Soybean Research Program (NCSRP), Nebraska Soybean Board, Wisconsin Soybean Marketing Board, Minnesota Soybean Research and Promotion Council, and North Dakota Soybean Council for their support to this project. We also thank Adam C. Roth (University of Wisconsin-Madison), Shaun N. Casteel (Purdue University), Ignacio A. Ciampitti (Kansas State University), Peter M. Kyveryga (Iowa Soybean Board), Mark A. Licht (Iowa State University), Laura E. Lindsey (The Ohio State University), Daren S. Mueller (Iowa State University), Emer-



son D. Nafziger (University of Illinois), Jordan Stanley (North Dakota State University), Michael J. Staton (Michigan State University Extension), University of Nebraska Extension Educators, Nebraska Natural Resource Districts, and Iowa Soybean Association for helping collect the producer data.

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