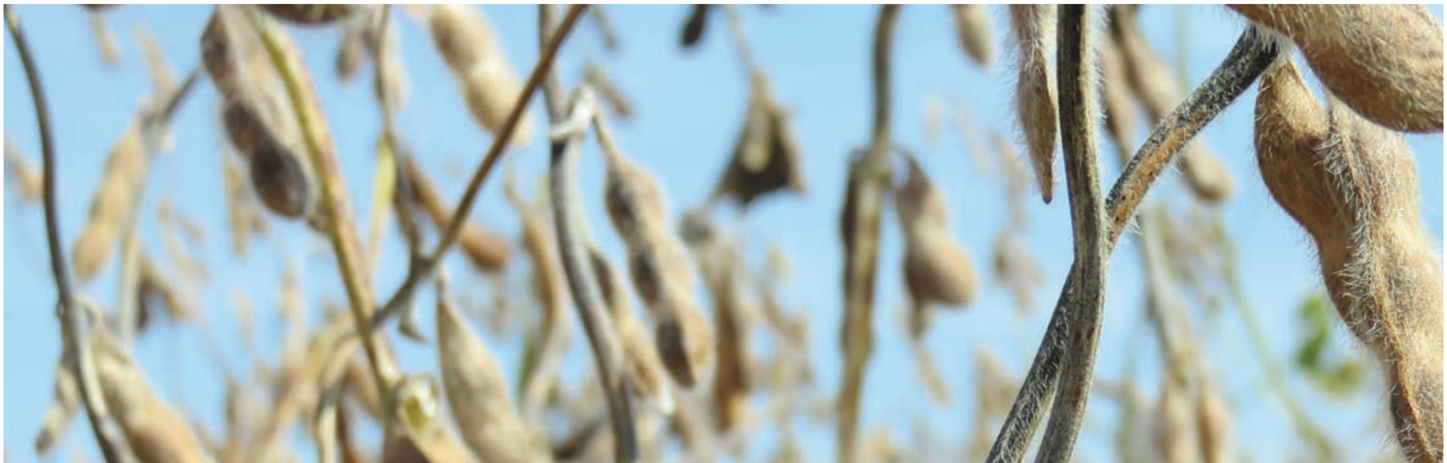

Benchmarking Soybean Production Systems in the North Central US

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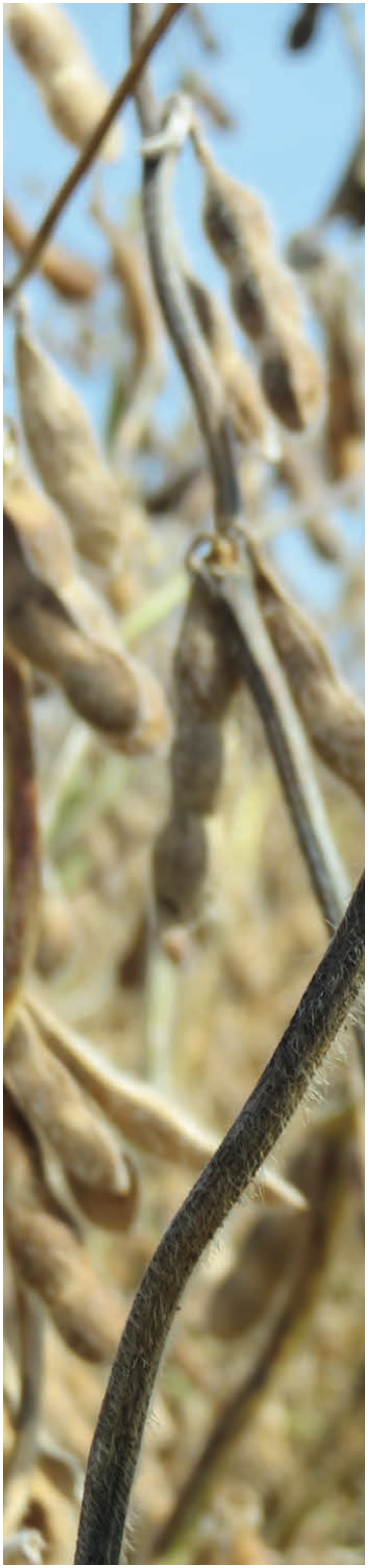
Nebraska Soybean Checkoff

NCSRP North Central Soybean Research Program

The North Central Soybean Research Program, a collaboration of 12 state soybean associations, invests soybean checkoff funds to improve yields and profitability via university research and extension.



Contents

Project Team

Project PIs: Patricio Grassini and Shawn P. Conley

Core Team: Juan Ignacio Rattalino Edreira, Jose Andrade, Spyridon Mourtzinis and Adam Roth

State Collaborators: Shaun Casteel, Ignacio Ciampitti, Hans Kandel, Peter Kyveryga, Mark Licht, Laura Lindsey, Daren Mueller, Emerson Nafziger, Seth Naeve and Michael Staton

Acknowledgments

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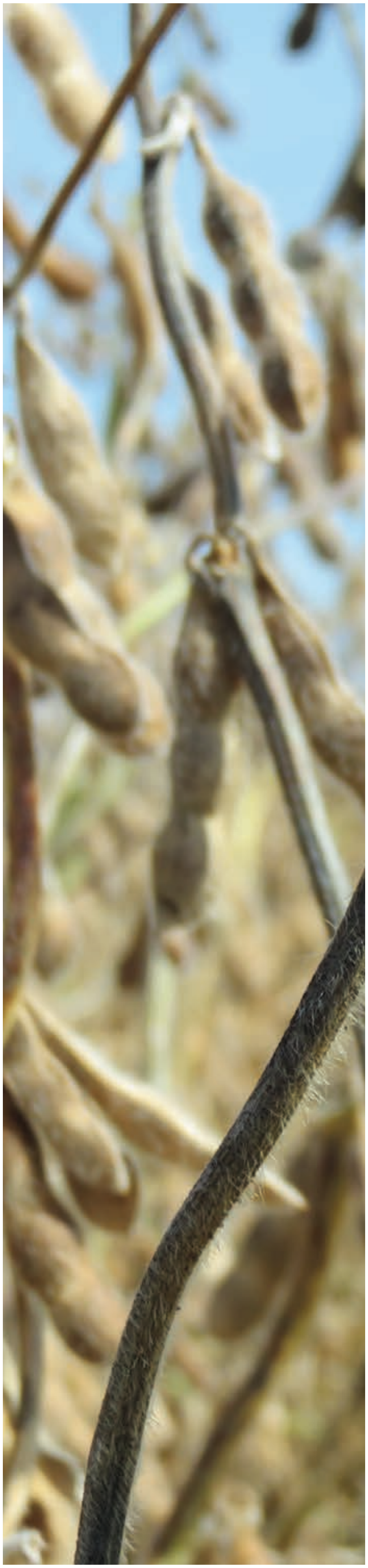


1. Introduction

Replicated field experiments are used in agricultural research to test new technologies and management practices. In these experiments, researchers selectively manipulate a production factor (i.e. a treatment such as a fungicide seed treatment) and, by comparing final yield against the yield of a "control" treatment (no seed treatment), the magnitude of the yield response and its economic profitability are assessed. A limitation of this approach is that it often examines the effect of management practices at a small number of sites and years due to practical constraints (e.g., costs, logistics, etc.). Hence, extrapolation of their findings is typically confined to a narrow range of environments. Likewise, field experiments cannot test the effect of a large number of production factors (and their interactions) on yield due to the large number of plots that would be needed. And, finally, the management selected as "background" for these experiments (e.g., planting date, tillage method) will also influence crop responses to a given technology or management. Given these limitations, it is relevant to search for alternative, cost-effective approaches that provide an indication of the management practices that perform best for a given climate-soil context.

Farmer survey data can be utilized as a cost-effective source of information to identify yield limiting factors and fine-tune management practices so that these yield limitations can be reduced or eliminated. An advantage of using farmer data is that it allows examination of opportunities for yield increase within the range of current management practices that are both cost-effective and logistically feasible in farmer fields. Another advantage of using farmer data is that, if surveyed fields are properly contextualized relative to their environment, it is possible to explore and quantify management × environment interactions. Such assessment would allow identification of groups of management practices that perform best for a given environment and provide a focus to traditional, costly field experiments so that they can target those management practices with the most likely impact on crop productivity and input-use efficiency. To summarize, analysis of farmer data can help accelerate the rate at which best management practices are identified and adopted by farmers for a particular soil-climate.

The Unites States is the largest soybean producer (35% of total global production), with the North Central region accounting for 82% of total US soybean production. During the past three years (2016-2018), we conducted a project funded by the North Central Soybean Research Program (NCSRP) to identify the key factors that preclude soybean farmers from obtaining yields that should be potentially possible on their respective individual farms. We collected data from more than 9,000 fields planted with soybean across the North Central region, representing 600,000 acres. Analysis of farmer survey data using advanced statistical methods and a spatial framework allowed us to identify the most critical yield-limiting factors for an agricultural area that includes 50.4 million acres planted to soybean, which, in turn represent 57% of US soybean area. Here we provide a summary report showing soybean yield and management practices in farmer's soybean fields in the North Central US region and a detailed analysis of the yield-limiting factors in each state.

2. Methodology

Soybean farmers provided data via returned surveys distributed by local crop consultants, extension educators, soybean grower boards, and Natural Resources Districts. Farmers were asked to report the average field yield for a number of fields planted with soybean. Requested data also included field location, crop management (e.g., planting date, seeding rate, row spacing, cultivar, and tillage method), applied inputs (e.g., irrigation, nutrient fertilizer, lime, manure, and pesticides), and incidence of biotic and abiotic adversities such as insect pests, diseases, weeds, hail, waterlogging, and frost (Figure 1).

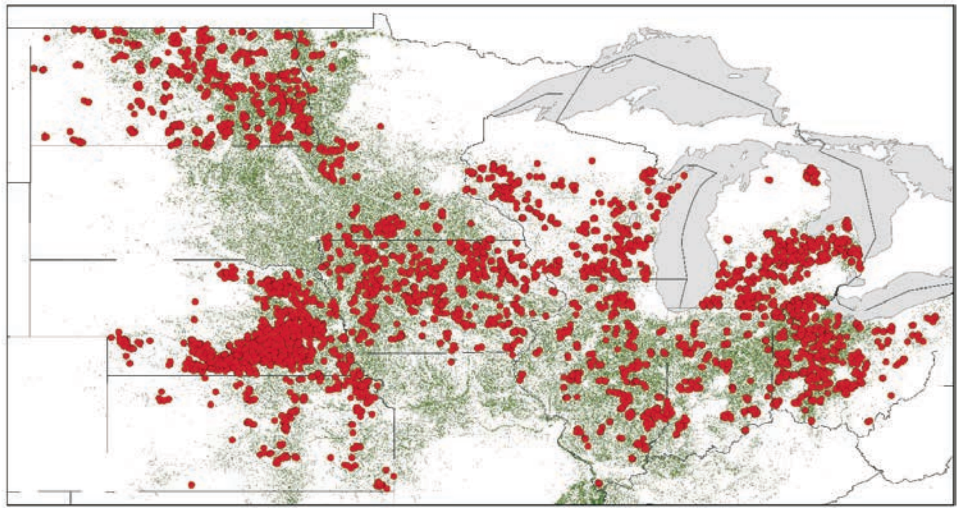
	EXAMPLE:	2014 Soybean	2014 Soybean	2015 Soybean	2015 Soybean
Specify field location by Section: Township: Range. →	NE ¼ 25 : 20N : 26W	[redacted]	[redacted]	[redacted]	[redacted]
Please sketch-in the boundaries of your field location within the Section →	NW1/4 NE1/4 SW1/4 SE1/4	NW1/4 NE1/4 SW1/4 SE1/4	NW1/4 NE1/4 SW1/4 SE1/4	NW1/4 NE1/4 SW1/4 SE1/4	NW1/4 NE1/4 SW1/4 SE1/4
OR GPS coordinates of field centroid: OR County & field location relative to Rd Intersection:	41.678, -100.257 Saunders Co, SW of Rd 11 & N	[redacted]	[redacted]	[redacted]	[redacted]
Dryland? OR Pivot, Gravity? Indicate field size (acres)	Pivot (130 ac)	Pivot (137ac)	Gravity (20ac)	Pivot (84ac)	Dryland (111ac)
Does this field have drainage? (no, old clay tile, new systematic tile, surface drainage, other)	No	No	No	No	No
Total Inches of Irrigation Applied to crop?	5 inches	3.5 in.	4.5 in	3.5 in	0
SOYBEAN YIELD (bushels/acre) for this FIELD:	70	80	70	85	39
Lowest | Highest Yield (bu/ac) of your soy fields that year *Use Irrigated fields yield range if this crop was Irrigated: *Use Dryland fields yield range if this crop was Dryland:	Low: 62 High: 80	Low: 61 High: 90	Low: 55 High: 86	Low: 61 High: 90	Low: 13 High: 66
Planting Date in this FIELD (Month/Day/Year):	5/15/2014	4/28/2014	5/2/2014	4/29/2014	5/4/2014
Variety Name (Brand & Number):	Pioneer P93M11	Channel 3402 RR2	Channel 3402RR2	Channel 2402RR2	Channel
Seeding Rate (seeds/ac):	125,000	140,000	140,000	140,000	140,000
Row spacing (inches):	30	30	30	15	15
Seed Treated (Yes/No)? What Brand Name Product(s)?	Yes (Cruiser-Max)	yes Acceleron	yes Acceleron	yes Acceleron	yes Acceleron
Prior Crop in this FIELD? Residue harvested or grazed?	Corn - Grazed	Corn - Grazed	Corn - No	Corn - Grazed	Corn - No
Tillage after prior crop? No-Till (NT); Ridge (RT); Strip (ST); Disk (D); Chisel (C); Vertical (V) – Indicate timing (month-year)	ST (March-2014)	NT	D (April 2014)	NT	NT
Any (non-starter) fertilizer after prior crop? Specify rate (pounds NUTRIENT/ac) and timing (month-year)	P_2O_5: 70 K_2O: 30 Other: S (11 lbs) Time: March-2014	P_2O_5: K_2O: Other: None Time:	P_2O_5: K_2O: Other: None Time:	P_2O_5: K_2O: Other: None Time:	P_2O_5: K_2O: Other: None Time:
Any STARTER fertilizer (Yes/No)? If Yes, specify nutrients	Yes (N, P, Zn)	No	No	No	No
Any Lime (L) or Manure (M)? If yes, specify timing (mm-yy)	M (Nov-2013)	No	No	No	No
PRE- or POST-emergence herbicide program or BOTH?	Both	Both	Both	Both	Both
Any in-season foliar fungicide (F) / insecticide (I)?	F and I	No	No	No	No
Soy Cyst Nematodes (Yes/No/I don't know)?	No	No	No	No	No
Iron Deficiency Chlorosis (Yes/No)?	No	No	No	No	No
Any significant yield loss due to Insects, Diseases, Weeds, Frost, Hail, Flood, Lodging? Specify problem	Frost (Sept-2014)	None	None	None	yes Hail (July 2014)

Figure 1. Example of an actual survey form filled out by a Nebraska soybean producer, providing information for three irrigated fields and one rainfed field sown with soybean in 2014 and 2015. This survey was used to collect information from producer fields across 10 states in the North Central US region. Note that farmer name is not shown and field location was hatched in order to keep personal information confidential.

We collected data from fields planted with soybean in 2014 to 2017 from 10 states in the North Central region (NE, WI, MI, IN, IL, IA, ND, OH, KS, and MN). During the 4 growing seasons, 1776, 2140, 2531, and 2686 fields (9133 total) were recorded in 2014, 2015, 2016, and 2017, respectively. Survey data were inputted into a digital database and screened to remove erroneous or incomplete data entries. We were interested in yield variation as related with management factors; hence, a few fields with extremely low yield due to unexpected adversities (e.g., hail, waterlogging, wind, and frost) were excluded from the analyses. After the quality control, the database contained 8015 fields, representing 500,000 acres (Figure 2).

As a first step, we generated maps showing the variation in soybean yield and management practices across the North Central US region. The survey data was grouped by agricultural district and we only considered agricultural districts with, at least, 10 surveyed fields containing information for a given management practice. We determined the dominant management practices in each Agricultural District based on the survey data. In the case of NE, we created separate maps for irrigated and rainfed soybean only in those cases in which management was different between the two water regimes. In the case of SCN incidence, average values were estimated based only on those fields in which farmers knew if there was SCN information or not, which means that the figures may be higher because many farmers did not test their fields for SCN. For nutrient applications, we look into fields receiving starter N and P_2O_5 and K_20 fertilizer applications larger than 10 lbs/ac. Descriptive maps for most important practices are shown in Section 3.

Figure 2. Distribution of fields across the north central US. Red circles denote individual fields and green area show the region of soybean acres. USDA-NASS. (2019) USDA-National Agricultural Statistics Service (NASS), National Cultivated Layer (https://www.nass.usda.gov/Research_and_Science/Cropland/SARS1a.php).



As a second step, we explored the management practices that explained variation in farmer yield within a given climate-soil context. We first group fields in homogenous regions to allow establish fair comparisons among fields. Therefore, surveyed fields were grouped based upon their climate and soil using the spatial framework developed for United States by the Global Yield Gap Atlas (http://www.yieldgap.org; Table 1), (Rattalino Edreira et al., 2017). This framework delineates regions called 'technology extrapolation domains' based on four attributes that govern crop yield and its inter-annual variability: (i) annual total growing degree-days, which, determines the length of crop growing season, (ii) aridity index, which defines the degree of water limitation in dryland cropping systems, (iii) annual temperature seasonality, which differentiates between temperate and tropical climates, and (iv) plant-available water holding capacity in the rootable soil depth, which determines the ability of the soil to supply water to support crop growth during rain-free periods. Each TED corresponds to a specific combination of growing-degree days, aridity index, temperature seasonality, and plant-available water holding capacity. TEDs were selected upon availability of surveyed fields (TEDs with >100 fields for rainfed or >50 fields for irrigated) and relevance in term of soybean area coverage within each state (TEDs representing > 5% of state soybean area). Following these criteria, a total number of 27 TED x water regime combinations were included into the analysis (Figure 3).

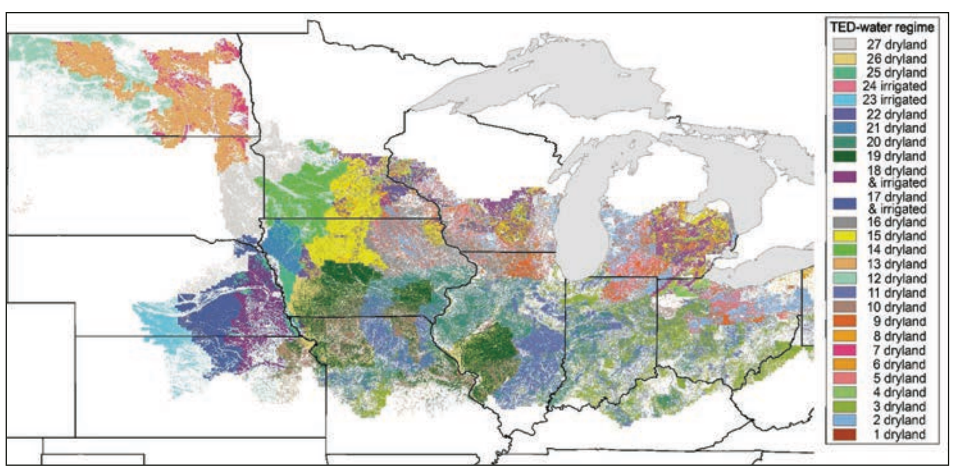
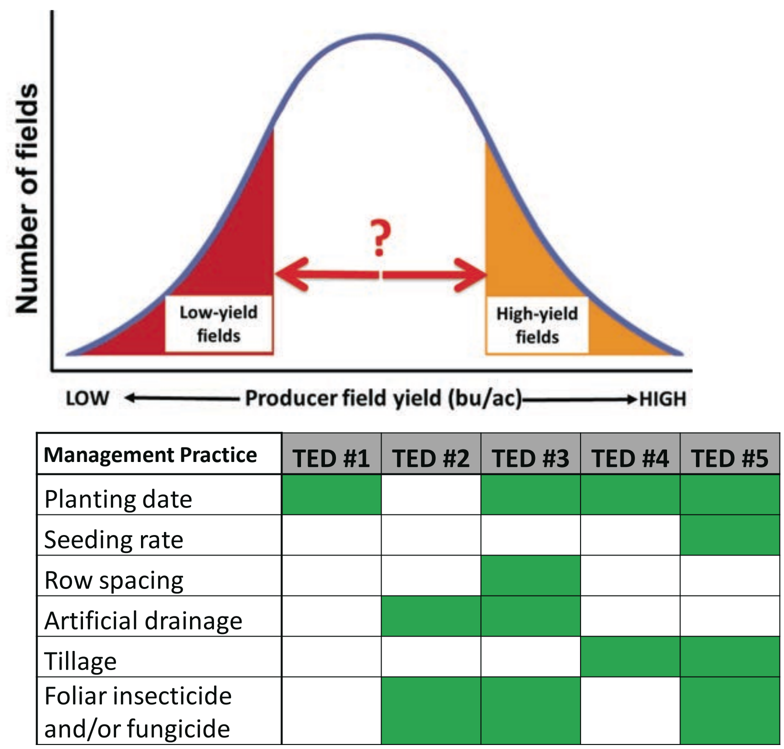


Figure 3. Distribution map of 27 TED x water regime combinations across the North Central US.

Figure 4. Scheme showing analysis of the producer data. The yield distribution at the top panel shows how fields were classified as high- and low- yield. The bottom panel shows that analysis performed to assess differences in management practices between high- and low-yield fields. Green cells indicate statistically significant differences for a given management practice between the two field yield categories, using a p-value ≤ 0.10 to infer statistical significance.

Which management practices are different in high- versus low-yield fields within a TED?



After fields were grouped into TEDs, we looked into management factors that could explain variation among fields located within the same climate-soil area. To do this, we first identified the high- and low-yielding fields within each TED (Figure 4). For each TED, fields within the lowest tercile (that is, below the 33rd percentile) and highest tercile (that is, above the 66th percentile) of the yield distribution were assigned to low- and high-yield categories, respectively. A t-test, or chi-square test in the case of categorical variables, was performed to evaluate differences in management practices between the high- and low-yield category for each TED. The goal was to identify the cohort of management factors that lead some fields to yield more than others given the same climate-soil background. When the p-value was small (less than 0.1, equivalent to one chance out of ten to be wrong about the statistical significance of the difference), we assumed that the examined management practice had a significant effect on soybean yield. A separate analysis is presented for each of the ten states in Section 4.

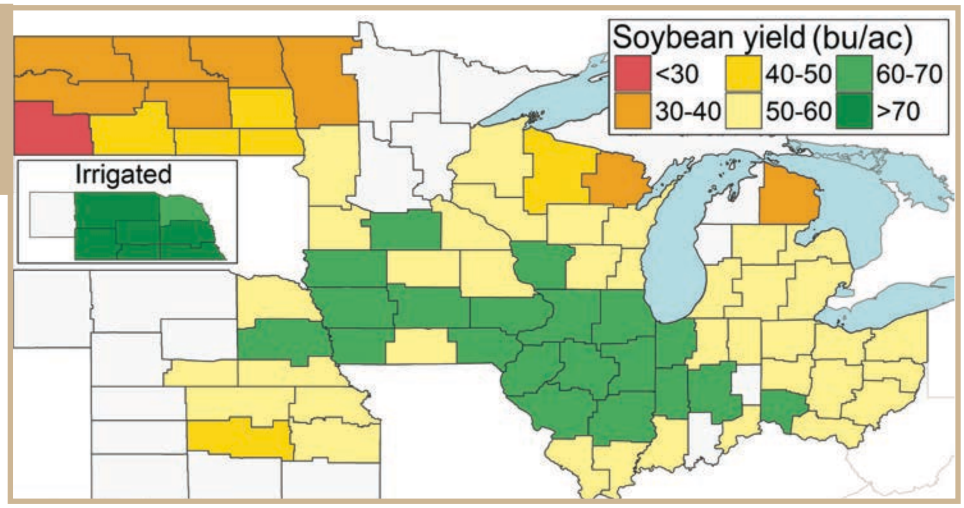
Table 1. TED name and the corresponding TED code developed using the spatial framework for the United States by the Global Yield Gap Atlas (http://www.yieldgap.org).

TED name	TED code	TED name	TED code	TED name	TED code
1 dryland	303603	**10 dryland**	504603	**19 dryland**	604603
2 dryland	303703	**11 dryland**	504803	**20 dryland**	604803
3 dryland	304803	**12 dryland**	602203	**21 dryland**	703503
4 dryland	403603	**13 dryland**	602303	**22 dryland**	703603
5 dryland	403703	**14 dryland**	603503	**23 irrigated**	704303
6 dryland	404803	**15 dryland**	603603	**24 irrigated**	704403
7 dryland	502303	**16 dryland**	603703	**25 dryland**	704503
8 dryland	503603	**17 dryland - 17 irrigated**	604403	**26 dryland**	704603
9 dryland	503703	**18 dryland - 18 irrigated**	604503	**27 dryland**	603403

3. Descriptive Analysis Maps: Soybean Yield & Management Practices Across the North Central US Region

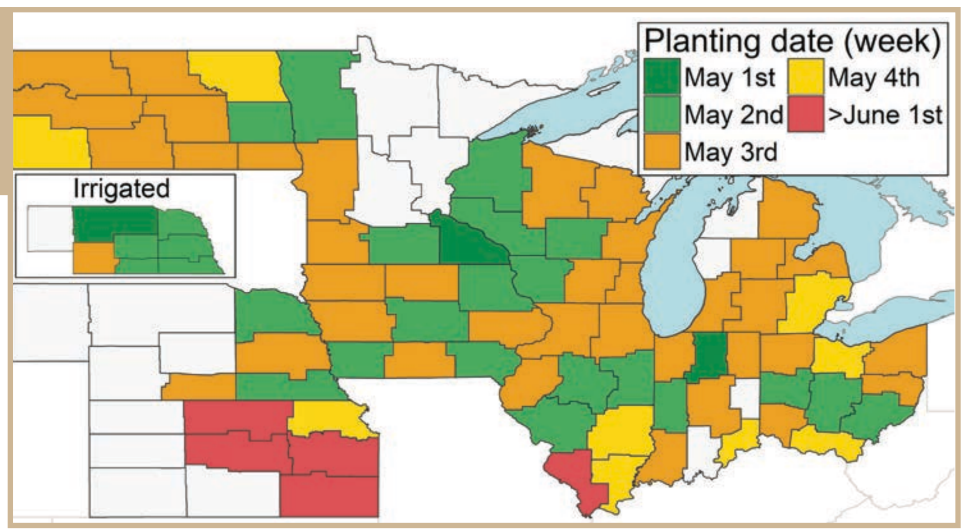
MAP 1

Soybean yield



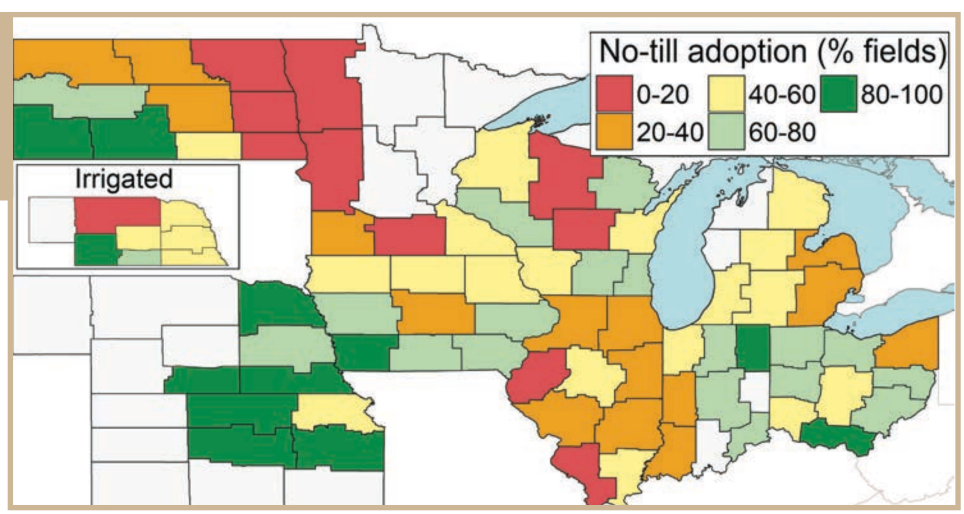
MAP 2

Planting date

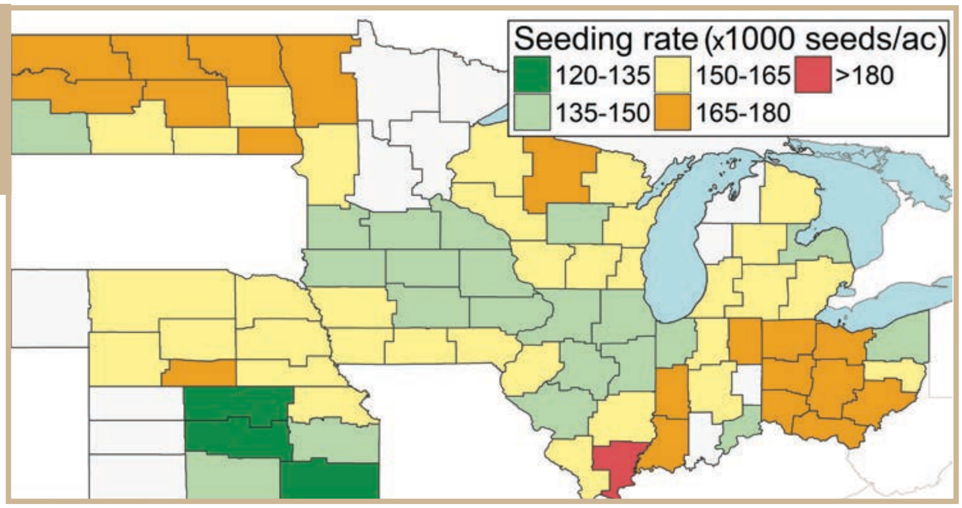


MAP 3

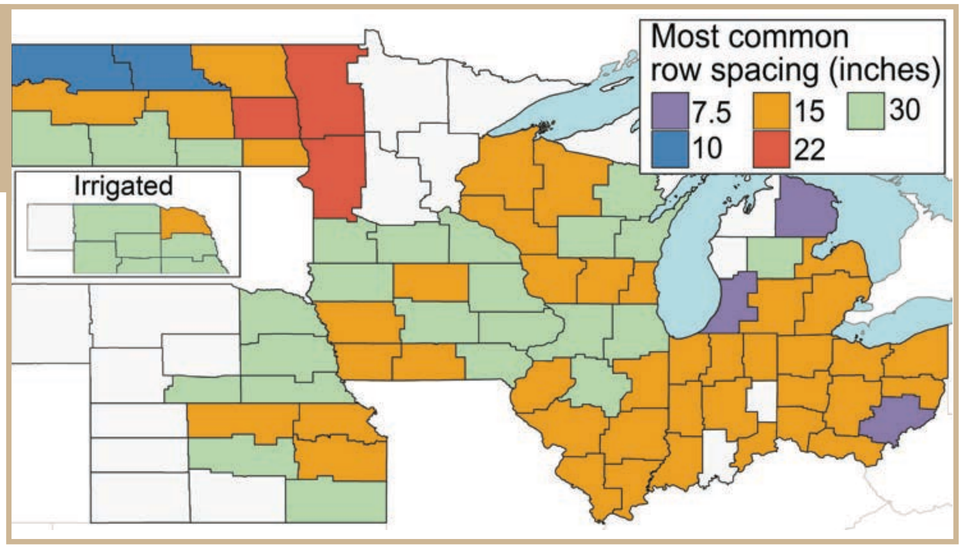
No-till adoption



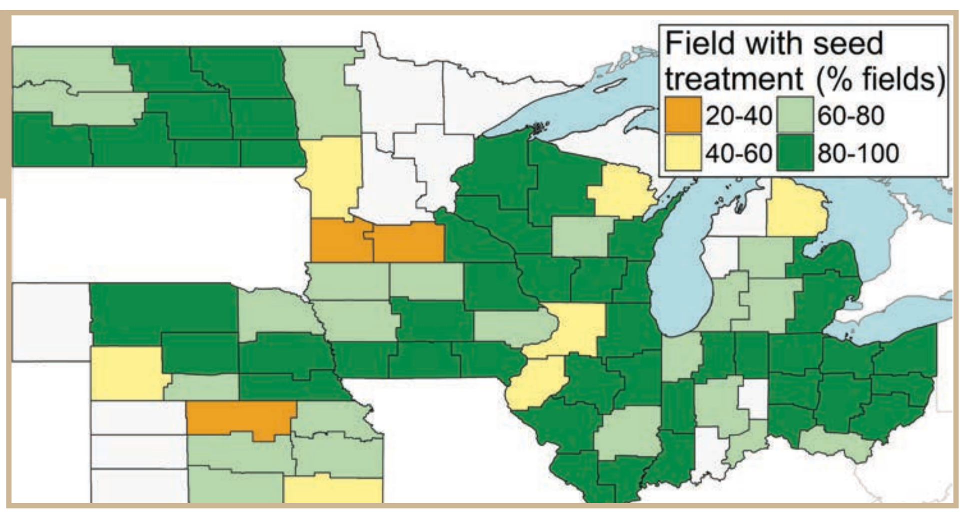
MAP 4
Seeding rate



MAP 5
Most common row spacing

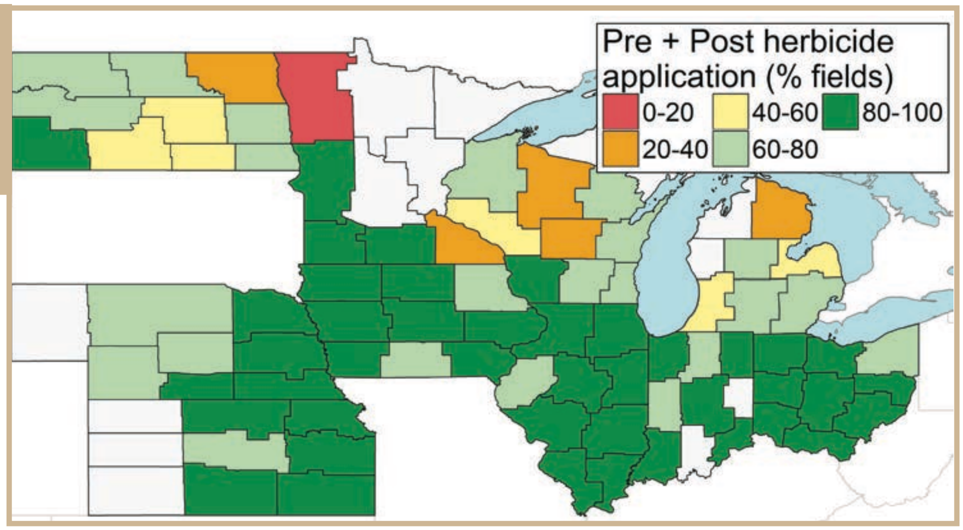


MAP 6
Fields with seed treatment



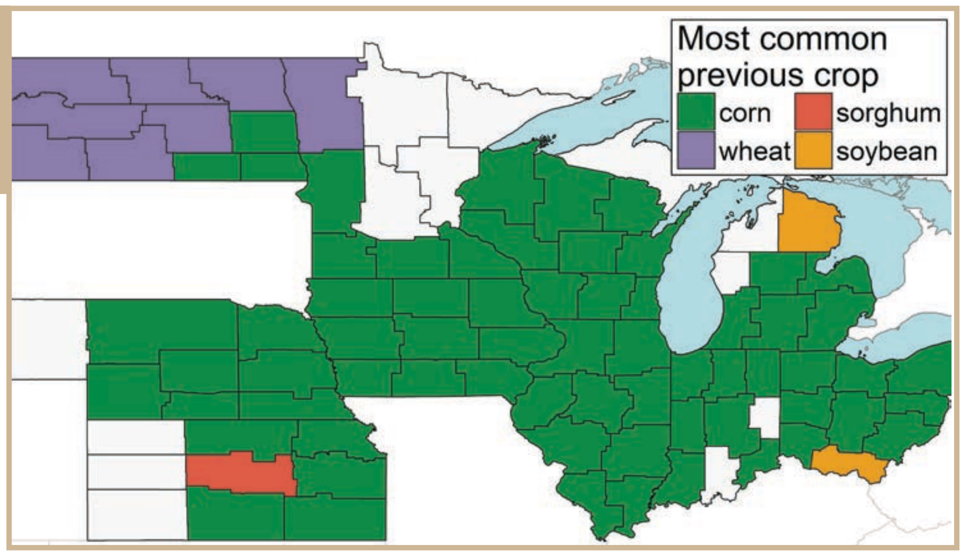
MAP 7

Pre + Post herbicide application



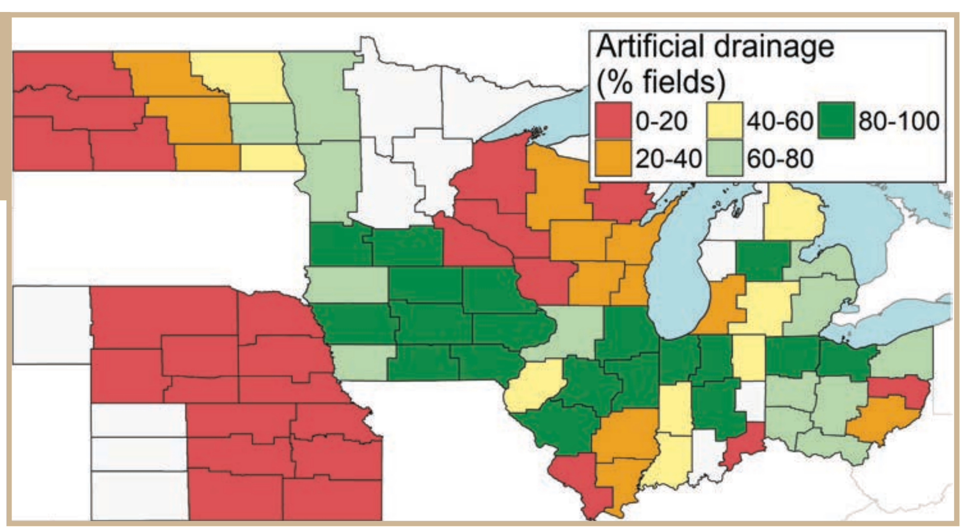
MAP 8

Most common previous crop



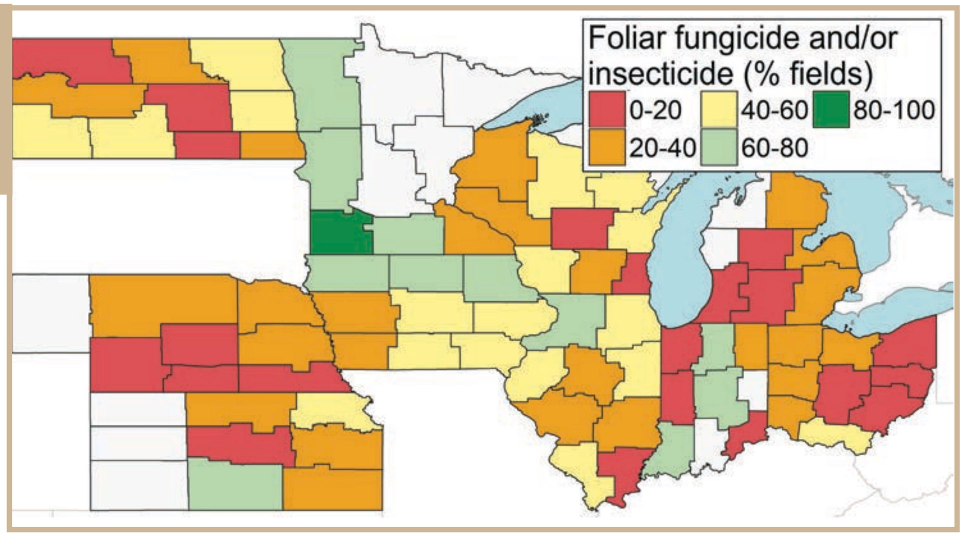
MAP 9

Artificial drainage



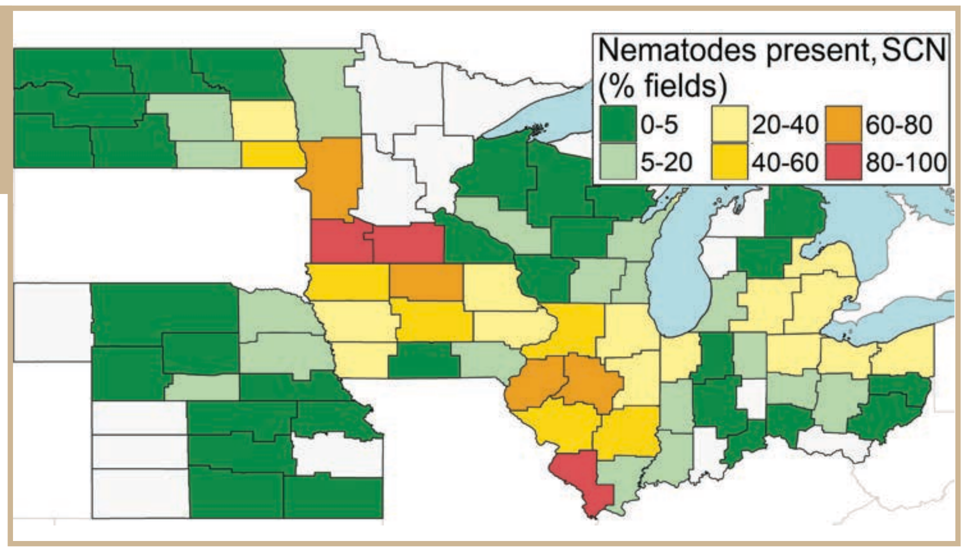
MAP 10

Foliar fungicide or insecticide



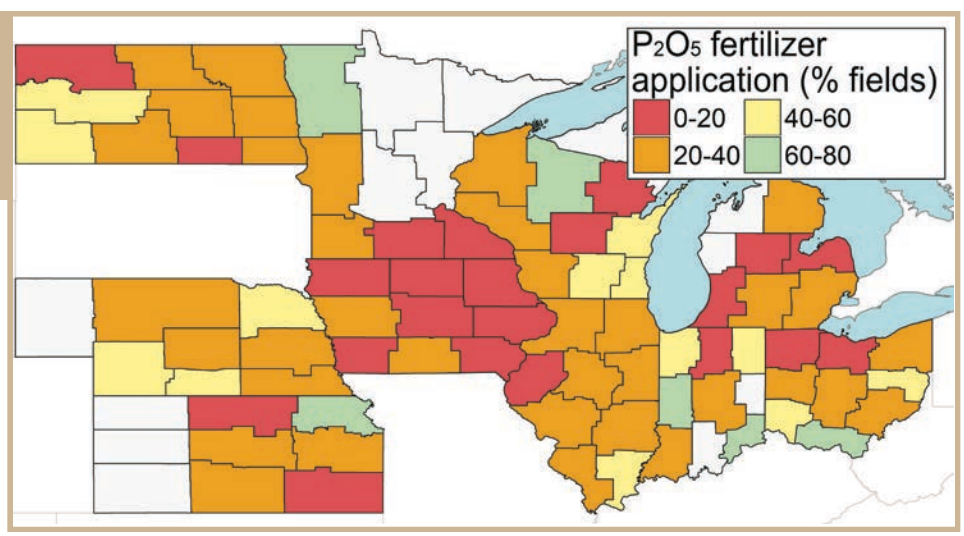
MAP 11

Nematodes present, SCN



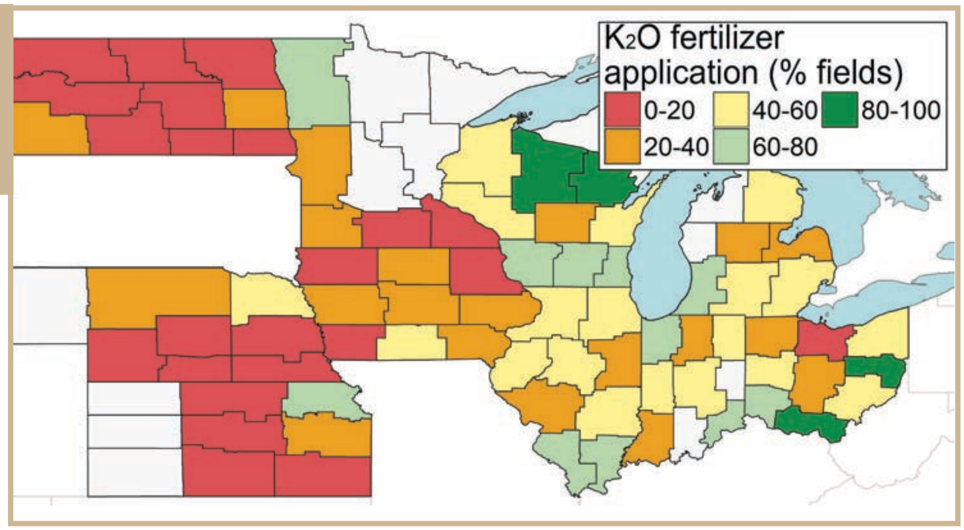
MAP 12

P_2O_5 fertilizer application



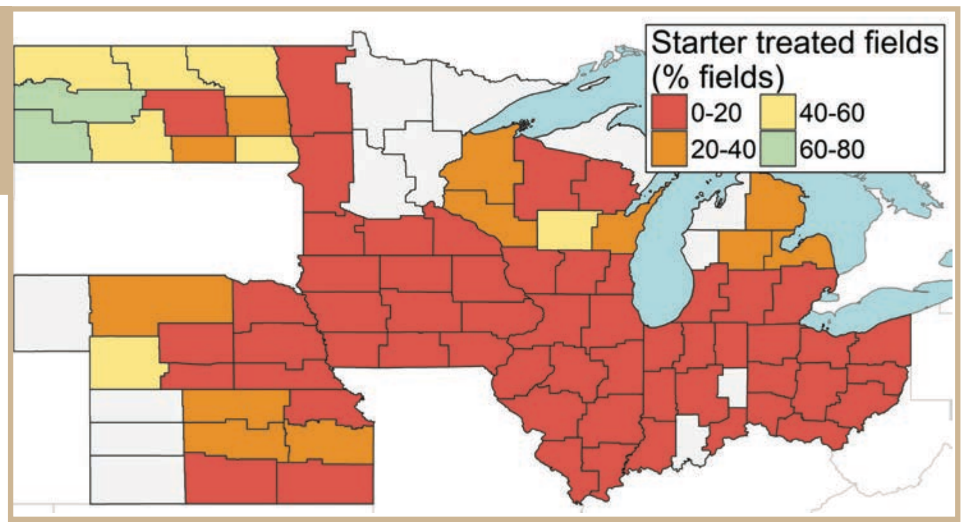
MAP 13

K_2O fertilizer application



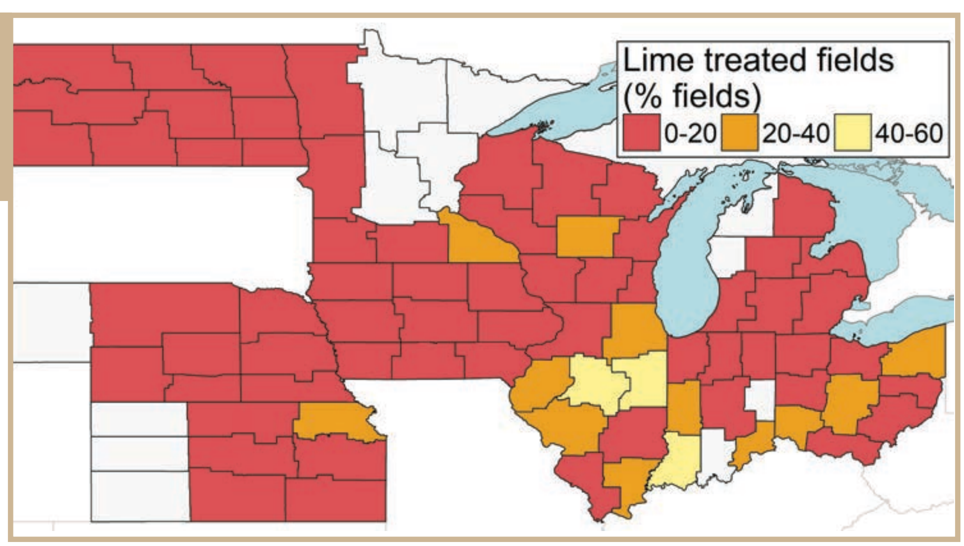
MAP 14

Starter fertilizer



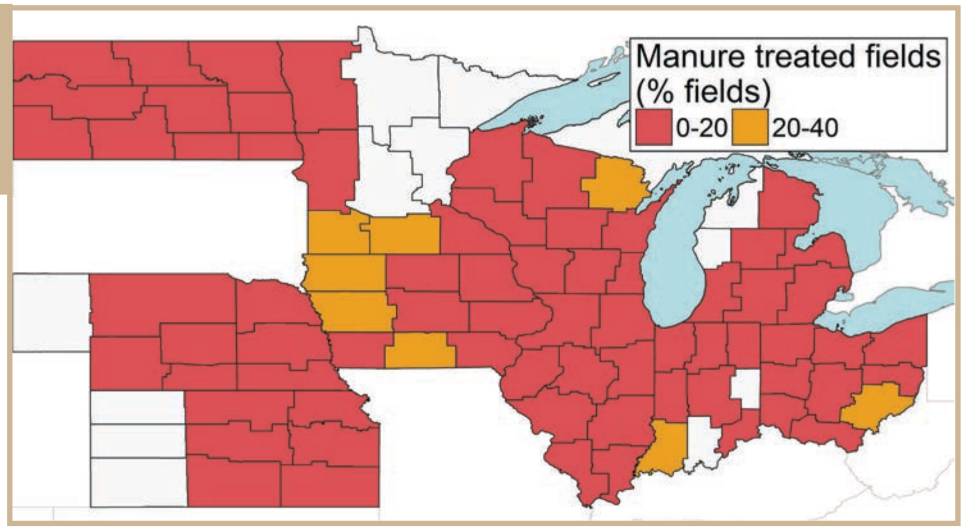
MAP 15

Lime treated fields



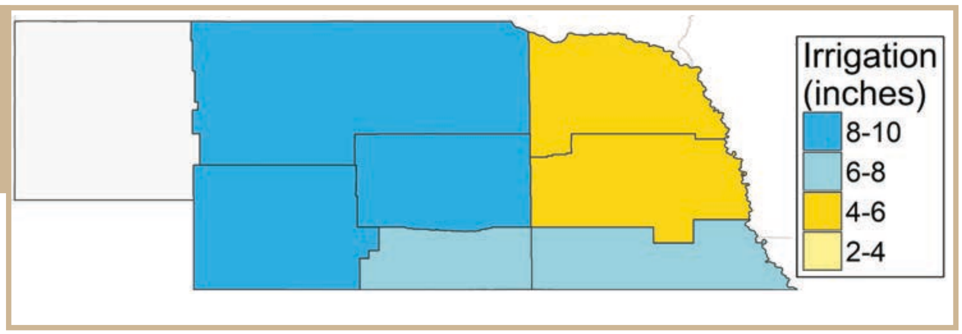
MAP 16

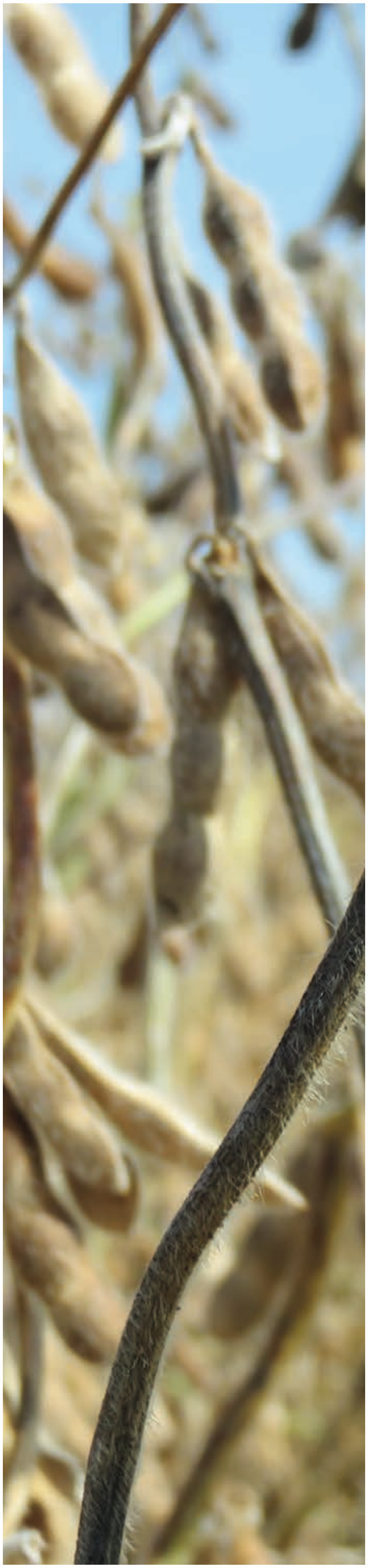
Manure treated fields



MAP 17

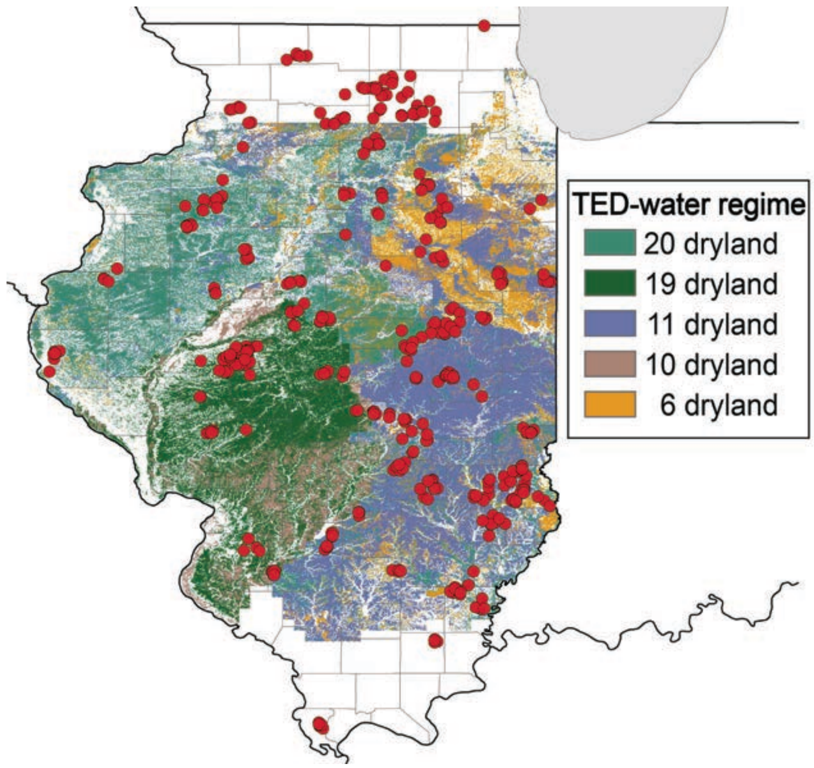
Irrigated fields





Summary of the Illinois Soybean Benchmarking and Yield Gap Surveys

Illinois accounted for about 12% of the U.S soybean harvested acres over the past five years (www.nass.usda.gov). Illinois participated in a multi-state project to assess soybean yield gaps and the management practices responsible for them. The yield gap is defined as the difference between yield potential, as determined by climate and soil, *versus* producer average yields. Producers were asked to provide field-specific information from fields planted with soybean from 2014 to 2017. Collected data included field location, yield, crop management, and applied inputs from 527 Illinois fields.



Fields were grouped into regions called TEDs (technology extrapolation domains), which represent regions within which climate and soil are reasonably similar. Specifically, TEDs are based on annual growing-degree day accumulation, precipitation, and temperature fluctuations, as well as plant available water-holding capacity in the rooting zone. In our analysis, we only included fields located in TEDs that represent >5% of soybean area within the state and have TEDS that at least 100 surveyed fields. In the case of Illinois, there were a total of 5 TEDs meeting these criteria (see map below).

Within each TED, fields were sorted into two groups based on their yields: the highest third were assigned to the 'high yield' (HY) and the lowest third to the 'low-yield' (LY). Then, average management practices implemented by the two groups were compared to identify the management practices responsible for the yield gap within a TED (details on methodology can be found on page 8).

In most TEDs in Illinois (4-5 out of 5), the high-yield category (significantly higher yield $p \leq 0.10$) consisted of fields with earlier planting date and those treated with foliar insecticide and/or fungicide. In some TEDs (3 out of 5), high-yield fields were also associated with artificial drainage and tillage.

Management Practices Comparison Between High- and Low-Yield Fields in Illinois

Green cells indicate statistically significant differences ($p \leq 0.10$) for a given management practice between the two field yield categories. For planting date and seeding rate, the values within green cells indicate the averages for the respective columns. For row spacing, green cells indicate differences in the proportion of fields under 7.5, 15, or 30 inches between high- and low-yield fields. For artificial drainage, tillage, and foliar insecticide and/or fungicide, values indicate the % of fields with that management practice. Keep in mind that yields in the HY and LY categories are a consequence of different combination of practices, and yield difference between HY and LY should not be associated with one single practice.

		---------------TED---------------									
		6D		10D		11D		19D		20D	
	Yield category	HY	LY	HY	LY	HY	LY	HY	LY	HY	LY
	Average bu/A	69	46	68	49	72	51	72	55	75	52
Management Practices	Planting date	May 15	May 26	May 12	May 31	May 11	May 19	May 11	May 21	May 9	May 20
	Seeding rate (x1000 seeds ac^{-1})					154	167			149	168
	Row spacing										
	% Fields with artificial drainage	71	32			79	50			92	67
	% Fields with tillage	61	36			59	47			73	48
	% Fields with foliar insecticide and/or fungicide	32	9	61	13	58	19			67	28

There were variable row spacing results. In TED 10D, there were more fields with 30-inch row spacing in the HY group while TED 11D had more fields with 15-inch row spacing in the HY group compared to the LY group (see above table).

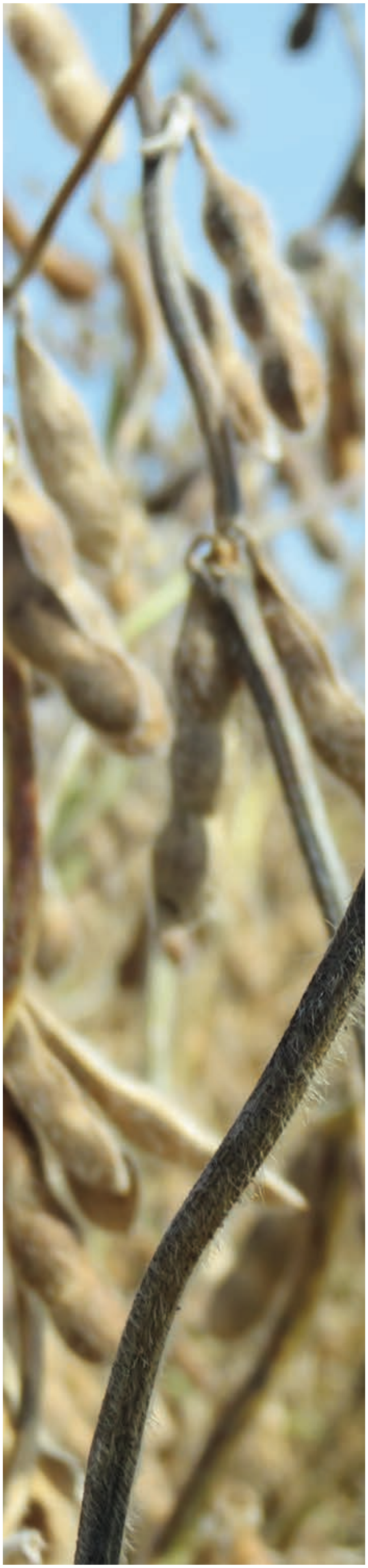
Our study focused on those management practices with greatest yield impact; there may be other reasons for adopting (or not) a given practice, e.g., economic and logistic consideration, pest resistance, soil erosion, etc.

References:

Key Management Practices That Explain Soybean Yield Gaps Across the North Central US

Sifting and winnowing: analysis of farmer field data for soybean in the US North-Central region

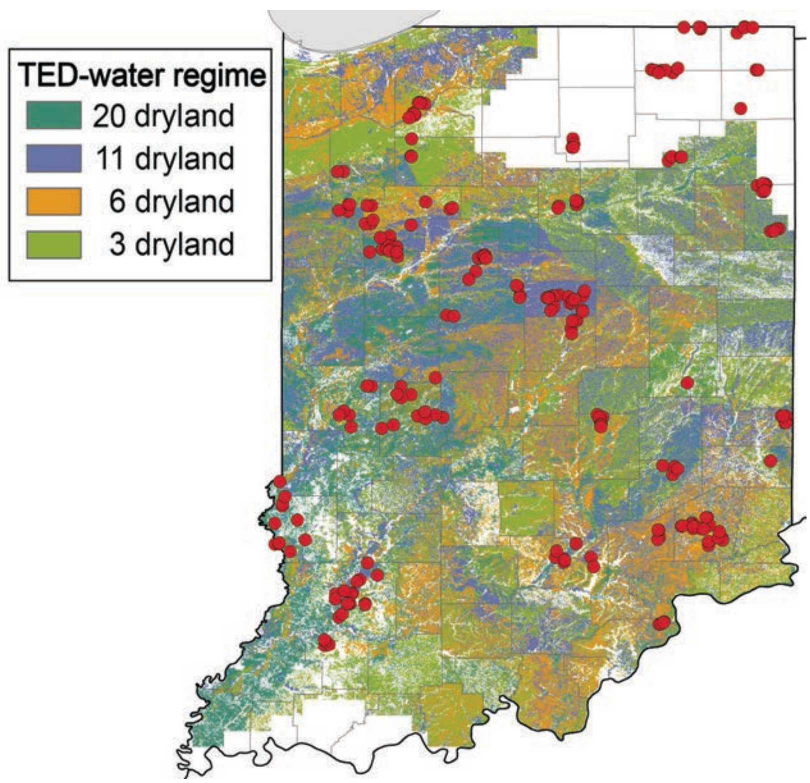
Both publications are available online at: https://coolbean.info/soybean-research/new-information/



Summary of the Indiana Soybean Benchmarking and Yield Gap Surveys

Indiana accounted for about 7% of the U.S soybean harvested acres over the past five years (www.nass.usda.gov). Indiana participated in a multi-state project to assess soybean yield gaps and the management practices responsible for them. The yield gap is defined as the difference between yield potential, as determined by climate and soil, *versus* producer average yields. Producers were asked to provide field-specific information from fields planted with soybean from 2014 to 2017. Collected data included field location, yield, crop management, and applied inputs from 234 Indiana fields.

Fields were grouped into regions called TEDs (technology extrapolation domains), which represent regions within which climate and soil are reasonably similar. Specifically, TEDs are based on annual growing-degree day accumulation, precipitation, and temperature fluctuations, as well as plant available water-holding capacity in the rooting zone. In our analysis, we only included fields located in TEDs that represent >5% of soybean area within the state and TEDs that have at least 100 surveyed fields. In the case of Indiana, there were a total of 4 TEDs meeting these criteria (see map below).



Within each TED, fields were sorted into two groups based on their yields: the highest third were assigned to the 'high yield' (HY) and the lowest third to the 'low-yield' (LY). Then, average management practices implemented by the two groups were compared to identify the management practices responsible for the yield gap within a TED (details on methodology can be found on page 8).

In most TEDs in Indiana (3-4 out of 4), the high-yield category (significantly higher yield p ≤0.10) consisted of fields with earlier planting date, those treated with foliar insecticide and/or fungicide, artificial drainage, and tillage. TED 11D had more fields with 15-inch row spacing in the HY group compared to the LY group (see the table Management Practices Comparison Between High- and Low-yield Fields on next page).

Management Practices Comparison Between High- and Low-Yield Fields in Indiana

Green cells indicate statistically significant differences (p≤0.10) for a given management practice between the two field yield categories. For planting date and seeding rate, the values within green cells indicate the averages for the respective columns. For row spacing, green cells indicate differences in the proportion of fields under 7.5, 15, or 30 inches between high- and low-yield fields. For artificial drainage, tillage, and foliar insecticide and/or fungicide, values indicate the % of fields with that management practice. Keep in mind that yields in the HY and LY categories are a consequence of different combination of practices, and yield difference between HY and LY should not be associated with one single practice.

		-----------TED -----------							
		3D		6D		11D		20D	
	Yield category	HY	LY	HY	LY	HY	LY	HY	LY
	Average bu/A	66	48	69	46	72	51	75	52
Management Practices	**Planting date**			May 15	May 26	May 11	May 19	May 9	May 20
	Seeding rate (x1000 seeds ac^{-1})					154	167	149	168
	Row spacing								
	% Fields with artificial drainage			71	32	79	50	92	67
	% Fields with tillage			61	36	59	47	73	48
	% Fields with foliar insecticide and/or fun-gicide	47	11	32	9	58	19	67	28

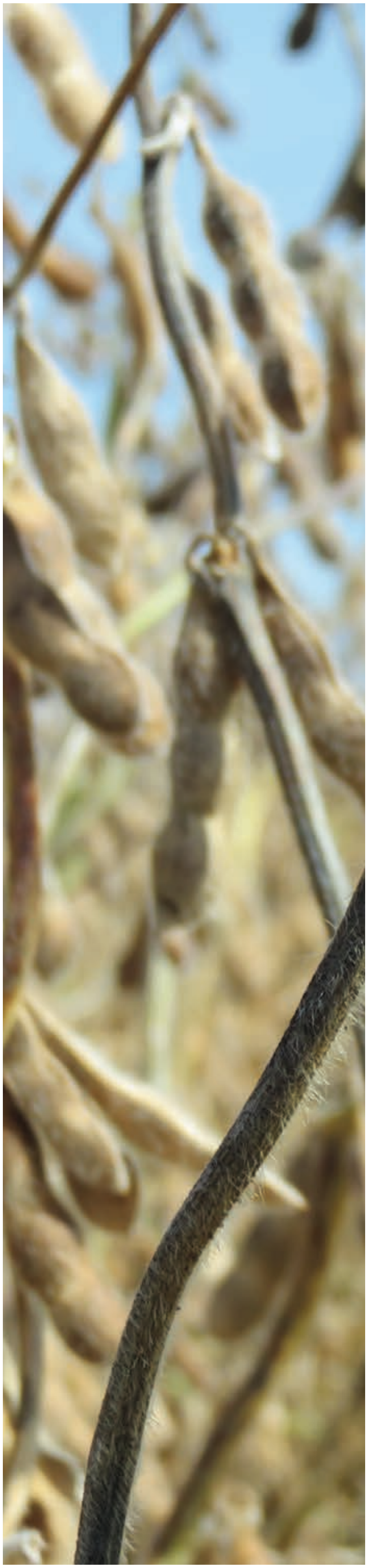
Our study focused on those management practices with greatest yield impact; there may be other reasons for adopting (or not) a given practice, e.g., economic and logistic consideration, pest resistance, soil erosion, etc.

References:

Key Management Practices That Explain Soybean Yield Gaps Across the North Central US

Sifting and winnowing: analysis of farmer field data for soybean in the US North-Central region

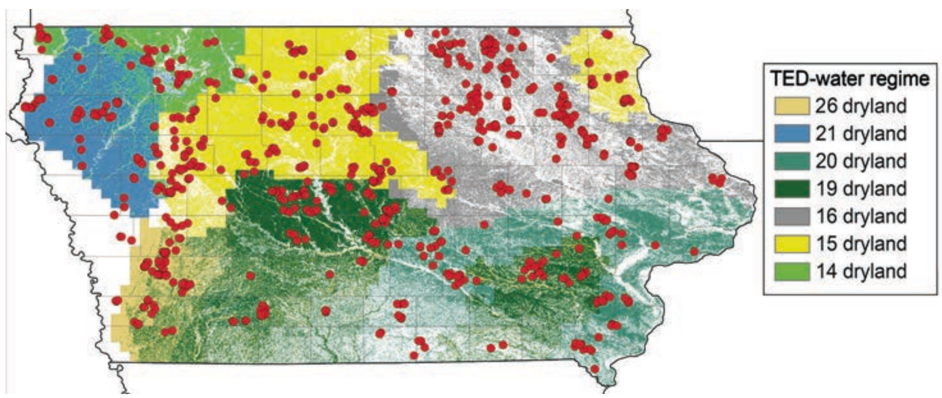
Both publications are available online at: https://coolbean.info/soybean-research/new-information/



Summary of the Iowa Soybean Benchmarking and Yield Gap Surveys

Iowa accounted for about 12% of the U.S soybean harvested acres over the past five years (www.nass.usda.gov). Iowa participated in a multi-state project to assess soybean yield gaps and the management practices responsible for them. The yield gap is defined as the difference between yield potential, as determined by climate and soil, *versus* producer average yields. Producers were asked to provide field-specific information from fields planted with soybean from 2014 to 2017. Collected data included field location, yield, crop management, and applied inputs from 1,327 Iowa fields.

Fields were grouped into regions called TEDs (technology extrapolation domains), which represent regions within which climate and soil are reasonably similar. Specifically, TEDs are based on annual growing-degree day accumulation, precipitation, and temperature fluctuations, as well as plant available water-holding capacity in the rooting zone. In our analysis, we only included fields located in TEDs that represent >5% of soybean area within the state and TEDs that have at least 100 surveyed fields. In the case of Iowa, there were a total of 7 TEDs meeting these criteria (see map below).



Within each TED, fields were sorted into two groups based on their yields: the highest third were assigned to the 'high yield' (HY) and the lowest third to the 'low-yield' (LY). Then, average management practices implemented by the two groups were compared to identify the management practices responsible for the yield gap within a TED (details on methodology can be found on page 8).

In most TEDs in Iowa (5-6 out of 7), the high-yield category (significantly higher yield $p \leq 0.10$) consisted of fields with earlier planting date and those treated with foliar insecticide and/or fungicide. In some TEDs (1-4 out of 7), high-yield fields were also associated with artificial drainage and tillage. In TEDs 15D and 16D, there were more fields with 30-inch row spacing in the HY group compared to the LY group (see the table Management Practices Comparison Between High- and Low-yield Fields on next page).

Our study focused on those management practices with greatest yield impact; there may be other reasons for adopting (or not) a given practice, e.g., economic and logistic consideration, pest resistance, soil erosion, etc.

Management Practices Comparison Between High- and Low-Yield Fields in Iowa

Green cells indicate statistically significant differences ($p \leq 0.10$) for a given management practice between the two field yield categories. For planting date and seeding rate, the values within green cells indicate the averages for the respective columns. For row spacing, green cells indicate differences in the proportion of fields under 7.5, 15, or 30 inches between high- and low-yield fields. For artificial drainage, tillage, and foliar insecticide and/or fungicide, values indicate the % of fields with that management practice. Keep in mind that yields in the HY and LY categories are a consequence of different combination of practices, and yield difference between HY and LY should not be associated with one single practice.

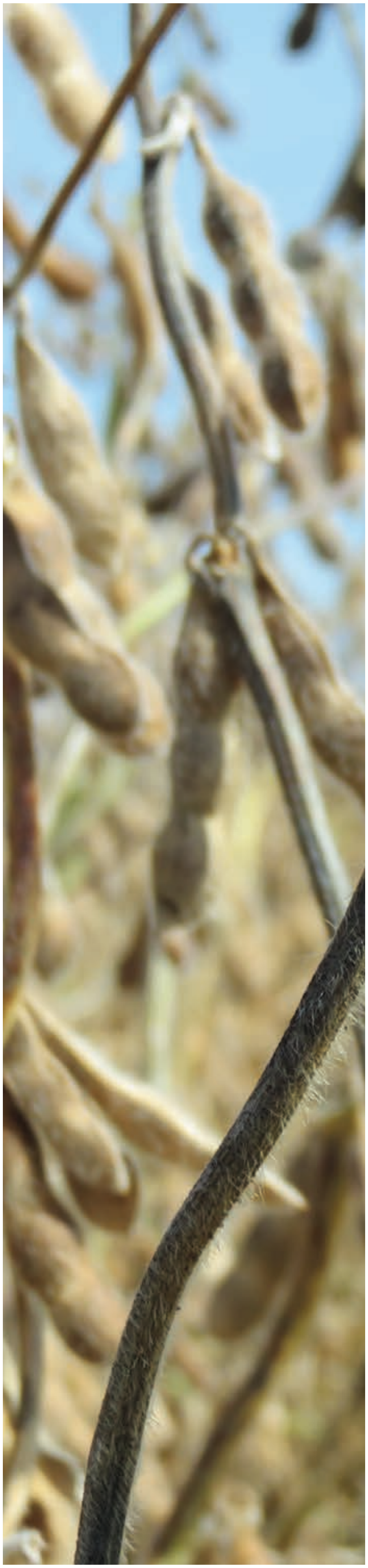
		--------------------TED --------------------													
		14D		15D		16D		19D		20D		21D		26D	
	Yield category	HY	LY	HY	LY	HY	LY	HY	LY	HY	LY	HY	LY	HY	LY
	Average bu/A	68	54	68	48	69	49	72	55	75	52	73	56	73	58
Management Practices	Planting date			May 15	May 19	May 13	May 17	May 11	May 21	May 9	May 20			May 10	May 20
	Seeding rate (x1000 seeds ac^{-1})	144	147	149	154					149	168				
	Row spacing														
	% Fields with artificial drainage											92	67		
	% Fields with tillage			74	61	53	40			73	48			38	11
	% Fields with foliar insecticide and/or fungicide	96	86	57	30	54	35			67	28	74	35	63	14

References:

Key Management Practices That Explain Soybean Yield Gaps Across the North Central US

Sifting and winnowing: analysis of farmer field data for soybean in the US North-Central region

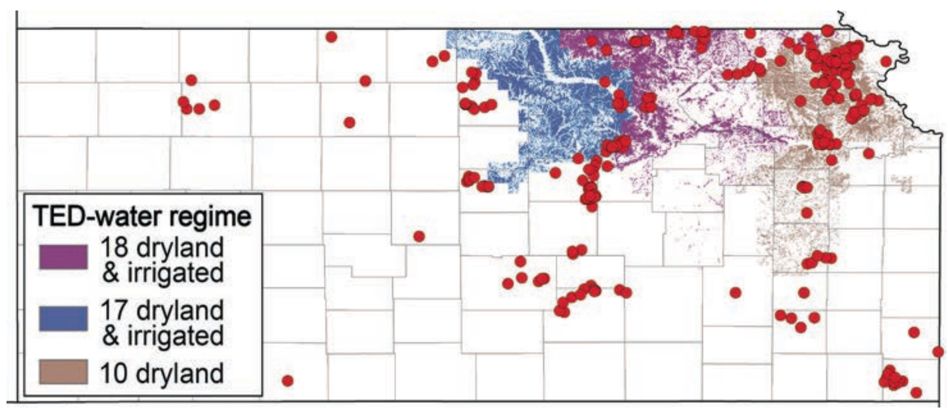
Both publications are available online at: https://coolbean.info/soybean-research/new-information/



Summary of the Kansas Soybean Benchmarking and Yield Gap Surveys

Kansas accounted for about 5% of the U.S soybean harvested acres over the past five years (www.nass.usda.gov). Kansas participated in a multi-state project to assess soybean yield gaps and the management practices responsible for them. The yield gap is defined as the difference between yield potential, as determined by climate and soil, *versus* producer average yields. Producers were asked to provide field-specific information from fields planted with soybean from 2014 to 2017. Collected data included field location, yield, crop management, and applied inputs from 318 Kansas fields.

Fields were grouped into regions called TEDs (technology extrapolation domains), which represent regions within which climate and soil are reasonably similar. Specifically, TEDs are based on annual growing-degree day accumulation, precipitation, and temperature fluctuations, as well as plant available water-holding capacity in the rooting zone. In our analysis, we only included fields located in TEDs that represent >5% of soybean area within the state and TEDs that have at least 100 surveyed fields. In the case of Kansas, there were a total of 5 TEDs meeting these criteria (see map below).



Within each TED, fields were sorted into two groups based on their yields: the highest third were assigned to the 'high yield' (HY) and the lowest third to the 'low-yield' (LY). Then, average management practices implemented by the two groups were compared to identify the management practices responsible for the yield gap within a TED (details on methodology can be found on page 8).

In most TEDs in Kansas (4 out of 5), the high-yield category (significantly higher yield $p \leq 0.10$) consisted of fields with earlier planting date and those treated with foliar insecticide and/or fungicide. In 2 TEDs, high-yield fields were also associated with tillage. In TED 10D, there were more fields with 30-inch row spacing in the HY group compared to the LY group (see the table Management Practices Comparison Between High- and Low-yield Fields on next page).

Our study focused on those management practices with greatest yield impact; there may be other reasons for adopting (or not) a given practice, e.g., economic and logistic consideration, pest resistance, soil erosion, etc.

Management Practices Comparison Between High- and Low-Yield Fields in Kansas

Green cells indicate statistically significant differences ($p \leq 0.10$) for a given management practice between the two field yield categories. For planting date and seeding rate, the values within green cells indicate the averages for the respective columns. For row spacing, green cells indicate differences in the proportion of fields under 7.5, 15, or 30 inches between high- and low-yield fields. For artificial drainage, tillage, and foliar insecticide and/or fungicide, values indicate the % of fields with that management practice. Keep in mind that yields in the HY and LY categories are a consequence of different combination of practices, and yield difference between HY and LY should not be associated with one single practice.

	TED									
	10D		17D		17I		18D		18I	
Yield category	HY	LY	HY	LY	HY	LY	HY	LY	HY	LY
Average bu/A	68	49	69	44	80	64	69	47	79	63
Management Practices: Planting date	May 12	May 31			May 7	May 15	May 18	May 22	May 9	May 17
Seeding rate (x1000 seeds ac^{-1})			157	149	164	160				
Row spacing										
% Fields with artificial drainage										
% Fields with tillage					73	56			42	23
% Fields with foliar insecticide and/or fungicide	61	13			31	9	58	9	73	22

References:

Key Management Practices That Explain Soybean Yield Gaps Across the North Central US

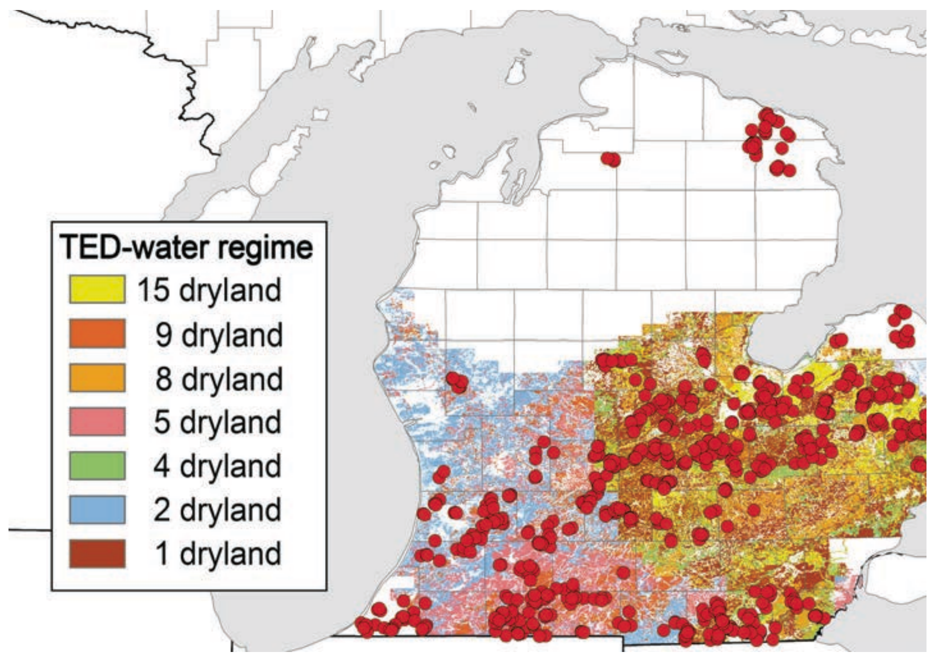
Sifting and winnowing: analysis of farmer field data for soybean in the US North-Central region

Both publications are available online at: https://coolbean.info/soybean-research/new-information/

Summary of the Michigan Soybean Benchmarking and Yield Gap Surveys

Michigan accounted for about 3% of the U.S soybean harvested acres over the past five years (www.nass.usda.gov). Michigan participated in a multi-state project to assess soybean yield gaps and the management practices responsible for them. The yield gap is defined as the difference between yield potential, as determined by climate and soil, *versus* producer average yields. Producers were asked to provide field-specific information from fields planted with soybean from 2014 to 2017. Collected data included field location, yield, crop management, and applied inputs from 956 Michigan fields.

Fields were grouped into regions called TEDs (technology extrapolation domains), which represent regions within which climate and soil are reasonably similar. Specifically, TEDs are based on annual growing-degree day accumulation, precipitation, and temperature fluctuations, as well as plant available water-holding capacity in the rooting zone. In our analysis, we only included fields located in TEDs that represent >5% of soybean area within the state and have at least 100 surveyed fields. In the case of Michigan, there were a total of 7 TEDs meeting these criteria (see map below).



Within each TED, fields were sorted into two groups based on their yields: the highest third were assigned to the 'high yield' (HY) and the lowest third to the 'low-yield' (LY). Then, average management practices implemented by the two groups were compared to identify the management practices responsible for the yield gap within a TED. Details on methodology can be found (details on methodology can be found on page 8).

In most TEDs in Michigan (6 out of 7), the high-yield category (significantly higher yield p ≤0.10) consisted of fields with earlier planting date and those treated with foliar insecticide and/or fungicide. In some TEDs (3 out of 7), high-yield fields were also associated with artificial drainage and tillage. In TED 2D, there were more fields with 15-inch row spacing in the HY group while TED 15D had more fields with 30-inch row spacing in the HY group compared to the LY group (see the table Management Practices Comparison Between High- and Low-yield Fields on next page).

Management Practices Comparison Between High- and Low-Yield Fields in Michigan

Green cells indicate statistically significant differences (p≤0.10) for a given management practice between the two field yield categories. For planting date and seeding rate, the values within green cells indicate the averages for the respective columns. For row spacing, green cells indicate differences in the proportion of fields under 7.5, 15, or 30 inches between high- and low-yield fields. For artificial drainage, tillage, and foliar insecticide and/or fungicide, values indicate the % of fields with that management practice. Keep in mind that yields in the HY and LY categories are a consequence of different combination of practices, and yield difference between HY and LY should not be associated with one single practice.

	----------------------TED ----------------------													
	1D		2D		4D		5D		8D		9D		15D	
Yield category	HY	LY	HY	LY	HY	LY	HY	LY	HY	LY	HY	LY	HY	LY
Average bu/A	63	42	65	41	64	43	64	40	66	47	67	45	68	48
Management Practices														
Planting date			May 17	May 23	May 14	May 22	May 14	May 19	May 15	May 22	May 13	May 18	May 15	May 19
Seeding rate (x1000 seeds ac^{-1})					156	165					149	154	149	154
Row spacing														
% Fields with artificial drainage	80	65	77	62			60	36						
% Fields with tillage					62	43					67	24	74	61
% Fields with foliar insecticide and/or fungicide	28	10	47	11	41	11	29	14			56	12	57	30

Our study focused on those management practices with greatest yield impact; there may be other reasons for adopting (or not) a given practice, e.g., economic and logistic consideration, pest resistance, soil erosion, etc.

References:

Key Management Practices That Explain Soybean Yield Gaps Across the North Central US

Sifting and winnowing: analysis of farmer field data for soybean in the US North-Central region

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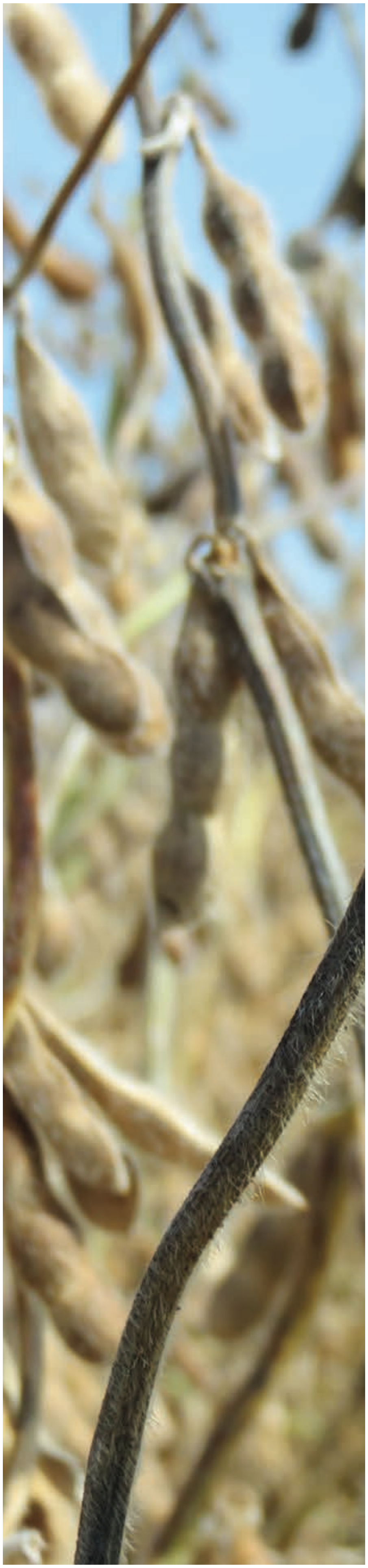
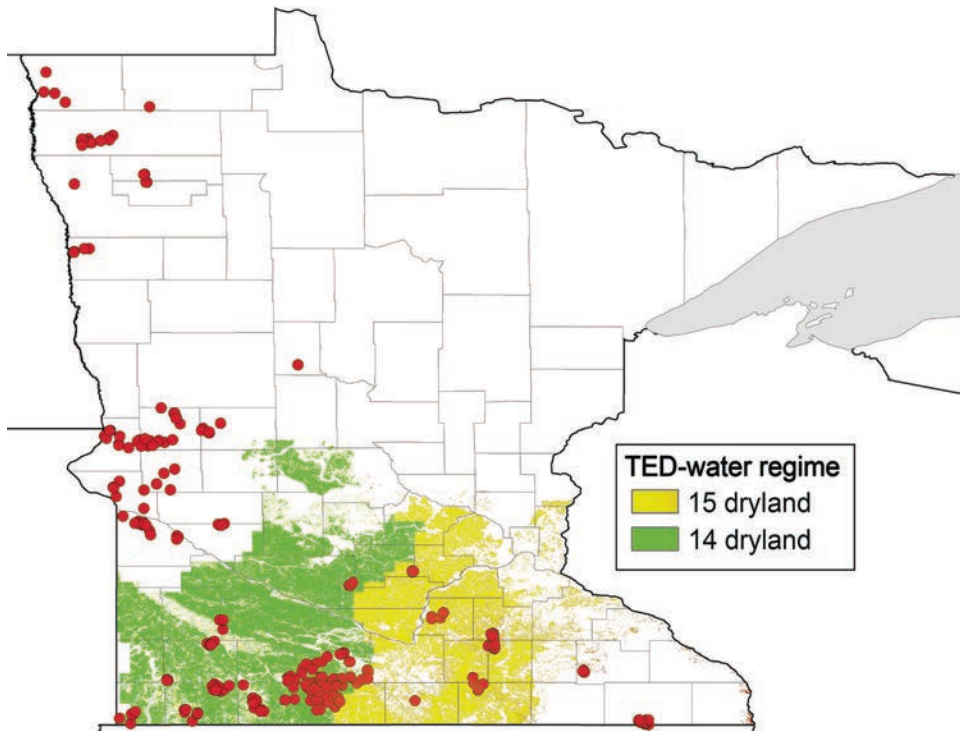


Summary of the Minnesota Soybean Benchmarking and Yield Gap Surveys

Minnesota accounted for about 9% of the U.S soybean harvested acres over the past five years (www.nass.usda.gov). Minnesota participated in a multi-state project to assess soybean yield gaps and the management practices responsible for them. The yield gap is defined as the difference between yield potential, as determined by climate and soil, *versus* producer average yields. Producers were asked to provide field-specific information from fields planted with soybean from 2014 to 2017. Collected data included field location, yield, crop management, and applied inputs from 271 Minnesota fields.

Fields were grouped into regions called TEDs (technology extrapolation domains), which represent regions within which climate and soil are reasonably similar. Specifically, TEDs are based on annual growing-degree day accumulation, precipitation, and temperature fluctuations, as well as plant available water-holding capacity in the rooting zone. In our analysis, we only included fields located in TEDs that represent >5% of soybean area within the state and TEDs that have at least 100 surveyed fields. In the case of Minnesota, there were a total of 2 TEDs meeting these criteria (see map below).



Within each TED, fields were sorted into two groups based on their yields: the highest third were assigned to the 'high yield' (HY) and the lowest third to the 'low-yield' (LY). Then, average management practices implemented by the two groups were compared to identify the management practices responsible for the yield gap within a TED. Details on methodology can be found (details on methodology can be found on page 8).

In most TEDs in Minnesota (1-2 out of 2), the high-yield category (significantly higher yield p ≤0.10) consisted of fields with earlier planting date and those treated with foliar insecticide and/or fungicide. In some TEDs (1 out of 2), high-yield fields were also associated with tillage. TED 15D had more fields with 30-inch row spacing in the HY group compared to the LY group (see the table on next page).

Management Practices Comparison Between High- and Low-Yield Fields in Minnesota

Green cells indicate statistically significant differences ($p \leq 0.10$) for a given management practice between the two field yield categories. For planting date and seeding rate, the values within green cells indicate the averages for the respective columns. For row spacing, green cells indicate differences in the proportion of fields under 7.5, 15, or 30 inches between high- and low-yield fields. For artificial drainage, tillage, and foliar insecticide and/or fungicide, values indicate the % of fields with that management practice. Keep in mind that yields in the HY and LY categories are a consequence of different combination of practices, and yield difference between HY and LY should not be associated with one single practice.

		------TED -----			
		14D		15D	
	Yield category	HY	LY	HY	LY
	Average bu/A	68	54	68	48
Management Practices	Planting date			May 15	May 19
	Seeding rate (x1000 seeds ac^{-1})	144	147	149	154
	Row spacing				
	% Fields with artificial drainage				
	% Fields with tillage			74	61
	% Fields with foliar insecticide and/or fungicide	96	86	57	30

Our study focused on those management practices with greatest yield impact; there may be other reasons for adopting (or not) a given practice, e.g., economic and logistic consideration, pest resistance, soil erosion, etc.

References:

Key Management Practices That Explain Soybean Yield Gaps Across the North Central US

Sifting and winnowing: analysis of farmer field data for soybean in the US North-Central region

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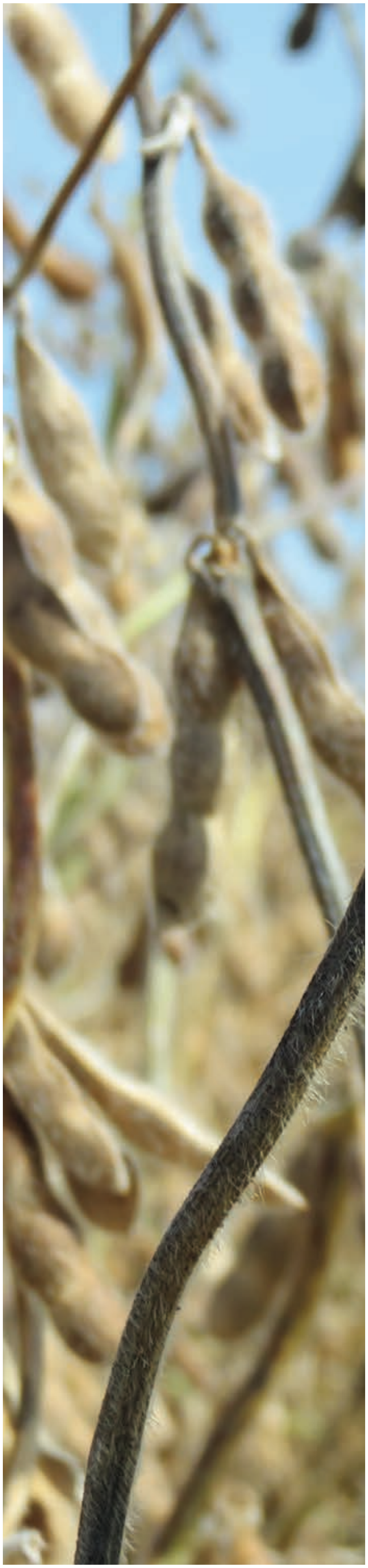
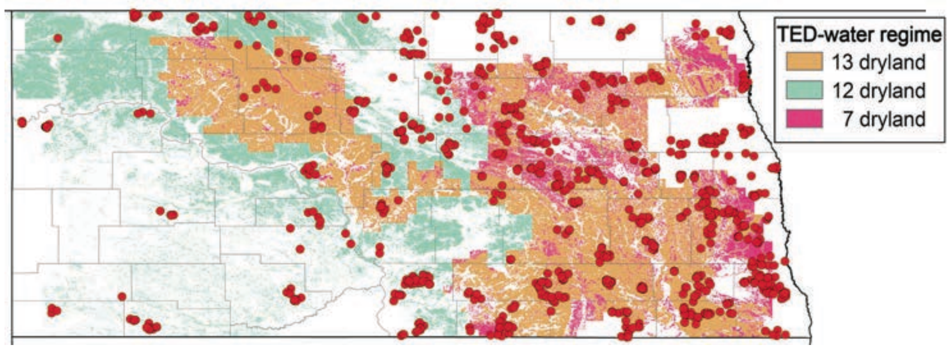


Summary of the North Dakota Soybean Benchmarking and Yield Gap Surveys

North Dakota accounted for about 7% of the U.S soybean harvested acres over the past five years (www.nass.usda.gov). North Dakota participated in a multi-state project to assess soybean yield gaps and the management practices responsible for them. The yield gap is defined as the difference between yield potential, as determined by climate and soil, *versus* producer average yields. Producers were asked to provide field-specific information from fields planted with soybean from 2014 to 2017. Collected data included field location, yield, crop management, and applied inputs from 1,002 North Dakota fields.

Fields were grouped into regions called TEDs (technology extrapolation domains), which represent regions within which climate and soil are reasonably similar. Specifically, TEDs are based on annual growing-degree day accumulation, precipitation, and temperature fluctuations, as well as plant available water-holding capacity in the rooting zone. In our analysis, we only included fields located in TEDs that represent >5% of soybean area within the state and TEDs that have at least 100 surveyed fields. In the case of North Dakota, there were a total of 3 TEDs meeting these criteria (see map below).



Within each TED, fields were sorted into two groups based on their yields: the highest third were assigned to the 'high yield' (HY) and the lowest third to the 'low-yield' (LY). Then, average management practices implemented by the two groups were compared to identify the management practices responsible for the yield gap within a TED. Details on methodology can be found (details on methodology can be found on page 8).

In most TEDs in North Dakota (2-3 out of 3), the high-yield category (significantly higher yield $p \leq 0.10$) consisted of fields with earlier planting date and those treated with foliar insecticide and/or fungicide. In one TED, high-yield fields were also associated with tillage and artificial drainage. In TEDs 7D and 13D, there were more fields with 15-inch row spacing in the HY group compared to the LY group while in TED 12D there were more fields with 7.5-inch row spacing in the HY group (see the table Management Practices Comparison Between High- and Low-yield Fields on next page).

Our study focused on those management practices with greatest yield impact; there may be other reasons for adopting (or not) a given practice, e.g., economic and logistic consideration, pest resistance, soil erosion, etc.

Management Practices Comparison Between High- and Low-Yield Fields in North Dakota

Green cells indicate statistically significant differences ($p \leq 0.10$) for a given management practice between the two field yield categories. For planting date and seeding rate, the values within green cells indicate the averages for the respective columns. For row spacing, green cells indicate differences in the proportion of fields under 7.5, 15, or 30 inches between high- and low-yield fields. For artificial drainage, tillage, and foliar insecticide and/or fungicide, values indicate the % of fields with that management practice. Keep in mind that yields in the HY and LY categories are a consequence of different combination of practices, and yield difference between HY and LY should not be associated with one single practice.

	------TED ------					
	7D		12D		13D	
Yield category	HY	LY	HY	LY	HY	LY
Average bu/A	47	31	49	29	51	32
Management Practices						
Planting date	May 15	May 23	May 15	May 21	May 16	May 20
Seeding rate (x1000 seeds ac^{-1})	167	162	163	171	171	168
Row spacing						
% Fields with artificial drainage					46	24
% Fields with tillage					83	68
% Fields with foliar insecticide and/or fungicide	35	15			38	17

References:

Key Management Practices That Explain Soybean Yield Gaps Across the North Central US

Sifting and winnowing: analysis of farmer field data for soybean in the US North-Central region

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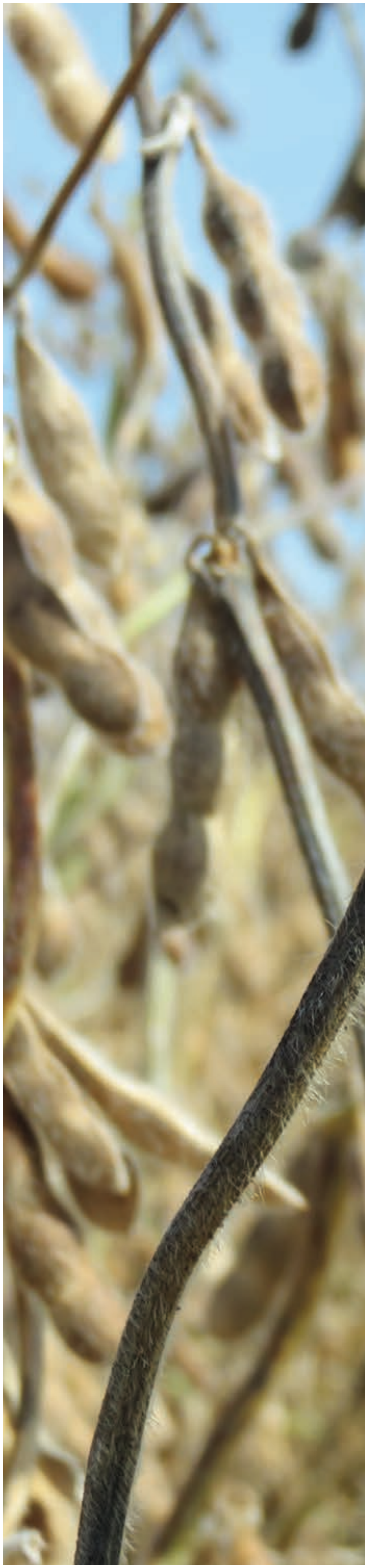
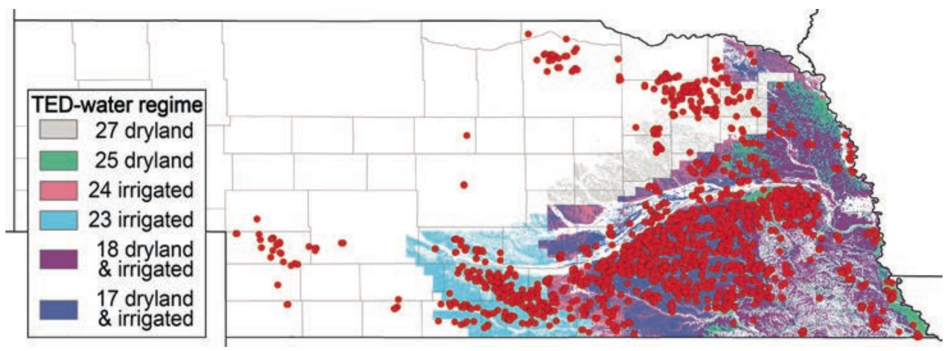


Summary of the Nebraska Soybean Benchmarking and Yield Gap Surveys

Nebraska accounted for about 6% of the U.S soybean harvested acres over the past five years (www.nass.usda.gov). Nebraska participated in a multi-state project to assess soybean yield gaps and the management practices responsible for them. The yield gap is defined as the difference between yield potential, as determined by climate and soil, *versus* producer average yields. Producers were asked to provide field-specific information from fields planted with soybean from 2014 to 2017. Collected data included field location, yield, crop management, and applied inputs from 1,983 Nebraska fields.

Fields were grouped into regions called TEDs (technology extrapolation domains), which represent regions within which climate and soil are reasonably similar. Specifically, TEDs are based on annual growing-degree day accumulation, precipitation, and temperature fluctuations, as well as plant available water-holding capacity in the rooting zone. In our analysis, we only included fields located in TEDs that represent >5% of soybean area within the state and TEDs that have at least 100 surveyed fields. In the case of Nebraska, there were a total of 8 TEDs meeting these criteria (see map below).



Within each TED, fields were sorted into two groups based on their yields: the highest third were assigned to the 'high yield' (HY) and the lowest third to the 'low-yield' (LY). Then, average management practices implemented by the two groups were compared to identify the management practices responsible for the yield gap within a TED. Details on methodology can be found (details on methodology can be found on page 8).

In most TEDs in Nebraska (6-7 out of 8), the high-yield category (significantly higher yield p ≤0.10) consisted of fields with earlier planting date and those treated with foliar insecticide and/or fungicide. In two TEDs, high-yield fields were also associated with tillage (see the table Management Practices Comparison Between High- and Low-yield Fields on next page).

Our study focused on those management practices with greatest yield impact; there may be other reasons for adopting (or not) a given practice, e.g., economic and logistic consideration, pest resistance, soil erosion, etc.

Management Practices Comparison Between High- and Low-Yield Fields in Nebraska

Green cells indicate statistically significant differences ($p \leq 0.10$) for a given management practice between the two field yield categories. For planting date and seeding rate, the values within green cells indicate the averages for the respective columns. For row spacing, green cells indicate differences in the proportion of fields under 7.5, 15, or 30 inches between high- and low-yield fields. For artificial drainage, tillage, and foliar insecticide and/or fungicide, values indicate the % of fields with that management practice. Keep in mind that yields in the HY and LY categories are a consequence of different combination of practices, and yield difference between HY and LY should not be associated with one single practice.

		TED															
		17D		17I		18D		18I		23I		24I		25D		27D	
	Yield category	HY	LY	HY	LY	HY	LY	HY	LY	HY	LY	HY	LY	HY	LY	HY	LY
	Average bu/A	69	44	80	64	69	47	79	63	82	64	83	62	71	52	64	46
Management Practices	Planting date			May 7	May 15	May 18	May 22	May 9	May 17	May 7	May 13	May 7	May 15	May 12	May 19	May 14	May 19
Management Practices	Seeding rate (x1000 seeds ac^{-1})	157	149	164	160							170	158	158	147		
Management Practices	Row spacing																
Management Practices	% Fields with artificial drainage																
Management Practices	% Fields with tillage			73	56			42	23								
Management Practices	% Fields with foliar insecticide and/or fungicide			31	9	58	9	73	22	31	9	29	6	54	5		

References:

Key Management Practices That Explain Soybean Yield Gaps Across the North Central US

Sifting and winnowing: analysis of farmer field data for soybean in the US North-Central region

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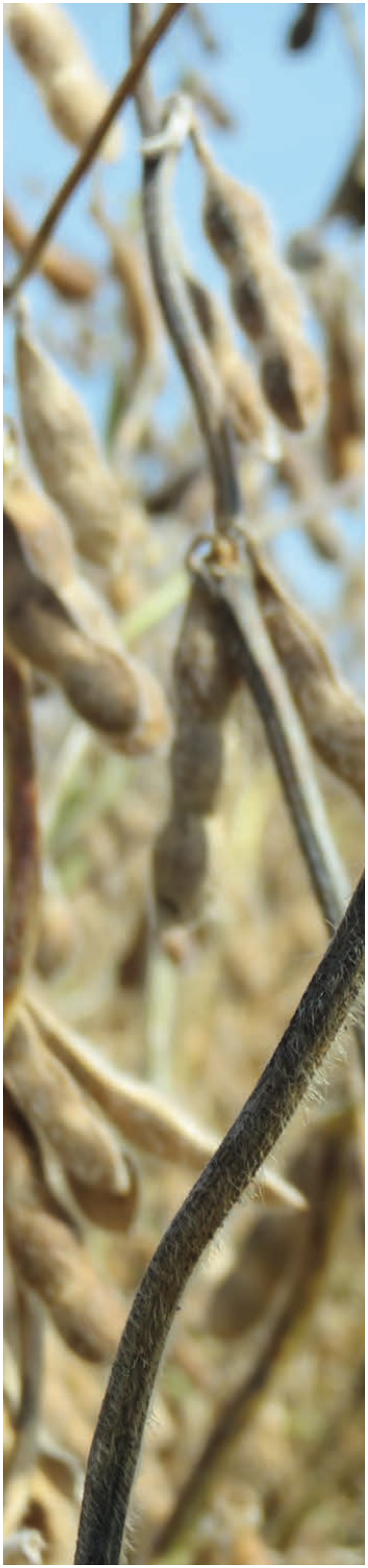
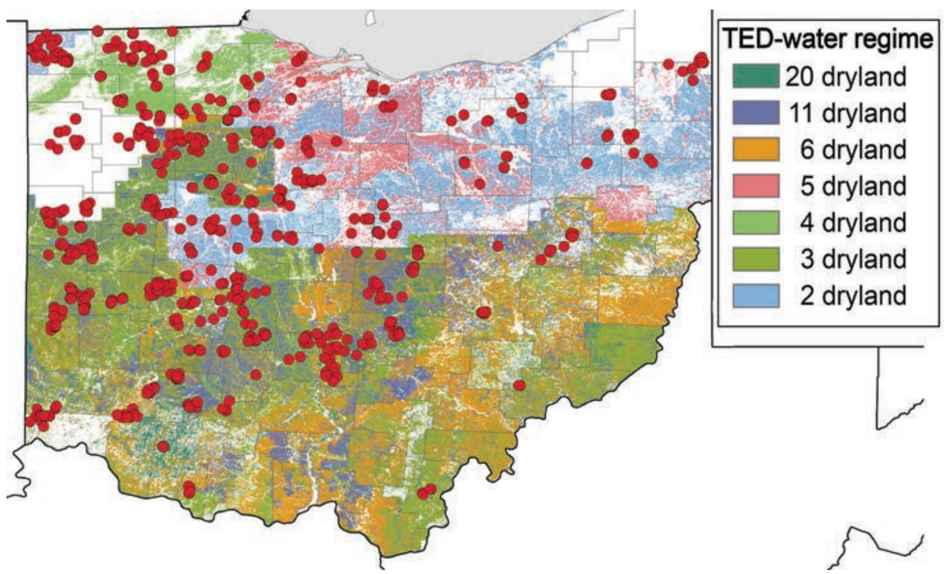


Summary of the Ohio Soybean Benchmarking and Yield Gap Surveys

Ohio accounted for about 6% of the U.S soybean harvested acres over the past five years (www.nass.usda.gov). Ohio participated in a multi-state project to assess soybean yield gaps and the management practices responsible for them. The yield gap is defined as the difference between yield potential, as determined by climate and soil, *versus* producer average yields. Producers were asked to provide field-specific information from fields planted with soybean from 2014 to 2017. Collected data included field location, yield, crop management, and applied inputs from 747 Ohio fields.

Fields were grouped into regions called TEDs (technology extrapolation domains), which represent regions within which climate and soil are reasonably similar. Specifically, TEDs are based on annual growing-degree day accumulation, precipitation, and temperature fluctuations, as well as plant available water-holding capacity in the rooting zone. In our analysis, we only included fields located in TEDs that represent >5% of soybean area within the state and TEDs that have at least 100 surveyed fields. In the case of Ohio, there were a total of 7 TEDs meeting these criteria (see map below).



Within each TED, fields were sorted into two groups based on their yields: the highest third were assigned to the 'high yield' (HY) and the lowest third to the 'low-yield' (LY). Then, average management practices implemented by the two groups were compared to identify the management practices responsible for the yield gap within a TED (details on methodology can be found on page 8).

In most TEDs in Ohio (6-7 out of 7), the high-yield category (significantly higher yield $p \leq 0.10$) consisted of fields with earlier planting date and those treated with foliar insecticide and/or fungicide. In some TEDs (4-5 out of 7), high-yield fields were also associated with artificial drainage and tillage. In TEDs 2D and 11D, there were more fields with 15-inch row spacing in the HY group compared to the LY group (see the table Management Practices Comparison Between High- and Low-yield Fields on next page).

Management Practices Comparison Between High- and Low-Yield Fields in Ohio

Green cells indicate statistically significant differences ($p \leq 0.10$) for a given management practice between the two field yield categories. For planting date and seeding rate, the values within green cells indicate the averages for the respective columns. For row spacing, green cells indicate differences in the proportion of fields under 7.5, 15, or 30 inches between high- and low-yield fields. For artificial drainage, tillage, and foliar insecticide and/or fungicide, values indicate the % of fields with that management practice. Keep in mind that yields in the HY and LY categories are a consequence of different combination of practices, and yield difference between HY and LY should not be associated with one single practice.

		TED													
		2D		3D		4D		5D		6D		11D		20D	
	Yield category	HY	LY	HY	LY	HY	LY	HY	LY	HY	LY	HY	LY	HY	LY
	Average bu/A	65	41	66	48	64	43	64	40	69	46	72	51	75	52
Management Practices	**Planting date**	May 17	May 23			May 14	May 22	May 14	May 19	May 15	May 26	May 11	May 19	May 9	May 20
	Seeding rate (x1000 seeds ac^{-1})					156	165					154	167	149	168
	Row spacing														
	% Fields with artificial drainage	77	62					60	36	71	32	79	50	92	67
	% Fields with tillage					62	43			61	36	59	47	73	48
	% Fields with foliar insecticide and/or fungicide	47	11	47	11	41	11	29	14	32	9	58	19	67	28

Our study focused on those management practices with greatest yield impact; there may be other reasons for adopting (or not) a given practice, e.g., economic and logistic consideration, pest resistance, soil erosion, etc.

References:

Key Management Practices That Explain Soybean Yield Gaps Across the North Central US

Sifting and winnowing: analysis of farmer field data for soybean in the US North-Central region

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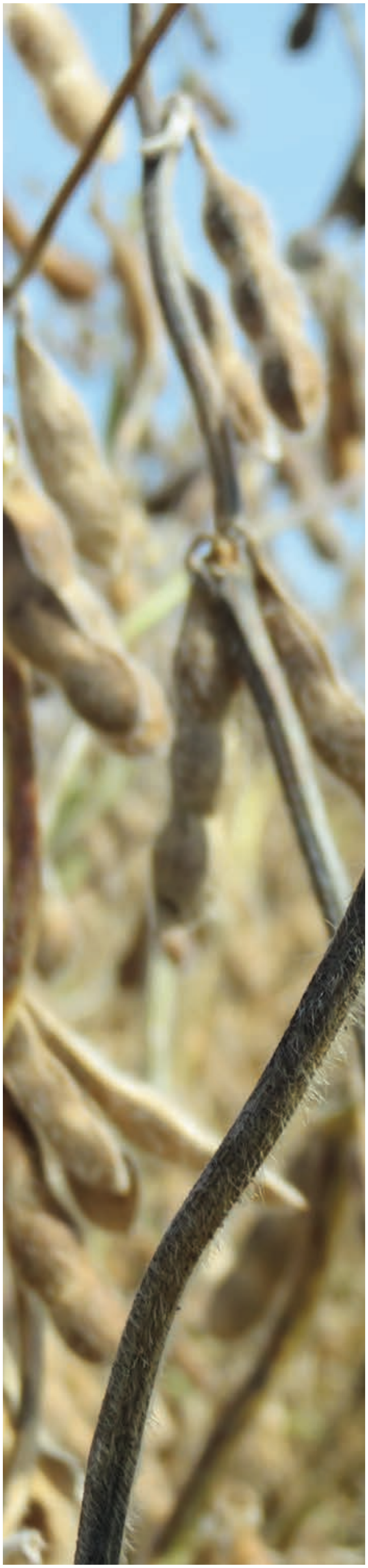
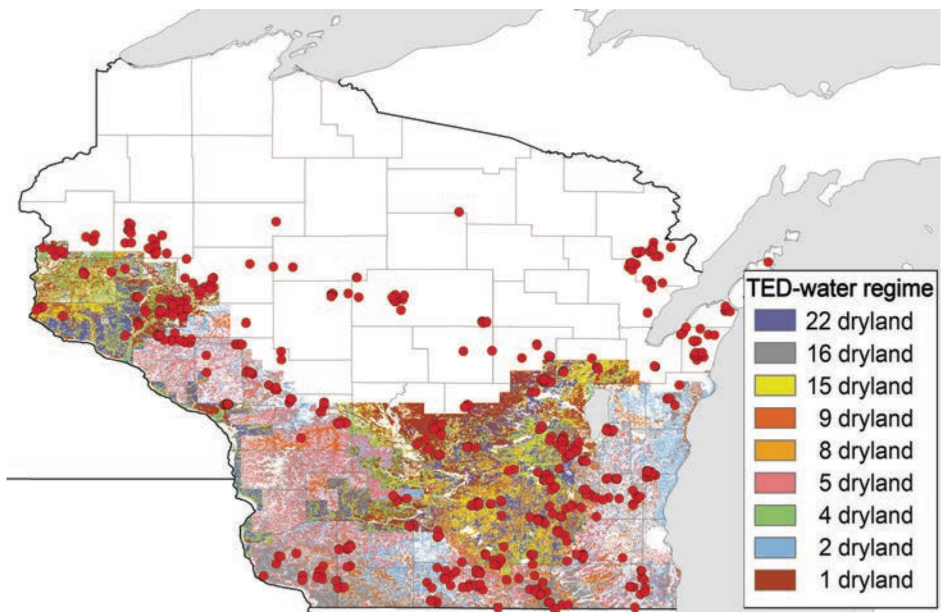


Summary of the Wisconsin Soybean Benchmarking and Yield Gap Surveys

Wisconsin accounted for about 2% of the U.S soybean harvested acres over the past five years (www.nass.usda.gov). Wisconsin participated in a multi-state project to assess soybean yield gaps and the management practices responsible for them. The yield gap is defined as the difference between yield potential, as determined by climate and soil, *versus* producer average yields. Producers were asked to provide field-specific information from fields planted with soybean from 2014 to 2017. Collected data included field location, yield, crop management, and applied inputs from 650 Wisconsin fields.

Fields were grouped into regions called TEDs (technology extrapolation domains), which represent regions within which climate and soil are reasonably similar. Specifically, TEDs are based on annual growing-degree day accumulation, precipitation, and temperature fluctuations, as well as plant available water-holding capacity in the rooting zone. In our analysis, we only included fields located in TEDs that represent >5% of soybean area within the state and TEDs that have at least 100 surveyed fields. In the case of Wisconsin, there were a total of 9 TEDs meeting these criteria (see map below).



Within each TED, fields were sorted into two groups based on their yields: the highest third were assigned to the 'high yield' (HY) and the lowest third to the 'low-yield' (LY). Then, average management practices implemented by the two groups were compared to identify the management practices responsible for the yield gap within a TED. Details on methodology can be found (details on methodology can be found on page 8).

In most TEDs in Wisconsin (7 out of 9), the high-yield category (significantly higher yield p ≤0.10) consisted of fields with earlier planting date and those treated with foliar insecticide and/or fungicide. In some TEDs (3-4 out of 9), high-yield fields were also associated with artificial drainage and tillage. In TED 2D, there were more fields with 15-inch row spacing in the HY group while TEDs 15D and 16D had more fields with 30-inch row spacing in the HY group compared to the LY group (see the table Management Practices Comparison Between High- and Low-yield Fields on next page).

Management Practices Comparison Between High- and Low-Yield Fields in Wisconsin

Green cells indicate statistically significant differences ($p \leq 0.10$) for a given management practice between the two field yield categories. For planting date and seeding rate, the values within green cells indicate the averages for the respective columns. For row spacing, green cells indicate differences in the proportion of fields under 7.5, 15, or 30 inches between high- and low-yield fields. For artificial drainage, tillage, and foliar insecticide and/or fungicide, values indicate the % of fields with that management practice. Keep in mind that yields in the HY and LY categories are a consequence of different combination of practices, and yield difference between HY and LY should not be associated with one single practice.

	-----TED-----																	
	1D		2D		4D		5D		8D		9D		15D		16D		22D	
Yield category	HY	LY	HY	LY	HY	LY	HY	LY	HY	LY	HY	LY	HY	LY	HY	LY	HY	LY
Average bu/A	63	42	65	41	64	43	64	40	66	47	67	45	68	48	69	49	67	47
Management Practices: Planting date			May 17	May 23	May 14	May 22	May 14	May 19	May 15	May 22	May 13	May 18	May 15	May 19	May 13	May 17		
Seeding rate (x1000 seeds ac^{-1})					156	165					149	154	149	154				
Row spacing																		
% Fields with artificial drainage	80	65	77	62			60	36										
% Fields with tillage					62	43					67	24	74	61	53	40		
% Fields with foliar insecticide and/or fungicide	28	10	47	11	41	11	29	14			56	12	57	30	54	35		

Our study focused on those management practices with greatest yield impact; there may be other reasons for adopting (or not) a given practice, e.g., economic and logistic consideration, pest resistance, soil erosion, etc.

References:

Key Management Practices That Explain Soybean Yield Gaps Across the North Central US

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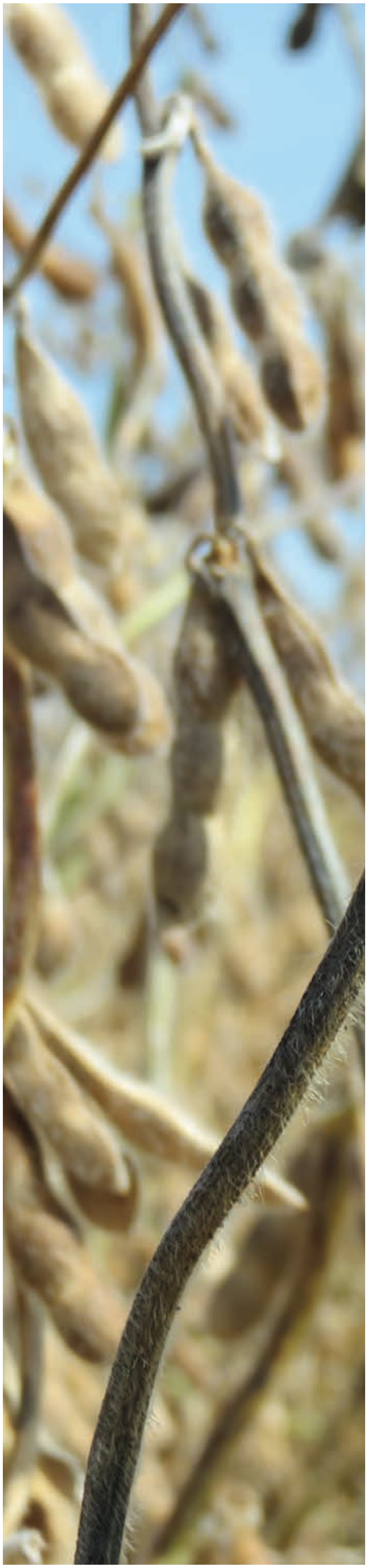

5. Scientific Articles Derived From This Project

Mourtzinis S, Rattalino Edreira JI, Conley SP, Grassini P (2017). From grid to field: assessing quality of gridded weather data for agricultural applications. *European Journal of Agronomy* 82, 163-172.

Rattalino Edreira JI, Mourtzinis S, Conley SP, Roth A, Ciampitti IA, Licht MA , Kandel H, Kyveryga PM , Lindsey LE , Mueller DS, Naeve SL, Nafziger E, Specht JE, Stanley J, Staton MJ, Grassini P (2017). Assessing causes of yield gaps in agricultural areas with diversity in climate and soils. *Agricultural & Forest Meteorology* 247, 170-180.

Mourtzinis S, Rattalino Edreira JI, Grassini P, Roth A, Ciampitti IA, Licht MA , Kandel H, Kyveryga PM , Lindsey LE , Mueller DS, Naeve SL, Nafziger E, Specht JE, Stanley J, Staton MJ, Conley SP (2018). Sifting and winnowing: Analysis of farmer field data for soybean in the US North-Central region. *Field Crops Research* 221, 130-141.

Andrade JF, Rattalino Edreira JI, Mourtzinis S, Conley SP, Ciampitti IA, Dunphy JE, Gaska JM, Glewen K, Holshouser DL, Kandel HJ, Kyveryga P, Lee CD, Licht MA, Lindsey LE, McClure MA, Naeve S, Nafziger ED, Orlowsky JM, Rosso J, Staton MJ, Thompson L, Specht JE, Grassini P (2019). Assessing the influence of row spacing on soybean yield using experimental and producer survey data. *Field Crops Research* 230, 98-106.

Azzari G, Grassini P, Rattalino Edreira JI, Conley S, Mourtzinis S, Lobell DB (2019). Satellite mapping of tillage practices in the U.S. Corn Belt since 2007. *Remote Sensing of Environment* 221, 417-429.

Rattalino Edreira JI, Mourtzinis S, Azzari G, Andrade JF, Conley SP, Lobell D, Specht JE, Grassini P (2019). From sunlight to seed: assessing limits to solar radiation capture and conversion in agro-ecosystems. *Agricultural & Forest Meteorology* (submitted)

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