



Management Strategies for Early- and Late-Planted Soybean in the North Central U.S.

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IN A BEAN POD:

- ▶ Management decisions that increased soybean yield were region-specific.
- ▶ No single management decision consistently increased seed yield across the entire study region.
- ▶ Integrated pest management (IPM) principles should be followed when deciding the use of pesticide inputs.

OVERVIEW

This research utilizes data from the Benchmarking Soybean Production in the North Central U.S. project, which involved collecting surveys about soybean yield and management practices from ten U.S. states that account for 82% of U.S. soybean production. The Benchmarking project identified combinations of management practices that allow farmers to maximize yield. Early planting was the management practice most consistently associated with higher yield (Mourtzinis et al., 2018). The Benchmarking project also demonstrated that there are interactions between planting date and other management decisions, indicating that early- and late-planted fields may have different management strategies to maximize yield and profitability.

While many farmers aim to plant soybeans early, weather conditions can cause farmers to plant later than is optimal. This research aimed to identify management decisions farmers can modify at planting or after planting to help maximize yield. Additionally, we estimated the maximum break-even price for the management decisions associated with higher yields. Using surveys from the Benchmarking project, with data on 5,682 fields between 2014 and 2016, we grouped fields based on environment through a classification system called technology extrapolation domains (TEDs). Within each TED, fields were classified into early- and late-planted categories using terciles. Fields were organized by planting date, and the first third of the fields were considered early-planted. The last third of fields when organized by planting date were considered late-planted. Conditional inference (CI) trees were created for each TED to evaluate the effect of management decisions within the two planting date timeframes on seed yield.

Management strategies that maximized yield and associated maximum break-even prices varied across TEDs and planting date. For early-planted fields, higher yields were associated with artificial drainage, insecticide seed treatment, and lower seeding rates. For late-planted fields, herbicide application timing and tillage intensity were related to higher yields. There was no individual management decision that consistently increased seed yield across all TEDs. Management decisions that increased soybean yield were region-specific, and integrated pest management (IPM) principles should be followed when deciding the use of pesticide inputs.

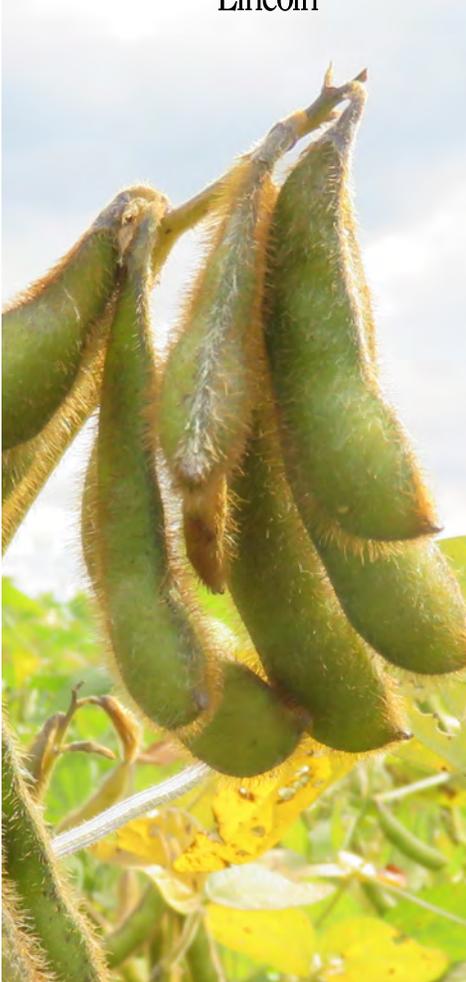
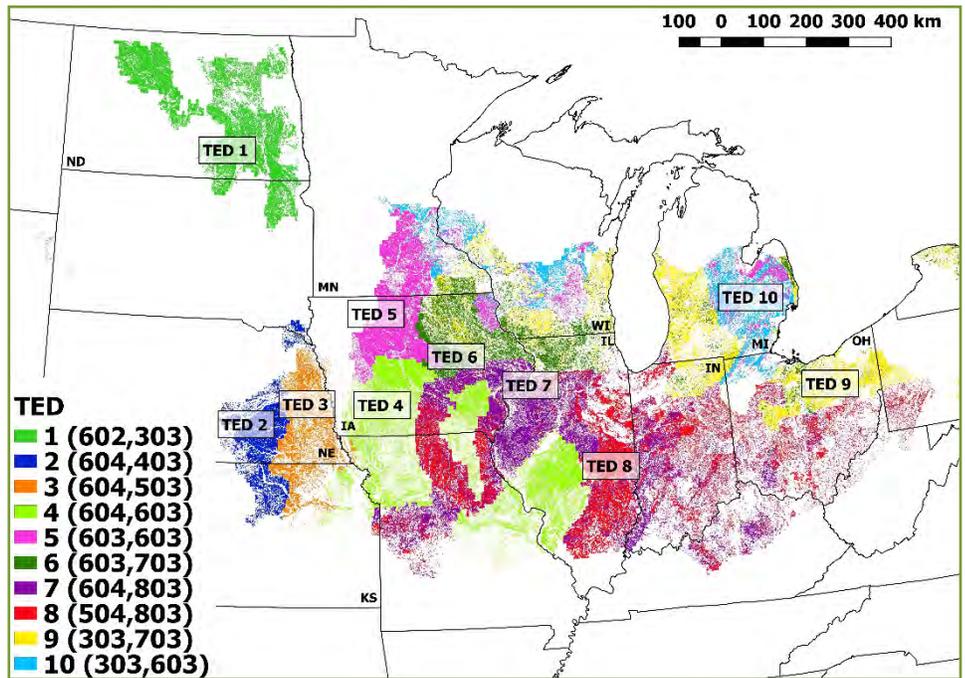


Figure 1. Technology extrapolation domains (TEDs) distributed across the North Central U.S. region. The six-digit numbers following the TED numbers are the reference numbers to locate these TEDs in the global database at yieldgap.org.



METHODS

We collected surveys from 5,682 soybean producer fields in ten North Central US states (Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, North Dakota, Nebraska, Ohio, and Wisconsin) between 2014 and 2016. The survey included questions about field location, seed yield, and management decisions. Year-specific conditions such as pest pressure, iron deficiency chlorosis incidence, and weather adversities were also reported by producers.

A few fields with yield below the 25th percentile due to documented unmanageable production site adversities (hail, waterlogging, wind, and frost) were excluded from the analyses. Fields planted after June 15th that also had wheat (*Triticum aestivum* L.) as a previous crop were removed from further analyses to exclude double crop soybean production systems, which are rare in the majority of the study area.

Using a system called technology extrapolation domains (TEDs), we grouped fields based on growing degree days, aridity, and soil root zone water holding capacity. The ten TEDs that included 180 or more fields from our survey were used for further analysis (Figure 1). All fields were rainfed except for TED 2, which included all irrigated fields. Within each TED, fields were classified as early- or late-planted when falling within the first or the third terciles of planting date data distribution, respectively. Some TEDs have a different number of fields in the early- and late-planted timeframe due to many fields being planted on the first or last day within each timeframe.

To explore the relationship between seed yield and management decisions within the two planting date timeframes, we created two conditional inference (CI) trees for each TED — one for early-planted fields and one for late-planted fields (Table 2). CI trees are formed by a statistical test that splits data into two categories, such that fields within each category have similar yield and that the average yield between the two categories is statistically different from each other. Each category can then be further split using the same statistical test, increasing the depth of the tree and allowing us to visualize interactions between management decisions. To ensure that each split included enough fields that results can be generalized to fields that were not included in this study, we required that all interior nodes had at least 1/3 of the total possible data. Terminal nodes were required to have at least ten fields. We used the software R 3.4.2 and the package partykit to generate the CI trees within these parameters.

Data collected on each field in the survey included seed yield, planting date, cultivar relative maturity (RM), seeding rate, row width, tillage type, artificial drainage, seed

**TECHNOLOGY
EXTRAPOLATION DOMAINS
(TEDs) LISTED BY STATE:**

- Illinois... TEDs 4, 6, 7, 8, and 9
- Indiana... TEDs 7, 8, 9, and 10
- Iowa... TEDs 3, 4, 5, 6, 7, 8, 9, and 10
- Kansas... TEDs 2, 3, 4, 7 and 8
- Michigan... TEDs 5, 6, 9, and 10
- Minnesota... TEDs 5, 6, 9, and 10
- North Dakota... TED 1
- Nebraska... TEDs 2 and 3
- Ohio... TEDs 5, 6, 7, 8, 9, and 10
- Wisconsin... TEDs 5, 6, 9, and 10

treatments, fertilizer type and amount, lime, manure, and pesticide application. For each TED and planting date combination, management decisions where 90% of fields had the same treatment were excluded from the analysis, such as artificial drainage in early-planted fields in TED 2. Where more than half of producer surveys did not reply to the question for a particular management decision, the management decision was excluded from analysis, such as inoculant seed treatment in late-planted fields in TED 8. A summary of management decisions within each TED and planting date time-frame is shown in Table 2.

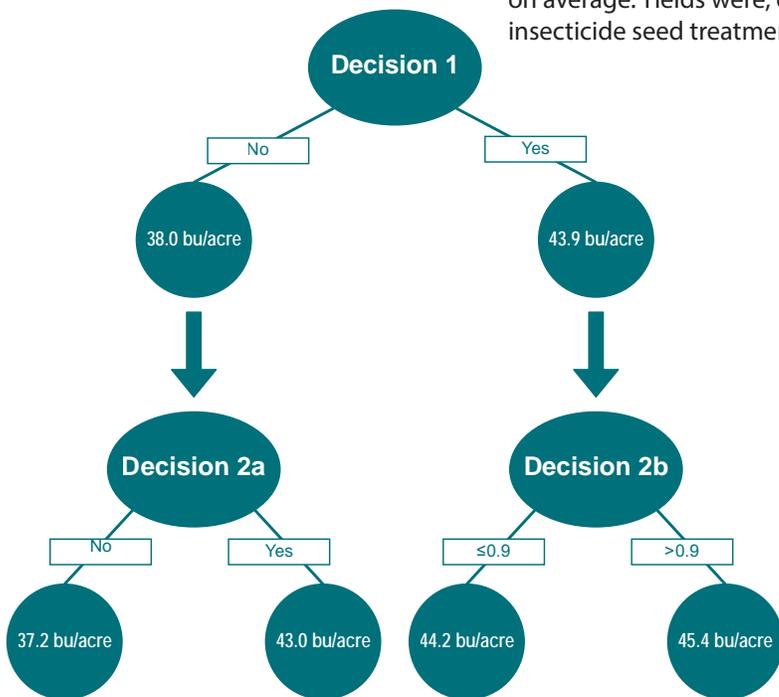
For in-season management decisions that increased yield, we calculated the maximum break-even price. The maximum break-even price is the highest price a producer can pay for a treatment and still expect a profit, or in other words, have a positive return on investment. Grain yield benefit was calculated using the CI trees by subtracting the average yield from the node without the yield-improving treatment from the average yield from the node with the yield-improving treatment. Grain yield was multiplied by grain price to calculate the maximum break-even price under three different grain price scenarios: \$8.10/bu, \$9.08/bu, and \$10.04/bu. These three values represent conservative, but realistic price scenarios, given that between January 2015 and June 2019, the lowest observed grain price was \$8.10/bu, and the median observed price was \$10.04/bu (USDA NASS, 2019). Maximum break-even prices are summarized for all TEDs at the end of this report.

TED 1: PARTS OF ND & SD

TED 1

Early-planting: 24 April – 18 May (65 fields)
Late-planting: 26 May – 14 June (71 fields)

Figure 2. Conditional inference tree for TED 1 showing significant management decisions for predicting yield in **early-planted** soybean fields.



Among early-planted fields in TED 1, insecticide seed treatment was associated with higher yield (Figure 2). Of fields with insecticide seed treatment, fields planted with a RM above 0.9 yielded 1.3 bu/acre higher on average. Among fields without insecticide seed treatment, artificial drainage was associated with 4.8 bu/acre higher yield on average. Yields were, on average, maximized for early-planted fields in TED 1 when insecticide seed treatment was utilized and relative maturity was above 0.9.

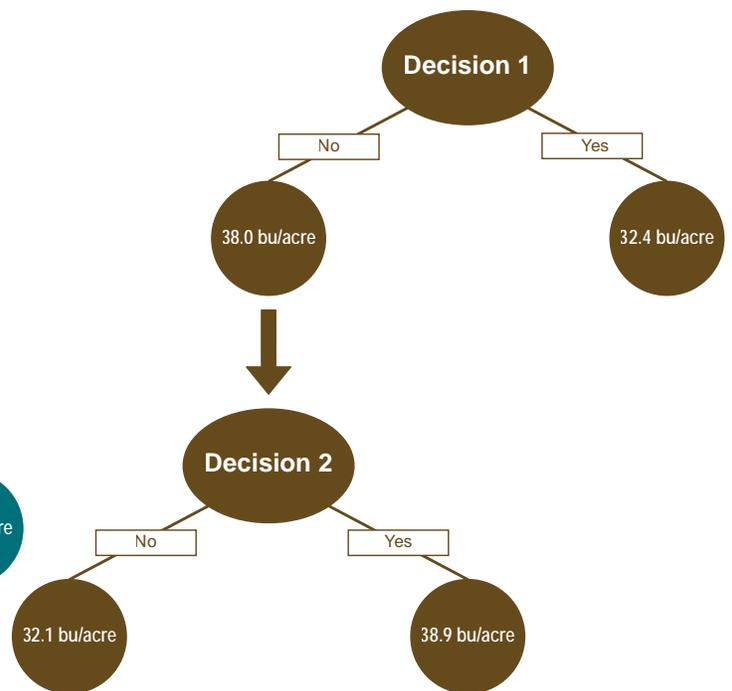


Figure 3. Conditional inference tree for TED 1 showing significant management decisions for predicting yield in **late-planted** soybean fields.



In addition to TED 1, early-planted fields in TEDs 6 and 10 also saw associations between yield and insecticide seed treatment. No TEDs had a significant difference in yield associated with insecticide seed treatment on late-planted fields. Randomized, replicated field trials have also observed that the difference in yield benefit of insecticide seed treatments varies by planting date (Mourtzinis et al., 2019).

Early-planted fields may also be more likely than late-planted fields to see a yield increase associated with artificial drainage due since drainage both reduces flooding and can improve planting and spraying conditions (Kanwar, Johnson, Schult, Fenton, & Hickman, 1983). Late-planted fields in the North Central U.S. are typically spraying applying foliar products during dryer times of the year than early-planted fields.

Optimal management strategies varied between early- and late-planted fields. Among late-planted fields in TED 1, where starter phosphorus (P) fertilizer was applied yielded on average lower than late-planted fields without starter P fertilizer (Figure 3). We do not believe the application of P fertilizer causes soybean yield reductions. More likely, fields receiving P fertilizer may have had previously low yields or had low soil test P values. The survey did not collect information on soil fertility levels. Among fields that did not receive starter P fertilizer, fungicide seed treatment was associated with 6.8 bu/acre higher yields. Of the ten TEDs and two planting timeframes in this study, late-planted fields in TED 1 was the only growing environment where fungicide seed treatments were associated with significantly higher soybean yields.

TED 2: PARTS OF SD, NE, & KS

TED 2

Early-planting: 6 April – 6 May (105 fields)

Late-planting: 17 May – 6 July (111 fields)

In early-planted fields in TED 2, starter fertilizer was associated with 7.4 bu/acre higher yield (Figure 4). Starter fertilizers were not associated with yield in other planting timeframes or TEDs, and maximum break-even price for starter fertilizer in this environment was \$60/acre when soybean price was \$8.10/bu.

Late-planted fields in TED 2 had 7.5 bu/acre higher yield on average when both PRE and POST herbicides were applied, as compared to fields with no herbicide application or POST herbicides alone (Figure 5). The maximum break-even price for adding a PRE herbicide to a field already receiving POST herbicide in this growing environment was

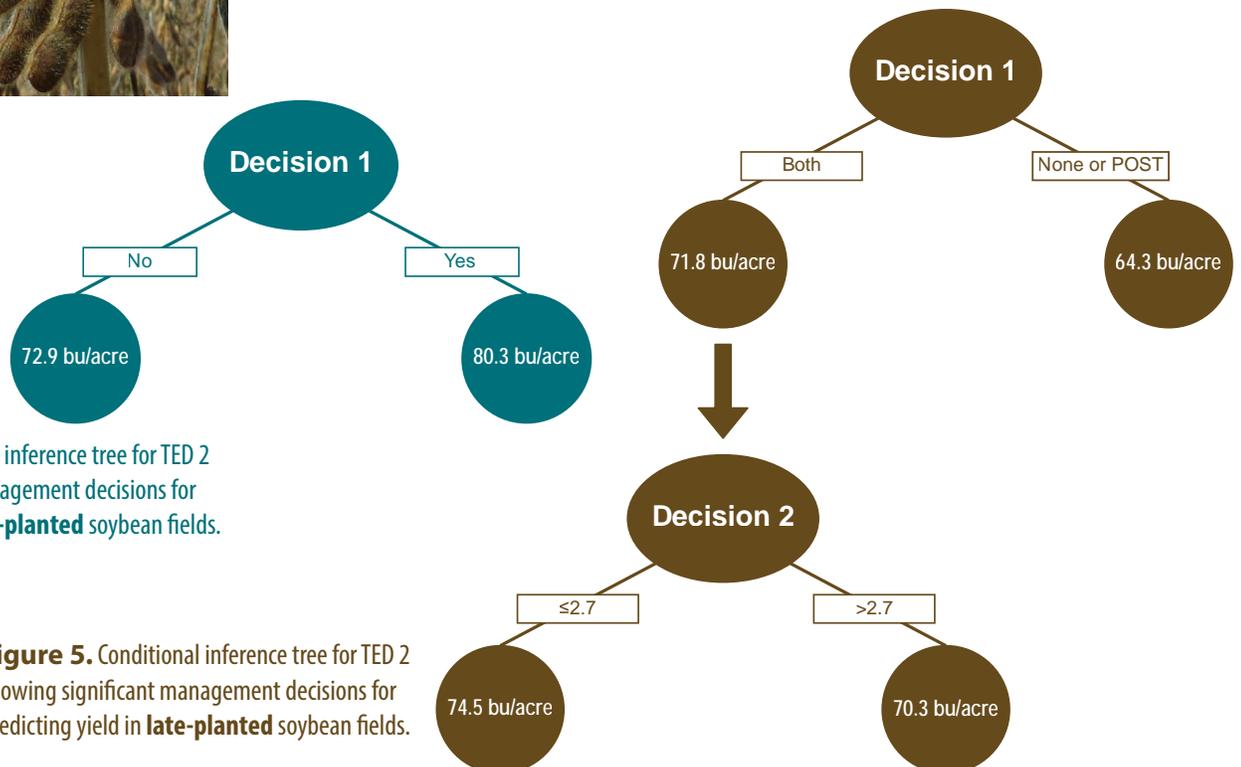


Figure 4. Conditional inference tree for TED 2 showing significant management decisions for predicting yield in **early-planted** soybean fields.

Figure 5. Conditional inference tree for TED 2 showing significant management decisions for predicting yield in **late-planted** soybean fields.



\$61/acre when soybean price was \$8.10/bu. The highest yielding late-planted fields in TED 2 had both PRE and POST herbicide applications and a relative maturity below 2.7.

In addition to TED 2, improved herbicide application timings in late-planted fields were associated with higher yields in TEDs 5 and 10. For early-planted fields, herbicide application timings were only associated with higher yield in one TED (6). Response to herbicide timings in late-planted fields could be due to delayed planting resulting in the soybean canopy fully closing later in the growing season and in some cases, never completely closing (Steele & Grabau, 1997). Full canopy closure is necessary to minimize weed pressure, especially from weeds with an extended emergence period (Hock, Knezevic, Martin, & Lindquist, 2005; Jha & Norsworthy, 2009).

TED 3: PARTS NE, KS, IA, & MO

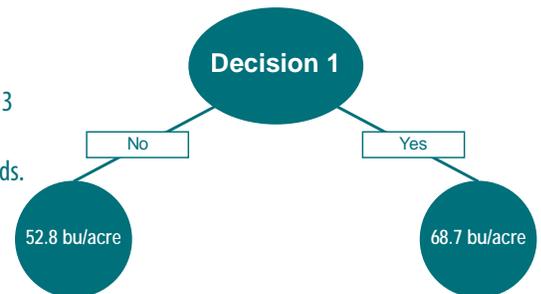
TED 3

Early-planting: 21 April – 14 May (59 fields)

Late-planting: 22 May – 1 July (64 fields)

Foliar fungicide application was associated with 15.9 bu/acre higher yields in early-planted fields in TED 3 (Figure 6). Of the ten TEDs and two planting timeframes included in this study, yield increases were only associated with foliar fungicide application in early-planted fields in TED 3 and late-planted fields in TED 6. Among late-planted fields in TED 3, there was no management decision that was significantly associated with higher yields.

Figure 6. Conditional inference tree for TED 3 showing significant management decisions for predicting yield in **early-planted** soybean fields.



TED 4: PARTS OF IA, KS, MO, & IL

TED 4

Early-planting took place from 22 April to 7 May (79 fields)

Late-planting took place from 20 May to 30 July (85 fields)

In TED 4, relative maturity greater than 3 was associated with 5.4 bu/acre higher yield in early-planted fields (Figure 7). For late-planted fields in TED 4, yield was an average of 4.6 bu/acre higher when RM was below 3.4 (Figure 8).

Figure 7. Conditional inference tree for TED 4 showing significant management decisions for predicting yield in **early-planted** soybean fields.

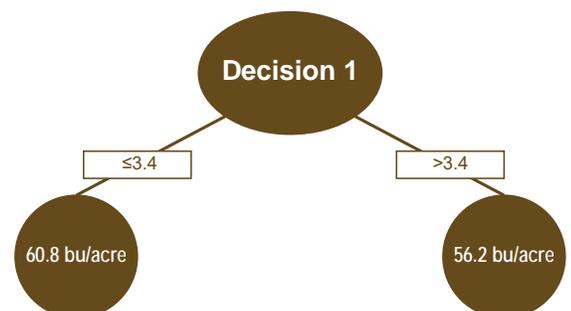
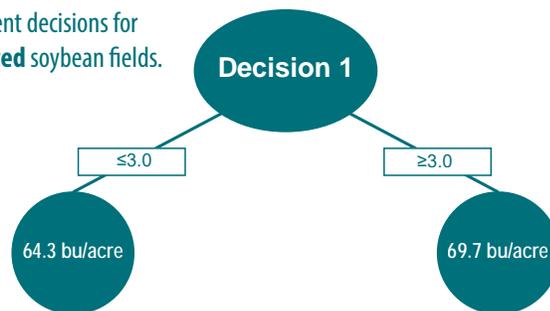


Figure 8. Conditional inference tree for TED 4 showing significant management decisions for predicting yield in **late-planted** soybean fields.

Early-planting: 18 April – 11 May (90 fields)

Late-planting: 22 May – 13 June (84 fields)

In early-planted fields in TED 5, fields where foliar insecticide was applied yielded an average of 5.3 bu/acre than fields without foliar insecticide application (Figure 9). Foliar insecticide was not associated with increased yield in late-planted fields within TED 5, and it was only associated with increased yield for early-planted fields in one other TED (TED 8). Insect pest pressure can vary by soybean planting date, which is important to keep in mind when scouting fields (Hammond et al., 1991; Zeiss & Klubertanz, 1994).

In late-planted fields in TED 5, fields planted with rows wider than 22 inches yielded on average 7 bu/acre higher (Figure 10). Among fields planted with rows narrower than 22 inches, increased herbicide application timings were associated with higher yield. Fields with narrow rows and both PRE and POST herbicide applications yielded on average 54.9 bu/acre, and fields with narrow rows and only PRE or POST herbicide application yielded on average 44.2 bu/acre. Response to herbicide timings in late-planted fields could be due to delayed planting resulting in the soybean canopy fully closing later in the growing season and in some cases, never completely closing (Steele & Grabau, 1997). Full canopy closure is necessary to minimize weed pressure, especially from weeds with an extended emergence period (Hock, Knezevic, Martin, & Lindquist, 2005; Jha & Norsworthy, 2009).

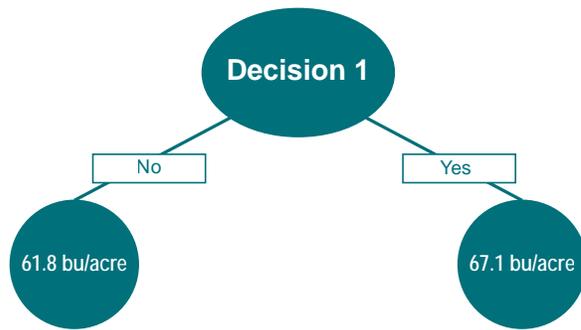


Figure 9. Conditional inference tree for TED 5 showing significant management decisions for predicting yield in **early-planted** soybean fields.

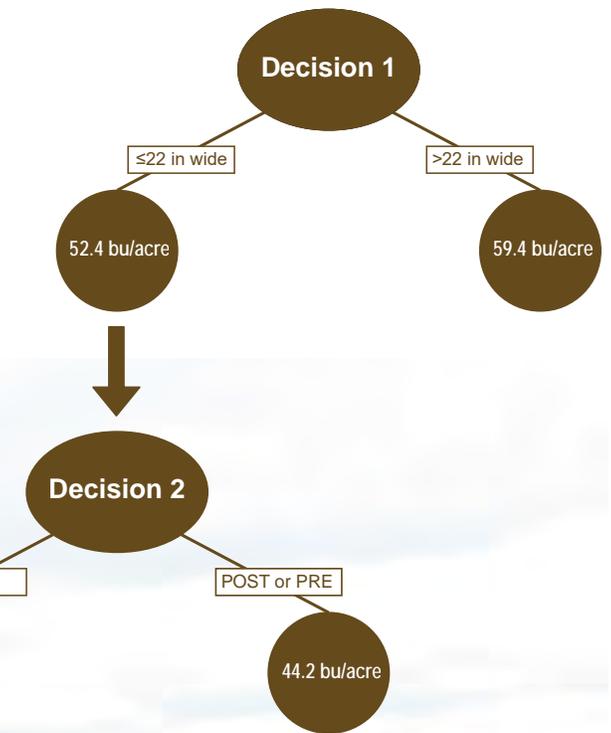


Figure 10. Conditional inference tree for TED 5 showing significant management decisions for predicting yield in **late-planted** soybean fields.



Early-planting: 17 April to 8 May (89 fields)

Late-planting: 21 May to 10 June (99 fields)

Among early-planted fields in TED 6, artificial drainage was associated with lower average yield. CI trees do not show causal relationships, so the lower observed yield on artificially drained fields is likely due to producers only tiling fields with poor drainage and consequently, lower-yielding fields. On fields with artificial drainage, average yield was 2.2 bu/acre higher when both PRE and POST herbicides were applied. For fields with drainage and PRE and POST herbicides, yield differences were also associated with nematicide and insecticide seed treatments. Insecticide seed treatment generally does not cause large yield increases, but it is more likely to improve yield in early-planted scenarios (Mourtzinis et al., 2019).

Of the late-planted fields in TED 6, the higher yields were observed in intensely tilled fields (Figure 12). Yield in minimally tilled fields was further associated with foliar fungicide. Fields with foliar fungicide yielded on average 4.7 bu/acre than fields without foliar fungicide. Minimally-tilled fields may respond to foliar fungicide when intensely-tilled fields do not since reduced tillage leads to larger amounts of plant residue on the surface. In some environmental conditions, residue can harbor inoculum that can splash onto soybean leaves and potentially cause foliar diseases.

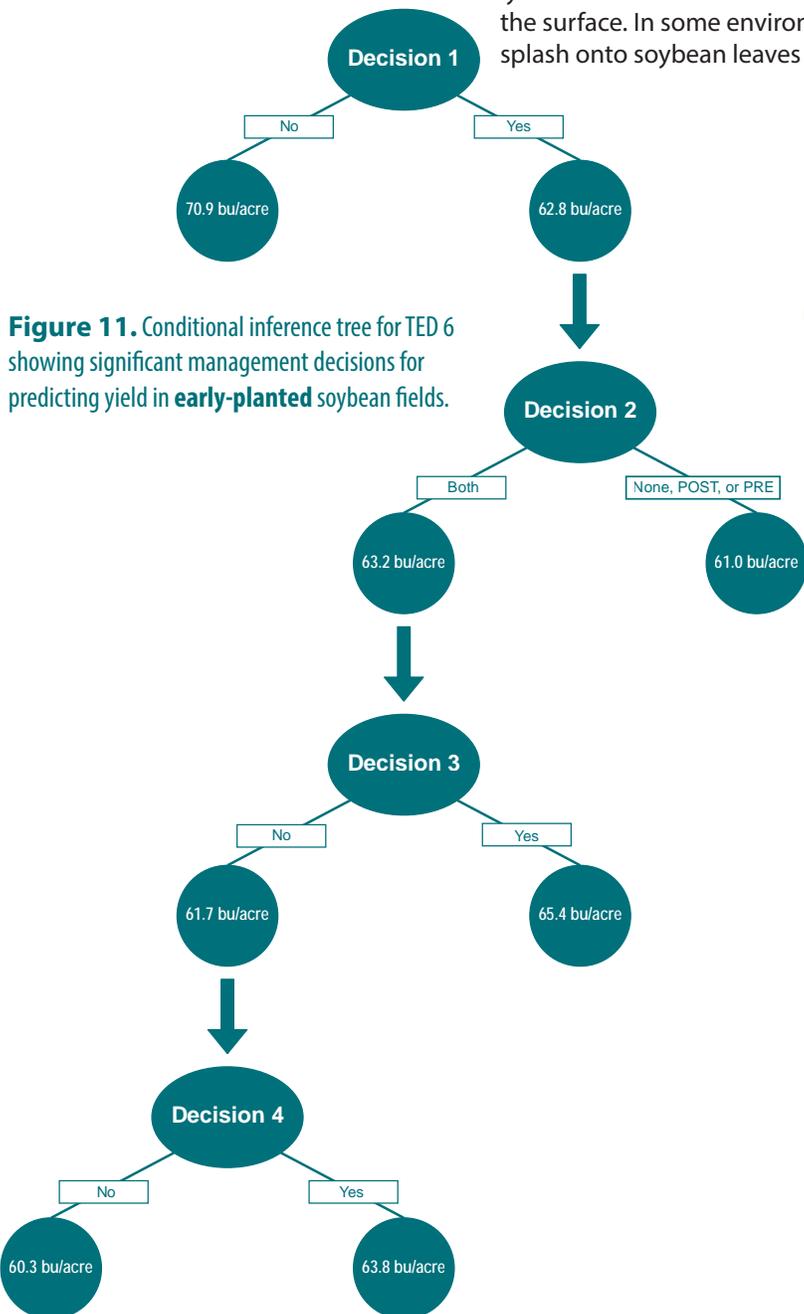


Figure 11. Conditional inference tree for TED 6 showing significant management decisions for predicting yield in **early-planted** soybean fields.

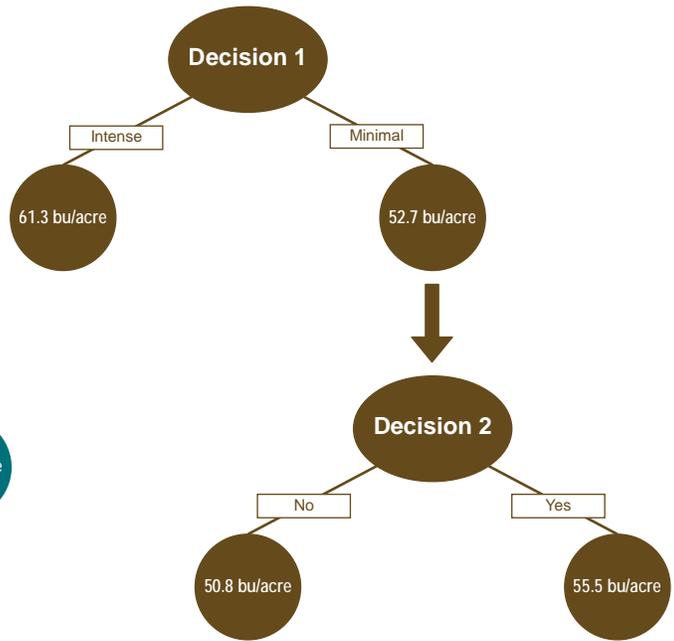


Figure 12. Conditional inference tree for TED 6 showing significant management decisions for predicting yield in **late-planted** soybean fields.

Early-planting: 10 April – 7 May (54 fields)

Late-planting: 22 May – 23 June (59 fields)

Seeding rate was a significant predictor of yield in TED 7 for both early- and late-planted fields. Among early-planted fields, seeding rates below 163,000 seeds/acre were associated with 13.4 bu/acre higher average yield. Maximum average yield in late-planted fields in TED 7 was observed when seeding rate was below 145,000 seeds/acre. Lowest average yield was observed when seeding rate was above 175,000 seeds/acre.

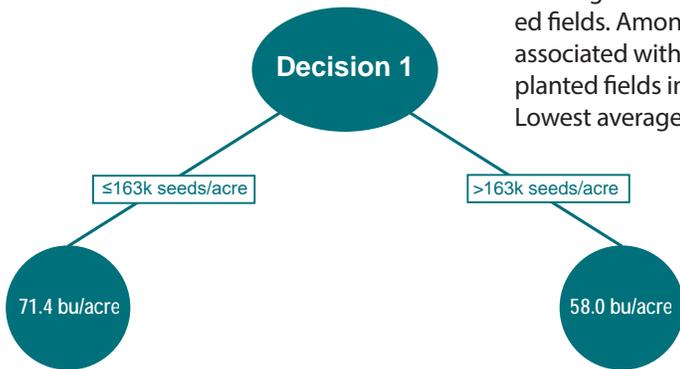


Figure 13. Conditional inference tree for TED 7 showing significant management decisions for predicting yield in **early-planted** soybean fields.

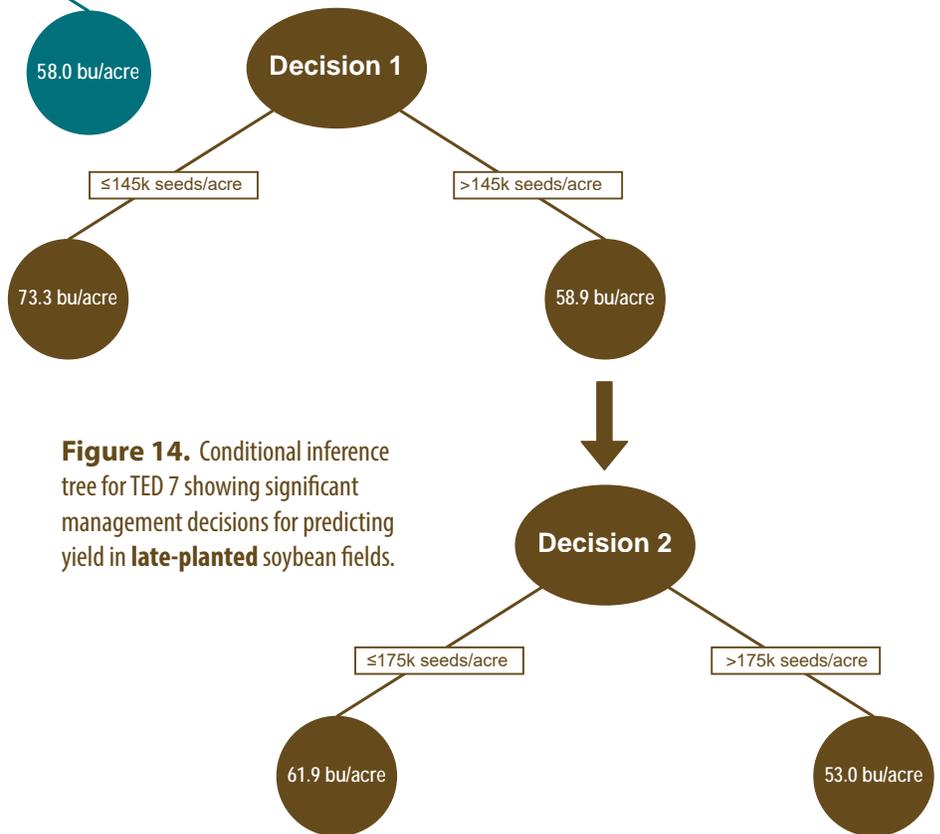


Figure 14. Conditional inference tree for TED 7 showing significant management decisions for predicting yield in **late-planted** soybean fields.

Early-planting: 18 April – 11 May (90 fields)

Late-planting: 22 May – 13 June (84 fields)

For TED 8 early-planted fields, seeding rates below 155,000 seeds/acre were associated with 11.5 bu/acre higher average yield (Figure 15). Among fields with seeding rates below 155,000 seeds/acre, foliar insecticide application was associated with 10.9 bu/acre higher yield.

Among late-planted fields in TED 8, planting after corn or sorghum was associated with 11.3 bu/acre higher yield than planting after soybean or wheat. Double crop fields were excluded from this study, so all fields including those after wheat represent full-season soybean. For fields planted after corn or sorghum, higher yield was observed on fields with artificial drainage. Among fields that did not receive artificial drainage, intense tillage was associated with 7.9 bu/acre higher average yield. The final significant management decision among late-planted fields in TED 8 was relative maturity. Reading down the CI tree, for soybean fields planted after corn or sorghum, without artificial drainage, minimally tilled fields yielded 3.1 bu/acre higher on average when the RM was below 3.8.

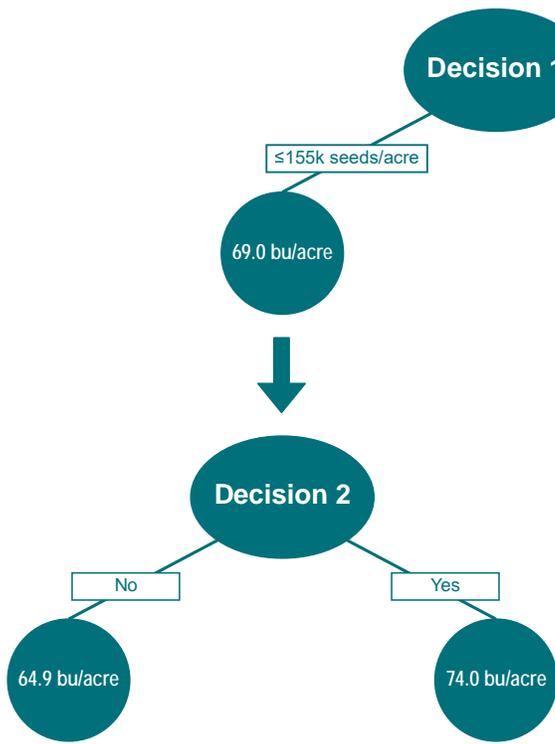


Figure 15. Conditional inference tree for TED 8 showing significant management decisions for predicting yield in **early-planted** soybean fields.

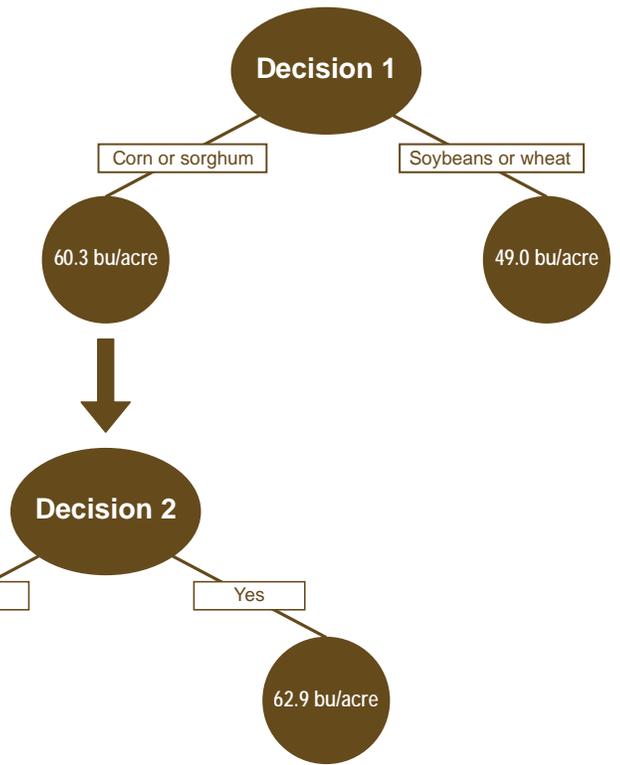
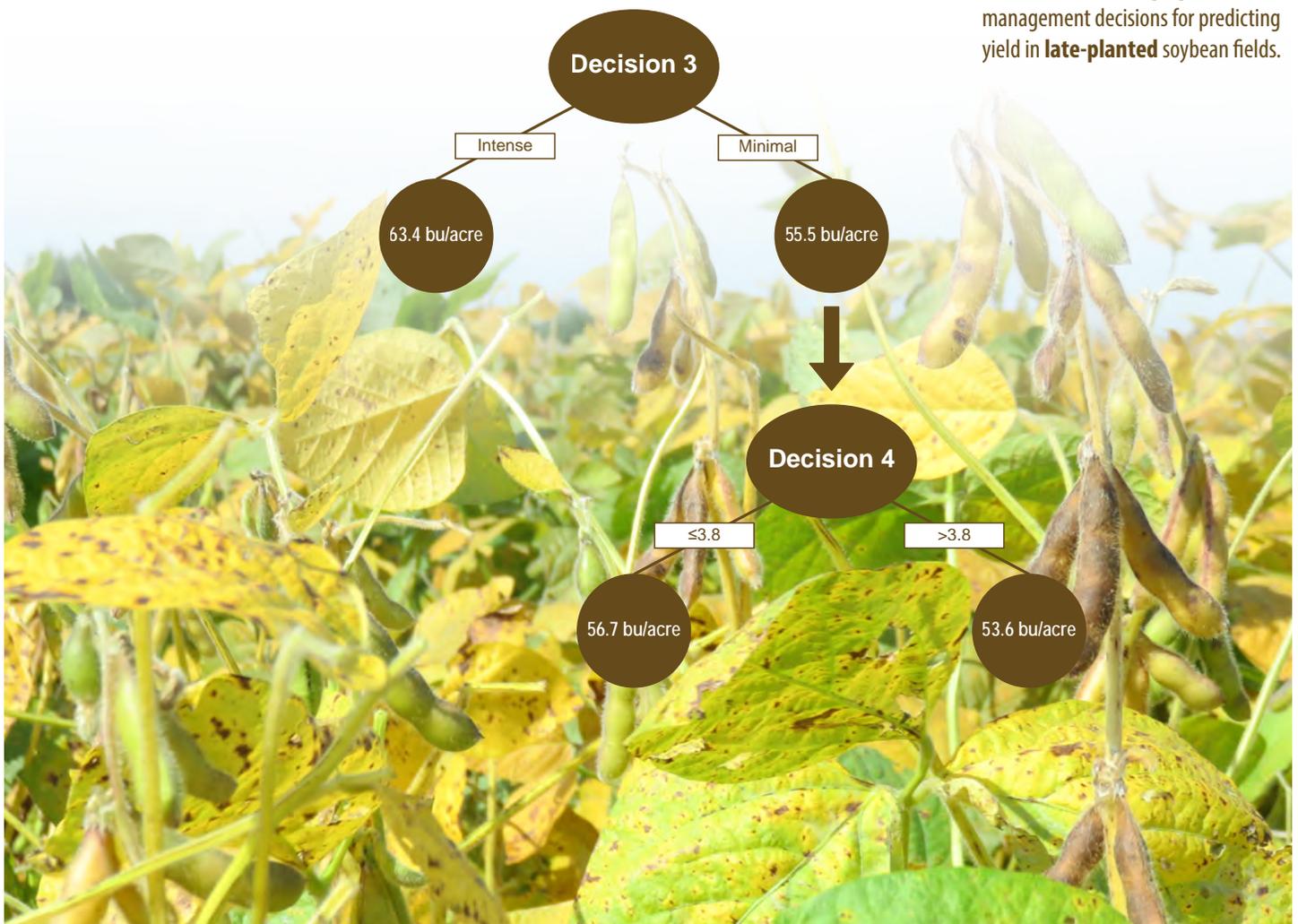


Figure 16. Conditional inference tree for TED 8 showing significant management decisions for predicting yield in **late-planted** soybean fields.



Early-planting: 29 April – 15 May (56 fields)

Late-planting: 26 May – 16 June (62 fields)

For early-planted fields in TED 9, inoculate seed treatment was associated with lower yield. This is likely due to farmers choosing to apply inoculant seed treatment in historically low-yielding fields. CI trees do not indicate that a given significant management decision causes lower yields, only that a management decision was observed in combination with lower yields. Among fields that did not receive inoculant seed treatments, foliar fungicide was associated with 13.5 bu/acre higher yields.

Among late-planted fields in TED 9, foliar insecticide was associated with 8.3 bu/acre higher average yield.

Figure 17. Conditional inference tree for TED 9 showing significant management decisions for predicting yield in **early-planted** soybean fields.

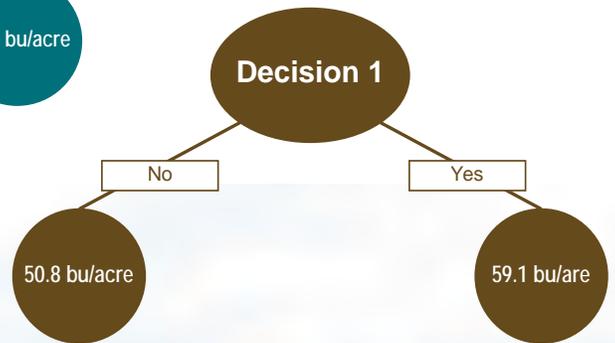
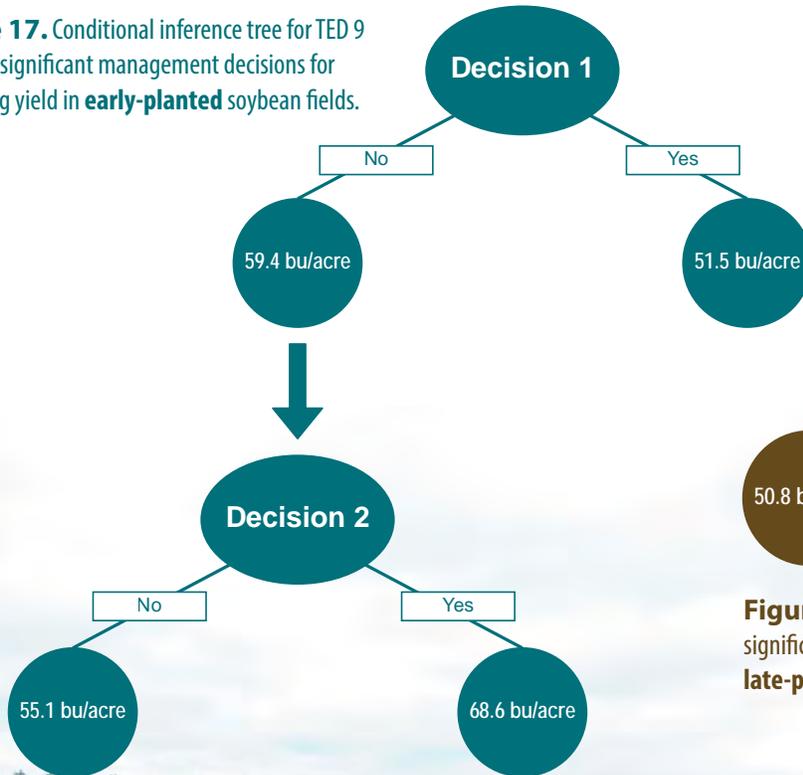


Figure 18. Conditional inference tree for TED 9 showing significant management decisions for predicting yield in **late-planted** soybean fields.



Early-planting: 26 April – 16 May (53 fields)

Late-planting: 25 May – 15 June (54 fields)

Among early-planted fields in TED 10, artificial drainage was associated with 9.9 bu/acre higher yield. Fields with both artificial drainage and insecticide seed treatment yielded an average of 8.8 bu/acre higher than fields with artificial drainage but without insecticide seed treatment. Insecticide seed treatment generally does not cause large yield increases, but it is more likely to improve yield in early-planted scenarios (Mourtzinis et al., 2019). Highest average yield among early-planted fields in TED 10, 67.8 bu/acre, was achieved when artificial drainage and insecticide seed treatment were both used and seeding rate was below 155,000 seeds/acre.

Late-planted fields in TED 10 that received only POST applications yielded 11.1 bu/acre lower on average than fields that received only PRE applications or both POST and PRE applications. Response to herbicide timings in late-planted fields could be due to delayed planting resulting in the soybean canopy fully closing later in the growing season and in some cases, never completely closing (Steele & Grabau, 1997). Full canopy closure is necessary to minimize weed pressure, especially from weeds with an extended emergence period (Hock, Knezevic, Martin, & Lindquist, 2005; Jha & Norsworthy, 2009).

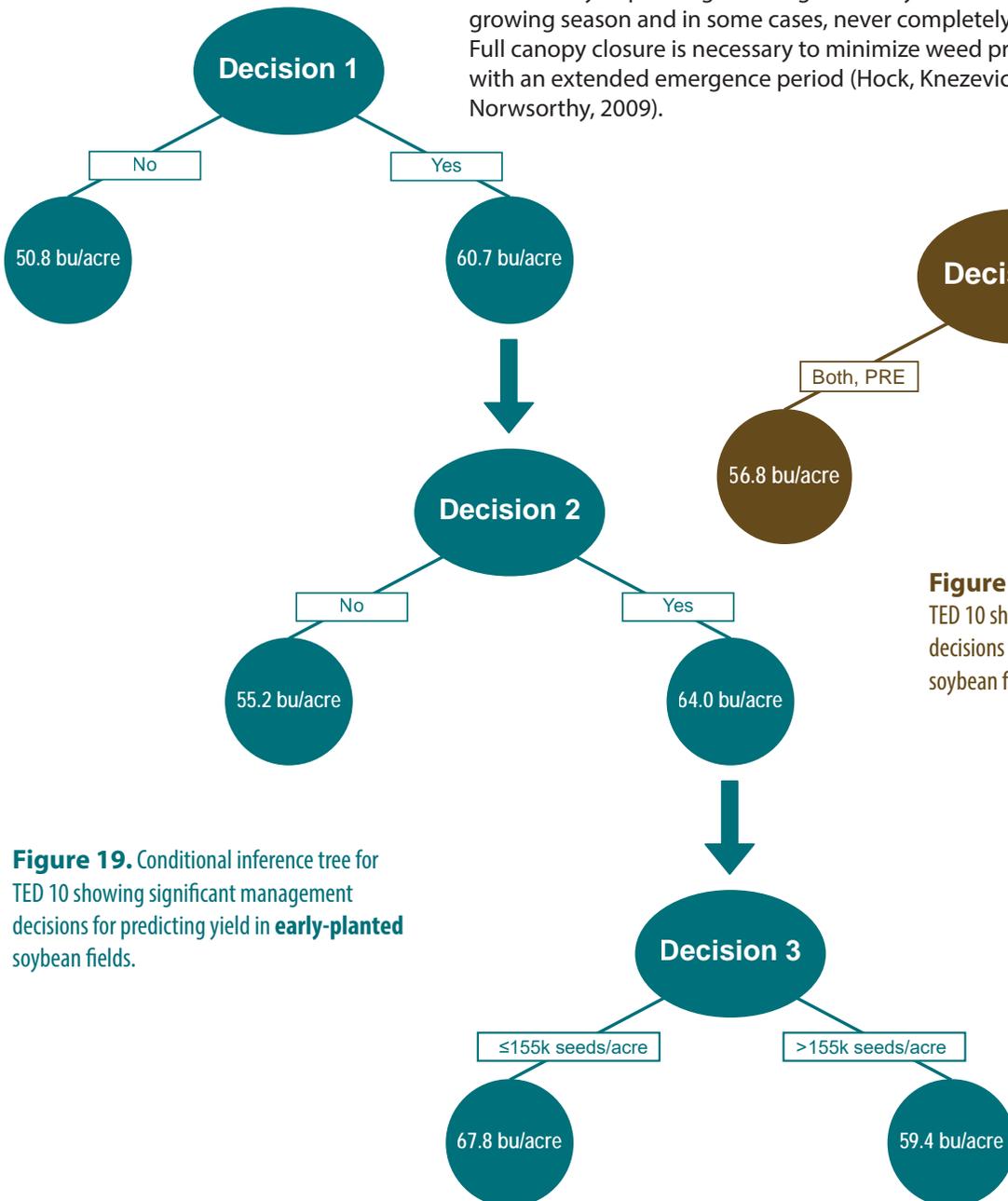


Figure 19. Conditional inference tree for TED 10 showing significant management decisions for predicting yield in **early-planted** soybean fields.

Figure 20. Conditional inference tree for TED 10 showing significant management decisions for predicting yield in **late-planted** soybean fields.

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MAXIMUM BREAK-EVEN PRICE

For management decisions that were associated with higher yields, we calculated the maximum break-even price a producer should pay for specific management decisions or inputs at three grain prices. If it costs more than the maximum break-even price to implement a given management practice, the management practice is likely to reduce field-level profits. In the following table, yield benefit was calculated by subtracting the average yield in fields without that treatment from fields with that treatment in the conditional inference trees.

Keep in mind that not every management decision has an associated break-even price. For example, TED 4 did not have any associated break-even prices because relative maturity was the only significant management decision identified in the CI tree analysis. Changing RM does not have an associated cost. Lowering seeding rate in TED 7 does not have an associated break-even price because when this decision increases yield, it also lowers input costs and improves profit margins. Similarly, TED 8 late-planted fields did not have decisions with in-season costs identified (tillage and drainage are multi-year choices; RM and rotation do not have associated costs).

TED #	Planting	Decision	Yield Benefit ----bu/acre----	Maximum break-even price if grain is:		
				\$8.10/bu ^a	\$9.08/bu	\$10.04/bu
				----- per acre-----		
1	Early	Insecticide ST ^b	5.9	\$48	\$54	\$60
1	Late	Fungicide ST	6.8	\$55	\$62	\$69
2	Early	Starter Fertilizer	7.4	\$60	\$67	\$74
2	Late	Herbicide ^c	7.6	\$61	\$69	\$76
3	Early	Foliar Fungicide	14.5	\$118	\$132	\$146
5	Early	Foliar Insecticide	5.3	\$43	\$49	\$54
5	Late	Herbicide	10.7	\$87	\$97	\$107
6	Early	Herbicide	2.2	\$18	\$20	\$22
		Nematicide ST	3.7	\$30	\$34	\$37
		Insecticide ST	2.8	\$23	\$26	\$28
6	Late	Foliar Fungicide	4.2	\$34	\$38	\$42
8	Early	Foliar Insecticide	9.2	\$75	\$84	\$92
9	Early	Foliar Fungicide	13.5	\$109	\$123	\$136
9	Late	Foliar Insecticide	8.3	\$67	\$75	\$83
10	Early	Insecticide ST	8.8	\$71	\$80	\$88
10	Late	Herbicide	11.1	\$90	\$101	\$112

^a All prices listed are in U.S. dollars ^b Seed treatment ^c Cost of adding a PRE-emergence herbicide



Adapted from: Matcham EG, Mourtzinis S, Conley SP, et al. *Management strategies for early- and late-planted soybean in the North-central United States*. *Agronomy Journal*.2020;1-16. <https://doi.org/10.1002/agj2.20289>