# Sifting and Winnowing:
# Analysis of Farmer Field Data for Soybean in the US North Central Region


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## In a bean pod…

- **Farmer survey data allowed us to identify key management factors influencing yields for an agricultural area that includes ca. 18 million ac planted with soybean.**
- **In five of the nine regions, highest yields were observed in early-planted fields.**
- **Other factors explaining on-farm yield variation were maturity group, and in-season foliar fungicide and/or insecticide application, and in some cases, their influence on yield depended upon planting date and water regime.**
- **Design of future agronomic studies can greatly benefit from farmer survey data analysis.**


## Introduction

Average crop yields will need to increase substantially during the next 33 years to meet expected food demand increase while avoiding massive expansion of cropland area (Alexandratos and Bruinsma, 2012; Grassini et al., 2013). This challenge can be achieved by increasing the rate at which best management practices are identified and adopted for a particular soil-climate context. Replicated field experiments are used in agricultural research to test new technologies and management practices. Farmer survey data can be utilized as a cost-effective source of information to identify yield constraints and fine-tune management practices so that these yield limitations can be ameliorated or eliminated (e.g., Lobell et al., 2005; Tittonell et al., 2008). 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, when they are properly contextualized relative to their biophysical environment, it is possible to explore and quantify management × environment interactions (Rattalino Edreira et al., 2017). Such assessment would allow identification of suites 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.


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In the present study, we focused on soybean fields in the North Central US region, which accounts for ca. 85% of US soybean production and ca. 30% of global production (FAOSTAT, 2016; USDA-NASS, 2016). The objective of this study was to utilize self-reported farmer data and multiple statistical techniques, together with a spatial framework, to identify the management practices with greatest influence on rainfed and irrigated soybean yields across diverse climate and soil conditions.

## Materials and methods

Soybean yield and management practices data were collected from 3,568 fields planted to soybean in 2014 and 2015 across 10 states in the US NC region: Iowa (IA), Illinois (IL), Indiana (IN), Kansas (KS), Michigan (MI), Minnesota (MN), Ohio (OH), North Dakota (ND), Nebraska (NE), and Wisconsin (WI) (Fig. 1). The majority of surveyed fields were non-irrigated, except in Nebraska, where there were both rainfed (34%) and irrigated fields (66%) located within the same region. Field corn was the predominant prior crop (88% of total fields).

Farmers reported data on field location, average yield (adjusted to 13% moisture content), and management practices, including planting date, seeding rate, row spacing, variety name, tillage method, drainage system, total irrigation amount (for irrigated crops), seed treatment, fertilizer inputs, lime, manure, and pesticides. Farmers also reported incidence of other field adversities such as pests, diseases, weeds, iron deficiency chlorosis, hail, waterlogging, and frost. Data were subjected to quality control to remove erroneous entries. After quality control, the database contained data from a total of 3,216 fields planted to soybean in 2014 and 2015 (92% of total surveyed fields). Fields were grouped into narrow (≈7 inches), intermediate (≈15 inches), and wide (≈30 inches) row spacing. Fields were classified based upon tillage method as (i) conventional (chisel and disk), (ii) reduced (strip-till, ridge-till, cultivator), and (iii) no-till. Fields were classified depending upon seed treatment as treated (i.e., fungicide or insecticide or both) or untreated. Fields were also classified according to presence or absence of artificial drainage system such as new systematic tiles, old clay tiles, etc.

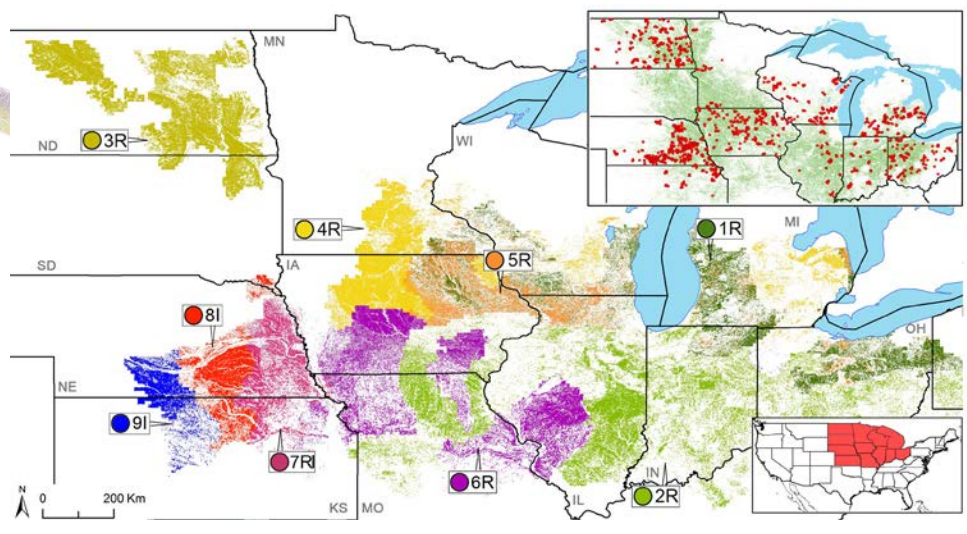



**Figure 1.** Map of the surveyed region showing nine technology extrapolation domains (TEDs). Each TED is shown with a different color. Upper inset: soybean harvested area in 2015 shown in green; (USDA-NASS, 2016) and location of 3,568 surveyed soybean fields (red dots). Bottom inset: location of US NC region within the conterminous US. Note: R=rainfed fields; I=irrigated fields; RI=rainfed and irrigated fields within the TED. Taken from Rattalino Edreira et al., 2017.

Mean pH was calculated for topsoil (0-12 inches) and subsoil (12-60 inches) for each field from the SSURGO database. To account for differences in slope and terrain across a field, which could influence the crop water balance and final seed yield, we calculated the topography wetness index (TWI) for each field. High values are associated with flat terrain whereas smaller values are associated with more uneven fields (e.g., fields with slopes). TWI is usually correlated with other soil attributes, including soil organic matter, soil texture, and phosphorous content; hence, higher TWI values are generally associated with more productive soils.

Fields were aggregated in clusters based on their biophysical properties using a technology extrapolation domain (TED) spatial framework (Rattalino-Edreira et al., 2017; http://www.yieldgap.org/web/guest/cz-ted). Multiple statistical procedures were used to identify the management and soil variables with the strongest influence on yield within each TED.

## Results

Descriptive analysis for soybean management practices in each TED are summarized in Table 1 and Fig. 2. The study region was characterized by diversity of

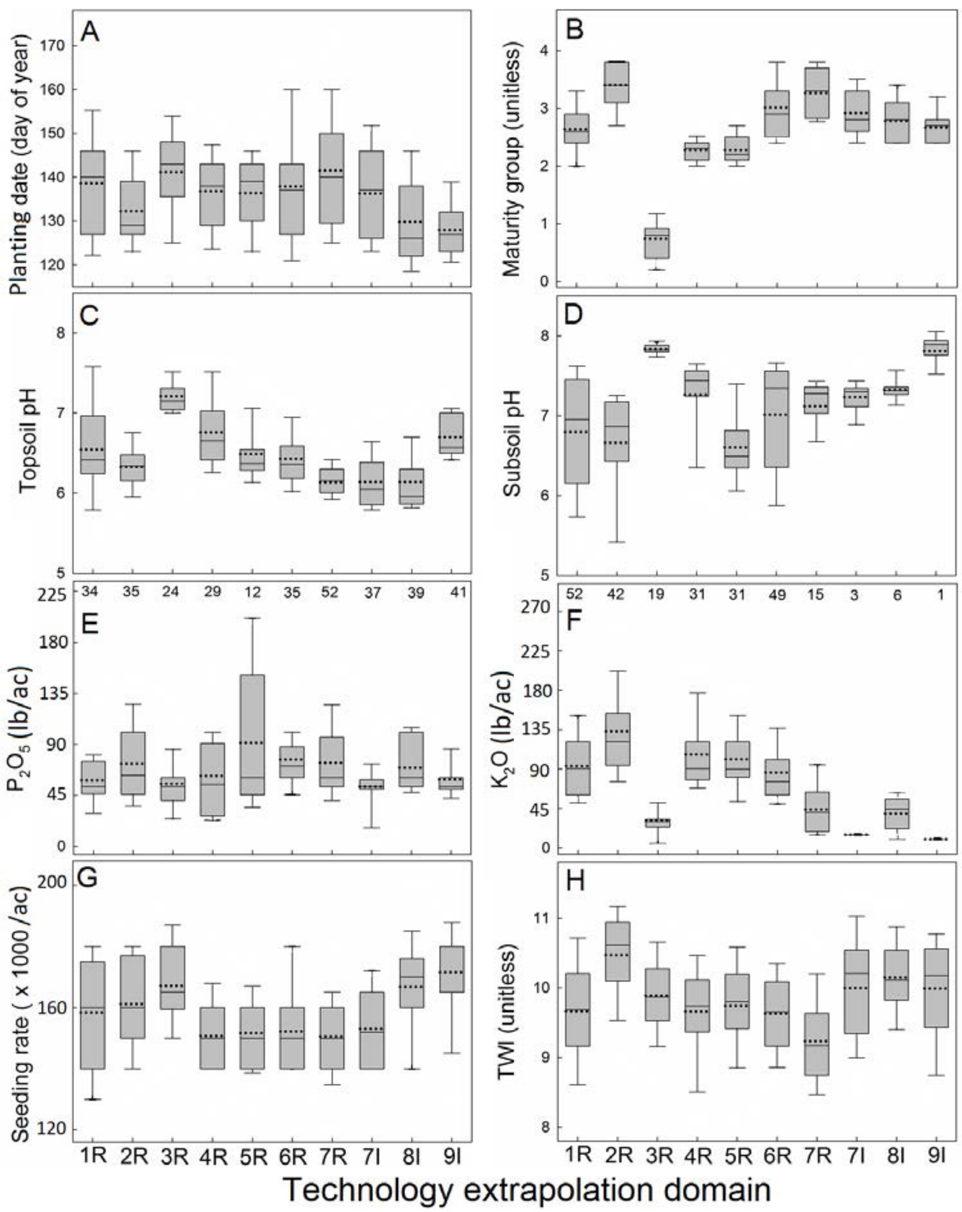



**Figure 2.** Description of rainfed (R) and irrigated (I) soybean farmer fields across technology extrapolation domains (TED). Variables include: (A) planting date, (B), maturity group, (C) topsoil (0-12 inch) pH, (D) subsoil (12-60 inch) pH, (E) $P_2O_5$ fertilizer rate, (F) $K_2O$ fertilizer rate, (G) seeding rate, and (H) topography wetness index (TWI). Boxes delimit first and third quartiles.

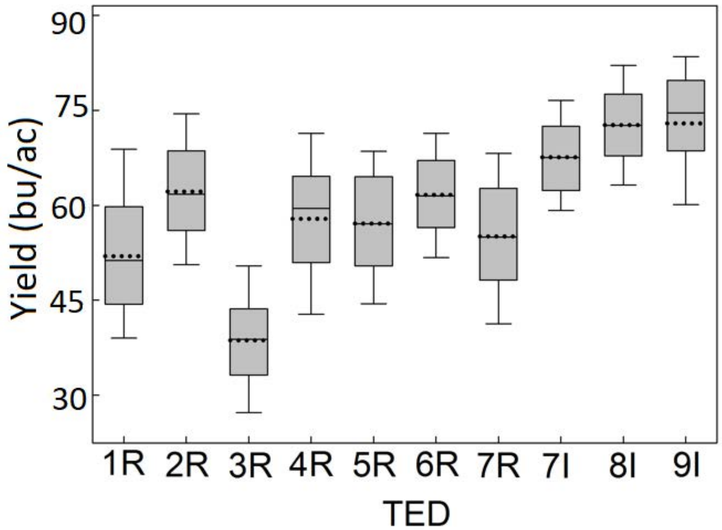
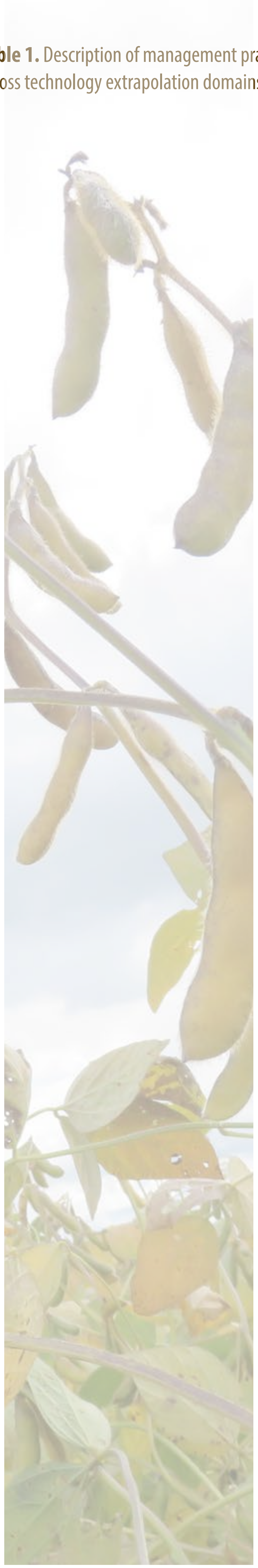



**Figure 3.** Box plots for farmer soybean rainfed (R) and irrigated (I) yields across 10 technology extrapolation domains (TED). Boxes delimit first and third quartiles. Solid and dotted lines inside the box indicate median and mean, respectively. Upper and lower whiskers represent maximum and minimum values, respectively.

soil types, weather, and management practices. Except for the alkaline subsoil in TEDs 3 and 9 (pH ≈ 8), average pH in the topsoil and subsoil ranged between 6 and 7.5, with the subsoil exhibiting slightly higher pH (Fig. 2 C-D). Higher TWI values in fields in TEDs 3, 7I, 8 and 9 indicated a smaller run-off potential and favorable soils compared to fields in other TEDs (Fig. 2 H). Topsoil and subsoil pH and TWI varied greatly across fields within some of the TEDs (e.g., TEDs 1 and 6), which further justified their inclusion as independent variables in the conditional inference tree analysis. Average planting date varied by up to 2 weeks among TEDs, from early-May to late-May in the southern (TED 2, 9) and northern (TED 3) regions, respectively (Fig. 2 A). Most varieties planted were MGs 2 and 3, except for fields located in the north-west region (TED 3; MGs 0 and 1) (Fig. 2 B). Narrow (≈7 inch) and intermediate (≈15 inch) row spacing prevailed across TEDs located in rainfed production environments; in contrast, wider row spacing (≈30 inch) was dominant in irrigated fields (Table 1). Seeding rates ranged from 140,000 to 180,000 seeds/ac (Fig. 2 G), which, given a typical emergence rate of ca. 85-90% in soybean (Gaspar et al., 2017), indicate that seeding rates used by farmers are much higher than those required to achieve a plant density that maximize yield (110,000–130,000 plants/ac; De Bruin and Pedersen, 2008). Higher seeding rates (ca. 10%) were observed in the eastern (TEDs 1 and 2) and western fringes (TEDs 3, 8 and 9) of the US NC region.

Applied fertilizer amounts (<52% of total fields received fertilizer – Fig. 2) ranged from 5 to 220 lb/ac ($P_2O_5$) and from 9 to 300 lb/ac ($K_2O$), respectively, with rates increasing following a west-east gradient (Fig. 2 E-F). Starter N fertilizer (i.e., a small N fertilizer application at planting) was rarely applied in fields located in the central and eastern parts of the US NC regions (<10% of fields) (Table 1). About 10-20% fields in the western fringe of the region received N starter (TEDs 7, 8, 9), with this frequency increasing up to ca. 40% in the TED located in the north-west region (TED 3). This TED also has the largest frequency of tilled fields (55%). In contrast, no-till was the most common tillage method across the rest of the TEDs. Frequency of fields with artificial drainage followed the east-west gradient in seasonal precipitation, increasing dramatically from <30% fields with artificial drainage systems in the western fringe of the US NC region to >70% fields with drainage systems in the central and eastern regions (Table 1). Harvest and/or grazing of the residue left by previous corn crop were rarely practiced, except for 35-50% of fields located in western TEDs (TEDs 7, 8, and 9). Lime and manure were applied in <20% of fields across TEDs and mostly in TEDs located in the central and eastern regions (Table 1).

**Table 1.** Description of management practices across technology extrapolation domains.



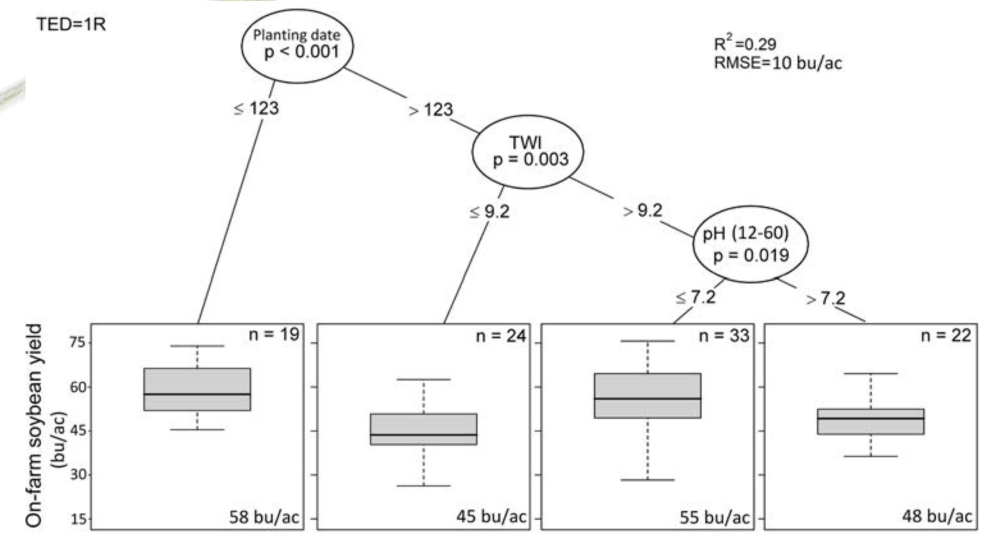
| **Production factor** (% fields) | **Technology Extrapolation Domains** (TEDs) 1R | 2R | 3R | 4R | 5R | 6R | 7R | 7I | 8I | 9I |
|---|---|---|---|---|---|---|---|---|---|---|
| **Inputs** | | | | | | | | | | |
| Seed treatment | 83 | 95 | 95 | 92 | 89 | 92 | 86 | 98 | 90 | 81 |
| Foliar fungicide | 20 | 38 | 11 | 40 | 47 | 39 | 20 | 24 | 20 | 19 |
| Foliar insecticide | 19 | 36 | 40 | 43 | 40 | 24 | 18 | 19 | 16 | 18 |
| Starter N fertilizer | 7 | 0 | 39 | 5 | 6 | 3 | 14 | 10 | 11 | 18 |
| Lime | 10 | 23 | 0 | 15 | 4 | 16 | 16 | 10 | 3 | 0 |
| Manure | 12 | 12 | 0 | 10 | 11 | 16 | 4 | 12 | 0 | 0 |
| **Field & crop management** | | | | | | | | | | |
| Artificial drainage | 69 | 73 | 36 | 88 | 88 | 83 | 20 | 12 | 4 | 18 |
| Residue management | | | | | | | | | | |
| Grazed | 0 | 1 | 1 | 1 | 0 | 7 | 22 | 20 | 24 | 34 |
| Harvested | 6 | 23 | 1 | 3 | 2 | 0 | 15 | 17 | 16 | 19 |
| **Tillage method** | | | | | | | | | | |
| No-till | 60 | 44 | 20 | 48 | 59 | 52 | 72 | 67 | 50 | 90 |
| Reduced till | 17 | 19 | 25 | 25 | 19 | 20 | 14 | 13 | 17 | 5 |
| Conventional till | 23 | 37 | 55 | 27 | 22 | 28 | 14 | 20 | 33 | 5 |
| **Row spacing** | | | | | | | | | | |
| Narrow (~7 inch) | 18 | 31 | 25 | 14 | 2 | 13 | 2 | 10 | 14 | 14 |
| Intermediate (~15 inch) | 60 | 61 | 49 | 35 | 64 | 47 | 53 | 29 | 22 | 22 |
| Wide (~30 inch) | 22 | 8 | 26 | 51 | 34 | 40 | 45 | 61 | 64 | 64 |
| **Adversities** | | | | | | | | | | |
| Iron chlorosis deficiency | 26 | 0 | 20 | 28 | 2 | 25 | 0 | 0 | 1 | 4 |
| Soybean cyst nematode | | | | | | | | | | |
| Yes | 16 | 15 | 7 | 28 | 26 | 11 | 7 | 19 | 13 | 7 |
| Unknown | 38 | 50 | 41 | 38 | 34 | 62 | 40 | 22 | 19 | 10 |

Use of a seed treatment, which usually includes fungicide and/or insecticide, was a widespread practice across all TEDs, with seed being treated in >80% of fields (Table 1). The frequency of fields that received foliar fungicide and/or insecticide applications ranged from 20 to 50% across TEDs and number of fungicide- and insecticide-treated fields were similar, in part because farmers tended to apply fungicide and insecticide together. A notable exception was the north-west TED (TED 3) where frequency of fields only treated with insecticides was much higher in relation with fungicide-treated fields (40 versus 11%). On average, 15% of surveyed fields reported incidence of soybean cyst nematode (SCN, Heterodera glycines Ichinoche); however, it was remarkable that ca. 35% of the farmers did not know (because of lack of soil testing) about the incidence of this pest in their soybean fields.

Average soybean yield ranged from ca. 40 bu/ac in short-season rainfed environments (TED 3) to ca. 75 bu/ac in favorable irrigated areas (TEDs 8 and 9) (Fig. 3).

The conditional inference tree analysis performed for rainfed fields located within one of the eastern TEDs (TED 1) is shown in Fig. 4. Planting date was the

Figure 4. Conditional inference tree for TED 1R located in the eastern region of the US NC region. In each boxplot, the central rectangle spans the first to the third yield quartiles. The solid line inside the rectangle shows the mean, which is also reported in the bottom right corner. The upper and lower whiskers represent the maximum and minimum values, respectively. TWI= topography wetness index.




most important variable influencing farmer soybean fields. On average, fields that were planted between day of year (DOY) 119 and 123 (late April and early May) yielded 58 bu/ac (left terminal node), which is 9% higher than average yield in late-planted fields. In late-planted fields (DOY from 124 to 167) (late May and early June), highest yields were achieved in fields with relatively higher TWI (>9.2) and lower subsoil pH (<7.2), but these yields were still lower than those reported for early-planted fields. The three variables of the explanatory model (planting date, TWI, and subsoil pH) captured approximately one third of total yield variability within the TED ($R^2$=0.29).

Planting date was also the most important factor influencing soybean yields in TEDs 4R, 5R, 6R, and 8I (Table 2, Fig. 4). Remarkably, late-planted fields could not achieve yields comparable to early-planted fields under any suite of management practices and soil and terrain parameters. Foliar fungicide or insecticide was also identified as a significant management factor increasing soybean yield in 5 of 9 TEDs (Fig. 5, Table 2). Higher yields were also generally related to high TWI, which may reflect a more favorable position in the landscape in relation with crop water supply and likely better soil quality (see section 3.2). Other management factors influencing yield in at least one TED were row spacing, maturity group, tillage method, and seeding rate (Fig. 5, 5, and Table 2).

Conditional inference trees also allowed us to capture (M)anagement × (E)nvironment interactions. For example, MG was a significant key secondary (TEDs 3 and 7) and tertiary management practice (TEDs 3 and 9). In the short-season environment of TED 3, higher yields were associated with late MGs (Table 2). This finding was not biased by the latitudinal distribution of MG varieties within TED 3 as the influence of MG persisted even when the analysis was conducted separately for the southern and northern portions of this TED. In contrast, in favorable irrigated environments (TEDs 7 and 9), higher yields were achieved with early MGs (Fig. 6, Table 2). Specht et al. (1986, 2001) noted that Midwestern U.S. full-season maturity cultivars in rainfed environments usually yield better than earlier-maturing ones. Drought can shorten reproductive development in the early-maturing cultivars aligning those stages with the hotter part of the growing season, which tends to exacerbate the impact of water deficit. Incidence of soybean cyst nematode (SCN) led to lower yields in TED 6 (Fig. 5), especially in no-till fields where yield penalty due to nematodes was 6% higher than in tilled fields.

**Table 2.** Summary of conditional inference trees in technology extrapolation domains (TEDs) 2R, 3R, 4R, 5R, 8I, and 9I. Values in brackets indicate number of fields (n) and average yield (Y, bu/ac).

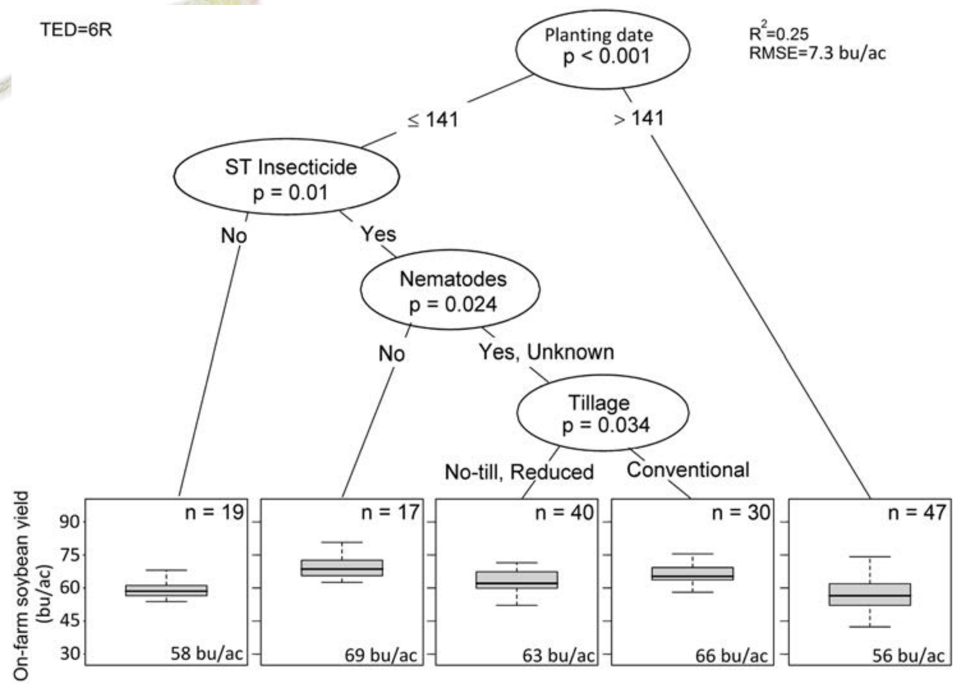
| TED# | N1 | N2 | N3 | N4 | [n, Y] | $R^2$ | RMSE (bu/ac) |
|---|---|---|---|---|---|---|---|
| 2R | Row spacing (narrow) | | | | [36, 56] | 0.10 | 9 |
| | Row spacing (intermediate, wide) | | | | [82, 65] | | |
| | Foliar insecticide | TWI (9.7-11.7) | | | [58, 42] | | |
| | (yes) | TWI (8.2-9.7) | | | [23, 38] | | |
| 3R | Foliar | MG (0.9-1.5) | | | [23, 44] | 0.19 | 7 |
| | insecticide (no) | MG (0.08-0.9) | MG (0.08-0.6) | | [39, 35] | | |
| | | | MG (0.6-0.9) | | [58, 36] | | |
| | Planting date | Foliar fungicide (no) | | | [39, 62] | | |
| | (DOY 108-136) | Foliar fungicide (yes) | | | [39, 66] | | |
| 4R | Planting date | Row spacing (narrow, medium) | | | [52, 51] | 0.31 | 9 |
| | (137-164 DOY) | Row spacing (wide) | | | [49, 56] | | |
| | Planting date | Subsoil pH (5.5-6.5) | | | [41, 65] | | |
| | (DOY 107-132) | Subsoil pH (6.6-8.1) | | | [23, 59] | | |
| 5R | Planting date | Foliar fungicide (no) | Planting date<br>(DOY 133-140) | | [27, 56] | 0.24 | 9 |
| | (DOY 137-164) | | Planting date<br>(DOY 141-161) | | [39, 51] | | |
| | | Foliar fungicide (yes) | | | [23, 59] | | |
| | | Foliar insecticide (yes) | | | [22, 78] | | |
| | (DOY 113-142) | Foliar insecticide (no) | Planting date<br>(DOY 113-124) | | [50, 75] | | |
| 8I | | | Planting date<br>(DOY 125-142) | TWI (8.3-10) | [18, 68] | 0.26 | 7 |
| | | | | TWI (10.1-11.7) | [38, 72] | | |
| | Planting date (143-175 DOY) | | | | [50, 75] | | |
| | Seeding rate (120,000-145,000<br>seeds/ac) | | | | [15, 65] | | |
| 9I | Seeding rate | TWI (8.4-9.1) | | | [18, 68] | 0.34 | 9 |
| | (145,000-210,000 seeds/ac) | TWI (9.1-11) | MG (2.4-2.7) | | [45, 78] | | |
| | | | MG (2.7-4.2) | | [25, 74] | | |

$N^{th}$: node number; TWI: topography wetness index; MG: maturity group; DOY: day of year. Row spacing: narrow (~ 7 in), medium (~15 in), wide (~ 30 in).

## Discussion

Planting dates and foliar fungicide and/or insecticide were the most consistent factors associated with yield variation. Additionally, our analysis exposed interesting interactions between management practices, for example, MG x water regime and nematodes x tillage. Interestingly, we could not detect a positive influence of narrow or intermediate row spacing on soybean yield despite the yield benefits of narrow row spacing reported in previous studies (e.g., Hanna et al., 2008). These contrasting results derived from on-farm data versus controlled experiments deserve further investigation. Planting date exhibited a consistent association with yields, with diminishing yield as planting date was delayed. It was remarkable that the yield loss due to late planting could not be fully compensated by any combination of other management practices,

**Figure 5.** Conditional inference tree for 6R, technology extrapolation domains. In each boxplot, the central rectangle spans the first to the third yield quartiles. The solid line inside the rectangle shows the mean, which is also reported in the bottom right corner. The upper and lower whiskers represent the maximum and minimum values, respectively.




such as seeding rate or row spacing. In other words, planting date appears to play a major role in setting the yield potential for a given field, as other factors cannot compensate for late planting. Hence, timely planting appears as a key factor to increase the current soybean yields in the US NC region.

Identification of the causes for yield variation is needed but not sufficient for increasing farmer yields. For example, we identified planting date as a key management factor explaining yield variation within the same TED. Hence, one would tend to think that it is relatively easy for a large number of farmers in the US North Central region to increase current soybean yield by planting earlier, especially considering that early planting date per se does not involve higher costs and labor. However, there are many reasons why farmers may still be reluctant to plant soybean earlier. The first constraint is a combination of farm logistics and cultural preference as many farmers only have one planter and they prefer to use it for planting corn first. The second limitation is associated with biophysical factors (i.e., water excess, cold weather) that could delay planting in many years. Finally, farmers tend to overestimate the risk associated with seed chilling injury, early frost, and seed and/or plant stand loss associated with early planting despite the well-documented benefits of early planting and associated measures to reduce risk, for example, by using seed treatments or monitoring of soil temperature (e.g., Tenorio et al., 2016). Additionally, the current crop insurance program sets a limit to very early planting for a given area. We note, however, that our analysis showed that a large number of the farmers are planting soybean much earlier than other farmers within the same TED suggesting that closing the portion of the yield gap due to planting date is possible through fine tune adjustment of farm logistics and a correct assessment of risk level. Indeed, over the past three decades, farmers have persistently shifted average soybean planting times in the US North Central region to earlier calendar dates at a rate of ca. 0.5 day/year (Specht et al., 2014). The present study indicates that there is still large room for improving soybean yields by increasing the rate at which farmers shift toward early planting.

In a broader context, given the growing pressure for increasing food production on existing cropland area, the approach used here represents a tremendous opportunity to help accelerate rates of yield gain and better prioritize

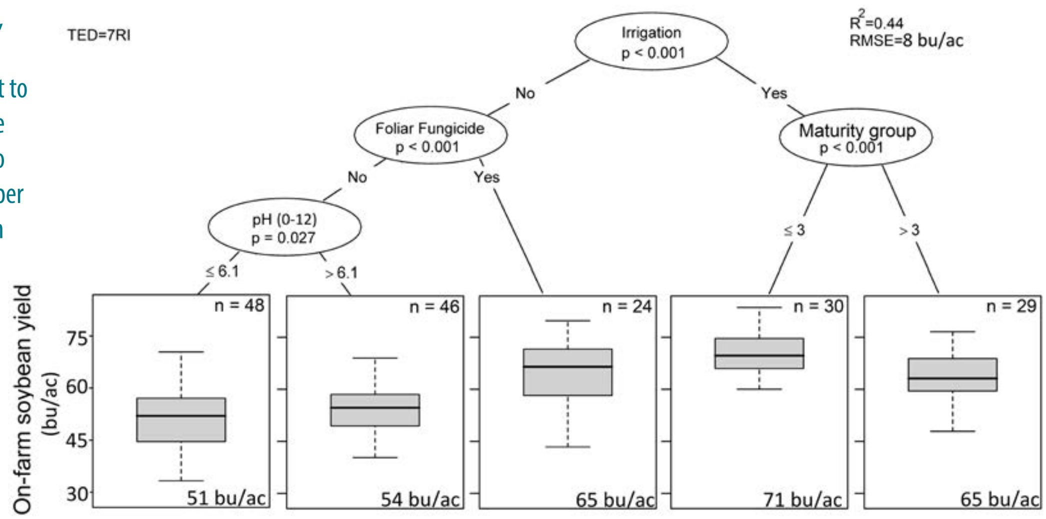



**Figure 6.** Conditional inference tree for 7RI, technology extrapolation domains. In each boxplot, the central rectangle spans the first to the third yield quartiles. The solid line inside the rectangle shows the mean, which is also reported in the bottom right corner. The upper and lower whiskers represent the maximum and minimum values, respectively.

research and Extension programs in major crop producing regions of the world. While replicated field trials will still be needed to establish cause-effect relationships, the information derived from analysis on farmer data as presented here can provide a focus to these trials in regard to which factors (and interactions) to investigate.

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