Corn and soybean planting order decisions impact farm gross revenue

IN A BEAN POD...

- Crop planting order can affect yield of both crops and overall gross farm revenue
- Crop planting order and cropping systems of both crops interact and should be optimized together
- Crop planting order decision is not a trivial task and multiple factors must be considered

INTRODUCTION

Rotating corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.], two of the most important crops globally, is a typical management choice in the US. The main reason the two crops are rotated is the increased yield compared to corn and soybean systems (Porter et al., 1997; Wilhelm and Wortmann, 2004; Stanger and Lauer, 2008; Grover et al., 2009; Mourtzinis et al., 2017a, 2017b) which were attributed to reduced pest pressure and improved soil properties. Within the same region, both crops are typically planted during the same spring interval; therefore, farmers who rotate both crops every year must decide which crop should be planted first. Due to the rotation-related crop productivity gains and anticipated crop selling prices that year, it may be optimal to prioritize corn over soybean or vice versa as the first planted crop. Such a decision, however, involves consideration of many additional factors.

Delayed planting can suppress corn and soybean yield in many important agricultural regions in the US (Long et al., 2017; Mourtzinis et al., 2019). Depending on the farm acreage associated with each crop a farmer must plant each spring and the planting capacity of available equipment (ac planted/day), and weather-related planting delays, planting of the second crop may be delayed significantly which could result in substantial yield losses. Additionally, background management choices, other than planting date, may further affect crop yields such as row spacing (Andrade et al., 2019), seed maturity (Mourtzinis & Conley, 2017), seeding rate (Gaspar et al., 2020) etc. Suboptimum background cropping systems may be associated with yield losses, even with optimum planting date, which in turn can suppress gross farm revenue (Mourtzinis et al., 2021). Therefore, total yield loss of both crops due to delayed planting and other background management choices, along with the projected crop selling prices of both crops, are important factors that should be considered when deciding which crop should be planted first.

The effect of rotation on crop yield as well as drivers for relative decisions under commodity price uncertainty have been examined (Livingston et al., 2015). However, there are no studies examining how crop planting order within the same growing season can affect yield of both crops and gross farm revenue under variable background management and commodity selling prices. Our goal is to evaluate the effect of these factors on gross farm revenue.

MATERIALS AND METHODS

There is a lack of replicated field trials where both crops were planted at the same field and on multiple dates. Therefore, to estimate yield trend due to multiple planting dates in the same environment (soil type × weather conditions), yields for both crops were simulated for 310 locations across 26 states the (Figure 1). Previously developed crop yield prediction algorithms (Mourtzinis et al., 2021) were used to estimate yield for planting dates between April 10th (day of year=100) and June 15th (day of year=165) in each of five consecutive years (2014 to 2018). The calendar dates used here span the typical planting date range that could be used for either crop.

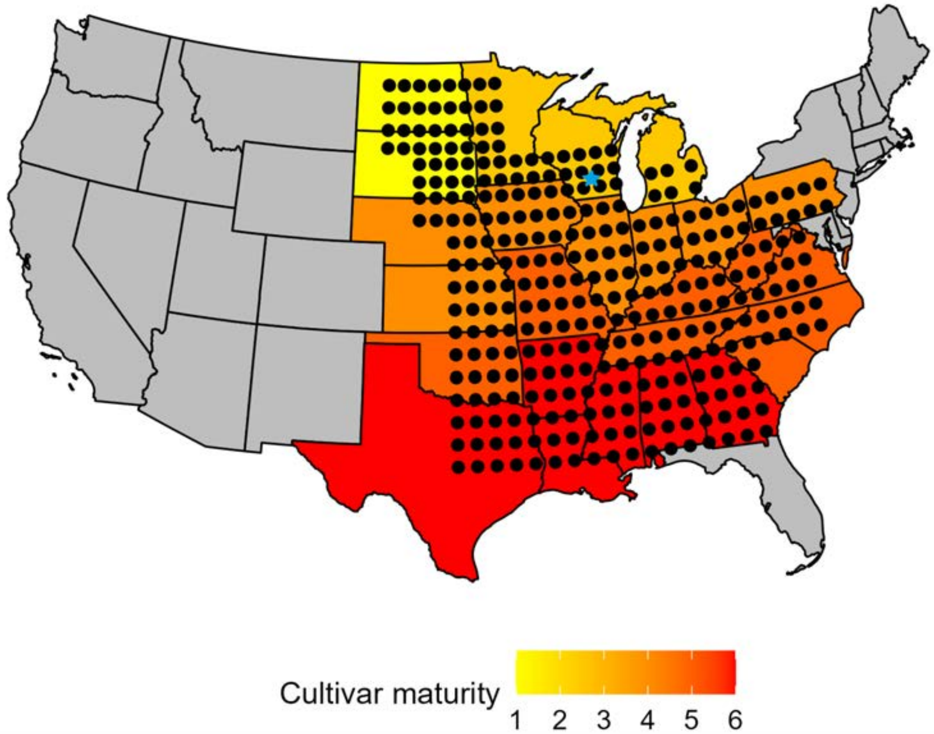

Figure 1. Locations where corn and soybean yield and gross farm revenue were simulated (see methods for assumptions). In each location, two maturities were used for corn (105 and 115). For soybean, three maturities were used and the average maturity in each state is shown with different color (yellow to red colors for early to late maturity, respectively). The blue star in Wisconsin shows the location of a randomly chosen field we present site-specific results.

To simulate yield of both crops in every field, assumptions about the environment and background cropping systems choices were necessary. Non-variable assumptions were that each crop in each year was rainfed, planted in a silt loam soil type with conventional tillage practices at 30-inch row spacing. The selected assumptions were chosen as they are considered common for both crops across the US. For corn, used seed maturities in every location were 105 and 115 whereas for soybean, state average seed maturities were used and are shown in Figure 1. Relative to farmer-chosen optimization of other management practices, aside from planting date, are listed in Table 1.

Table 1. Management decisions for typical and low-input corn and soybean cropping systems.

Management	Typical Corn	Low-input Corn	Typical Soybean	Low-input Soybean
Seeding rate (seeds/ac)	33,000	26,000	140,000	90,000
Nitrogen rate (lb/ac)	160	40	0	0
Previous crop	Soybean	Soybean	Corn	Corn

A field in WI was randomly chosen for a more comprehensive description of the effect of management decisions and crop planting order. For that field, soybean maturity was set to 2.5 and corn maturity to 115. Partial economic analysis was conducted using the estimated yields and crop price selling assumptions using constant corn and soybean price (5.1 and 12.2 $/bu, respectively). Soybean seed cost was set to $65/140,000 seeds. For corn, seed cost was set to $300/80,000 seeds and nitrogen cost was set to 1 $/lb. We assumed that the farmer would plant 5000 ac of farmland, 2500 ac for each crop in each year. The available equipment allowed for planting of 250 ac/day for both crops (i.e., 10 days from start to end dates of planting for each crop). For each scenario (plant first corn and then soybean and vice versa, price ratio and planting date), the gross generated farm revenue (corn + soybean acres) was estimated.

The same partial economic analysis described for the WI field was repeated for the rest 309 fields across the US using the same assumptions for field size, range of planting dates, seed and nitrogen costs. For each cropping system (Table 1), within the range of planting dates we used, the first date at which corn planting should be prioritized over soybean planting for maximum gross farm revenue was estimated and averaged by state.

RESULTS

Downward yield trends for both crops were observed at the Wisconsin field due to delayed planting within each of the five years (Figure 2). Between 100 and 120 day of year (doy), corn yield was relatively high and (vs. soybean) constant, but thereafter corn yield declined rather sharply. When focusing on mean trend over five years (top left graph in Figure 2), after 120 doy the rate of corn yield loss was greater than the rate of soybean yield loss but after 135 doy, the rate of corn yield loss was even greater. Depending on the year, both crops lost approximately 25% of maximum yield due to delayed planting after early May. Overall, variable yield losses were observed between the two crops and during the five years as a result of variable weather conditions.

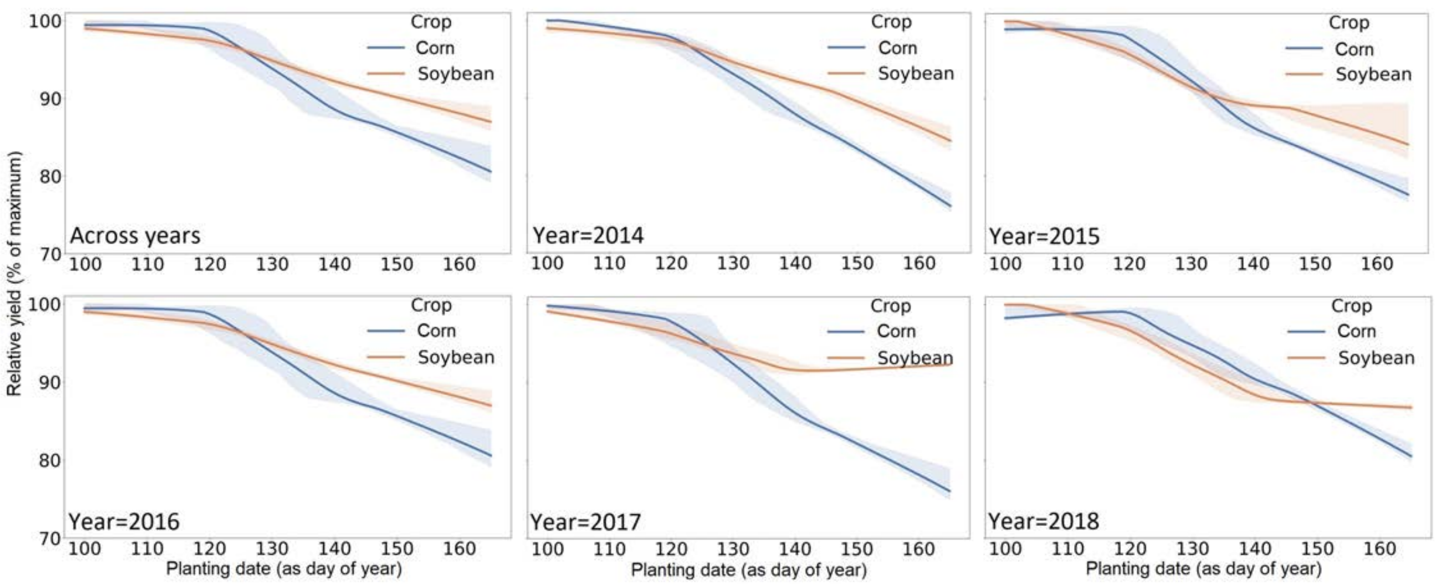

Figure 2. Corn and soybean relative yield response to planting date for typical input systems (see Table 1) in the field in Wisconsin. To calculate relative yield, maximum yield of each crop was set as maximum, and all other yields were calculated as % of maximum. Shaded areas show the 95% confidence intervals.

By calculating the ratio of corn + soybean gross revenue for each planting date for two scenarios (plant corn first followed by soybeans or soybean first followed by corn), we can examine the trend of gross farm revenue across the examined planting dates (Figure 3). Results suggest that when typical management is used for both crops (Figure 3 A, Table 1), soybean should be prioritized over corn for early planting dates (up to 112 doy). This is also the case when typical management used only for corn and low-input for soybean. If planting would initiate after 112 doy, prioritizing corn over soybean would result in greater revenue. These results are associated with cropping systems that typically result in high yield (Figure 4 A).

However, it is possible that background cropping system choices, other than planting date, of one or both crops are not optimum for maximum yield. For low-input corn cropping system choices, a large yield reduction was observed (c.a. 26 bu/ac, Figure 4 B). In this case, prioritizing planting of soybean over corn for approximately half of the examined dates would result in increased revenue (Figure 3 B and D). For low-input soybean cropping system choices, a small yield reduction was observed (*c.a.* 2 bu/ac, Figure 4 C). In this case, results were similar to when systems for both crops were typical. Finally, when cropping systems of both crops were low-input (Figure 4 D), soybean planting should be prioritized over corn for half of the examined planting period (Figure 3 D).

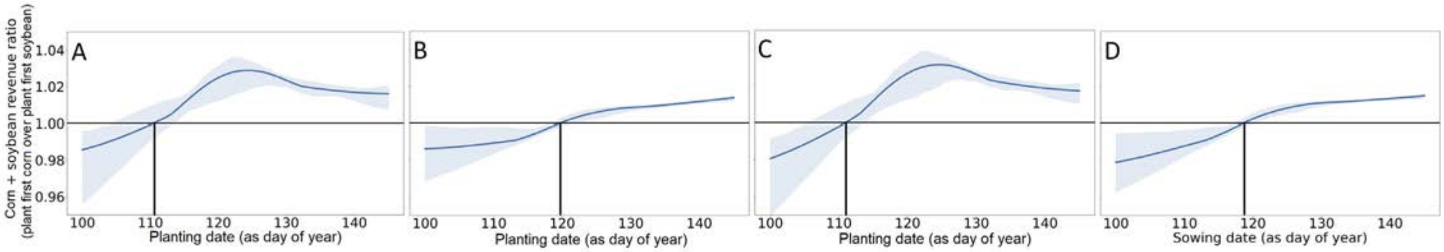

Figure 3. Ratio of gross farm revenue (corn + soybean acres) in the field in Wisconsin for price ratio=0.42 when planting corn acres first and th soybean over planting soybean acres first and then corn for A) typical cropping systems for both crops, B) typical soybean and low-input corn cropping system, C) low-input soybean and typical corn cropping system and, D) low-input cropping systems for both crops. See Table 1 in methods section for typical and low-input management choices. Shaded areas show the 95% confidence intervals. Note: The last day we simulated yield for both crops was 165 doy. Since the farmer can plant 250 ac/day and 2500 ac of each crop need to be planted, that means 20 total days are needed to plant both crops. Therefore, planting date in x-axis stops at 145 doy which that is the last date to start planting any of the two crops in this exercise (145+20=165 doy).

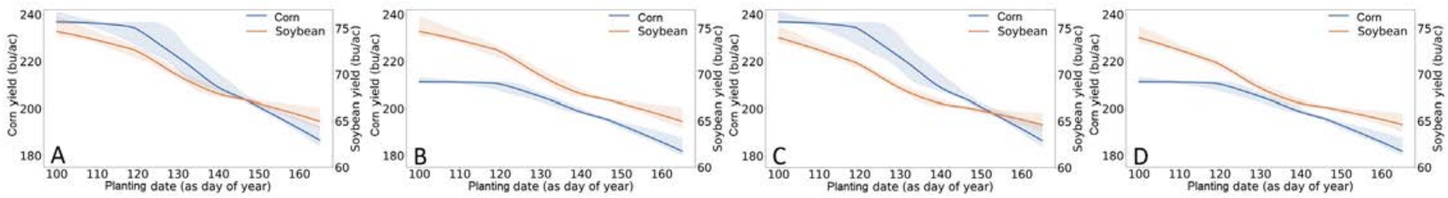

Figure 4. Five-year mean corn (left y-axis) and soybean (right y-axis) yield in the field in Wisconsin for A) typical cropping systems for both crops, B) typical soybean and low-input corn cropping system, C) low-input soybean and typical corn cropping system and, D) low-input cropping systems for both crops. See Table 1 in methods section for typical and low-input management choices. Shaded areas show the 95% confidence intervals.

Repeating the previous analysis for the 309 fields across the US (see Figure 1), the state-average date that corn should be prioritized over soybean varied due to cropping system (typical vs. low-input) and by state (Figure 5). When cropping systems for both crops were typical, corn planting should be prioritized early in the growing season in almost every state when compared with low-input cropping systems. A similar trend was observed when typical system was used for corn and low-input for soybean when compared to low-input for corn and typical for soybean. Overall, it appears that corn revenue is more sensitive to management decisions than soybean revenue. This implies that planting order decisions should first incorporate management optimization.

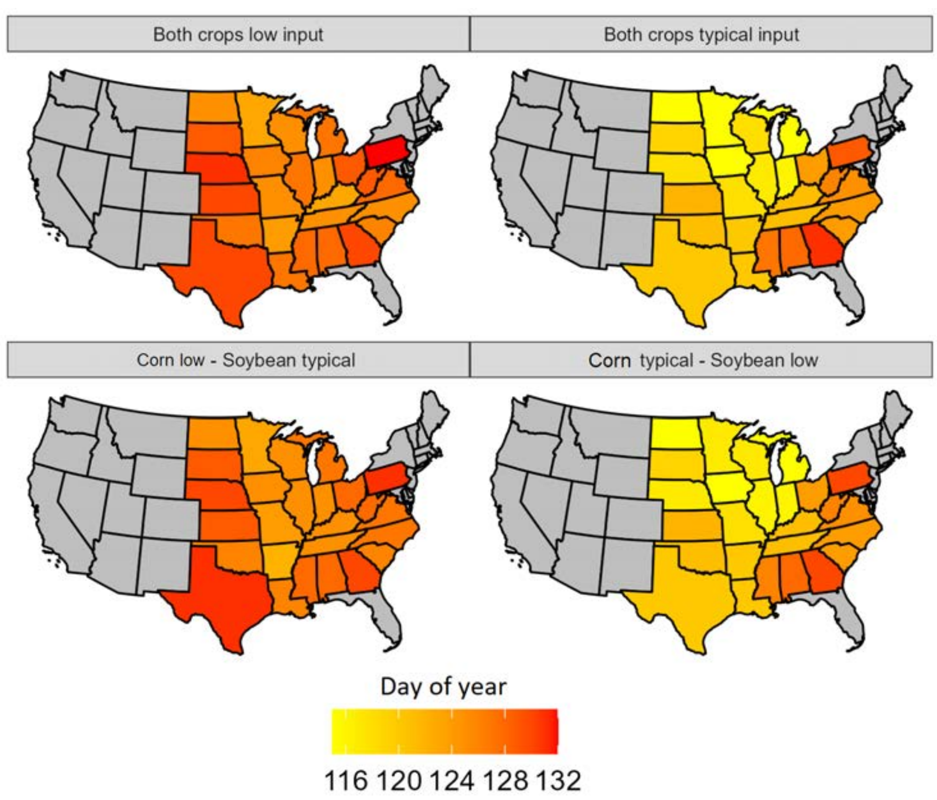

Figure 5. Day of year that corn planting should be prioritized over soybean planting for maximum gross farm revenue (corn + soybean acres) between 110 to 145 day of year (yellow to red colors) for four combinations of input systems (see methods for input system information). Note: The last day we simulated yield for both crops was 165 doy. Since the farmer can plant 250 ac/day and 2500 ac of each crop need to be planted, that means 20 total days are needed to plant both crops. Therefore, planting date in x-axis stops at 145 doy which that is the last date to start planting any of the two crops in this exercise (145+20=165 doy).

DISCUSSION

The detrimental effect of delayed planting on corn and soybean yield is well-known and was also observed in this study. Planting dates after 120 doy would result in yield reductions that reach up to 25% of maximum yield. This suggests that early planting should be a management practice exercised by farmers to protect yield and revenue and aligns with previous studies across the US (Kucharik, 2008; Edreira et al., 2017; Mourtzinis et al., 2019). Nevertheless, concurrent planting during the optimal period for both crops in every field a farmer manages is simply not possible for many farmers due to equipment and personnel availability constraints. Currently, there is no information in the literature about the effect of planting order decisions on gross farm revenue, which was the objective of this work.

Results suggest that soybean planting should be prioritized over corn if weather conditions allow for early planting (100-110 doy). Simulated yield trends due to planting delay show that soybean yield loss rate was greater than that of corn the first *c.a.* 15 days of the growing season. Therefore, prioritizing soybean planting over corn could protect from the larger relative yield loss compared to corn for the same period. However, at later dates, after 120 doy, corn yield loss rate was sharper than that of soybean. This suggests that if planting of the first crop would initiate during this period, corn planting should be prioritized over soybean.

Across the North Central US region, there is a large variability in management practices farmers use, even within the same region (Mourtzinis et al., 2018). Although optimum planting is associated with high crop yield, suboptimal background management practices can suppress yield even if planting occurred during the optimal time (Mourtzinis et al., 2021). Considering that a farmer grows two crops each year, two cropping systems need to be optimized for maximum yield. It is possible that the cropping system of one or both crops are not optimized (*e.g.,* too early or late maturing cultivars for the region or inadequate seeding rate, fertilizer etc.). Such situations can complicate and alter planting order optimal decisions. Our US-wide simulation exercise suggests that optimizing such decisions should be region-specific which further complicates this decision-making process and limits generalizable recommendations.

Results in this study reveal the importance of accounting for crop planting order when farmers have multiple fields and grow both corn and soybean in rotation. Perhaps more importantly, we show that crop planting order should not be decided without considering yield potential of both crops in each field as affected by the specific cropping systems farmers use in each field. Additionally, costs of cropping system operations and projected crop selling prices may further impact the final farm revenue. We note that in this work we used the "simple" scenario where a farmer grows the two crops in two equally sized fields without considering all possible economic parameters (variable seed and fertilizer cost etc.). However, it is common for farmers to plant multiple fields each year, with variable soil types, perhaps with more than one planter with different planting capacities, and the two crops are planted each year in unequal number of acres (*e.g.,* 65% corn and 35% soybean). Considering the aforementioned decisions farmers need to consider and all possible combinations, a near infinite number of scenarios may exist across large agricultural regions.

Here we report simulated estimates from previously developed algorithms which exhibited a high degree of accuracy. We understand that other factors not included in the algorithms (e.g., drying costs may vary due to harvest date) may affect the results to some degree and therefore, field verification is needed and would help refine the recommendations regionally. Regardless of any potential uncertainty in the estimates, associated with possible model inadequacies, this study highlights the complexity of the task and identify gaps in knowledge, existing data, and available tools to help farmers with such important decisions. As described earlier, the vast number of parameters and decisions call for the development and use of tools that go beyond the capabilities of traditional research. Data-driven knowledge, built upon years of extensive data collection efforts (Edreira et al., 2017) and validated in subsequent field trials (Andrade et al., 2022), can be a powerful alternative to traditional random-

ized trials. Use of machine learning algorithms, that can capture complex associations in high-dimensional data, can be a promising approach. Survey data and replicated field trials, designed specifically to provide data relative to this important issue, can provide high quality data that can be used to train algorithms. In turn, proper information extraction from these algorithms can provide actionable knowledge (https://coolbean.info/wp-content/uploads/sites/3/2022/12/2022_SoybeanAlgorithm_final.pdf) and further guide the design of more efficient field trials that can fill the gap of missing knowledge.

CONCLUSIONS

Optimization of field-specific cropping systems to increase a crop's yield is a complicated task that involves multiple parameters and uncertainty. Using a hypothetical scenario for a "simple" case, we showed that soybean planting should be prioritized over corn if weather conditions allow for early planting (in mid-April). Additionally, we demonstrated that farmers need to consider a vast number of parameters which affect their farm operations, productivity, and gross revenue. Currently, replicated field trials or available tools, specifically designed to address these issues, do not exist. As farming becomes more expensive due to increased input and operational costs, data-driven approaches that can further optimize the entire farming system can benefit farmers and allow for increased revenue and food production.

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