**Understanding interactions between soybean planting date and maturity across environments: development of a decision support tool**

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The soybean planting decision tool

Choosing soybean maturities and when to plant soybeans are two critical decisions that farmers make each year. Typically, soybean variety selection occurs months before soybean planting occurs. An added complexity in the decision making is the weather conditions at the time of planting. Each year farmers are faced with the decision of planting into marginal conditions or the potential of late planting. Also, spring and early season weather sometimes forces farmers to replant soybeans later than ideal planting windows. A soybean planting decision support tool is presented here with the objective to assist in better understanding planting date by maturity by location interactions on soybean yield and crop staging. The decision tool has the potential for use in Extension, teaching, and research and presently covers 11 geographic locations (Fig. 1). Within a location the user can select a soybean maturity (12 options) and a planting date (24 options) and visualize graphically the impact on yield and crop staging, as well as the optimum date of planting date and maturity group selection for maximum yields.



**Figure 1**. Coverage of the soybean planting decision tool.

Databases

Version 1 of the decision tool contains both data simulated by a model and measured data. The simulated data was generated using the APSIM soybean model (Robertson et al., 2001; Keating et al., 2003) and recently calibrated soybean varieties for the Midwest (Archontoulis et al., 2014). A combination of 11 locations in Iowa, Minnesota, and Missouri, 24 planting dates (April-5 to July-30 in 5 day increments), 12 generic soybean maturity groups (0.0 to 5.5 in 0.5 maturity group increments) and 34 historical years resulted in 107,712 simulated data points which are presented graphically by the decision tool. The generic cultivars are average cultivars and reflect an average response across a range of cultivars belonging to the same group. The measured data represent harvested soybean yields from seven Iowa State University Research Farms in 2014 (Table 1). The combination of 7 locations, 4 planting dates, 3 maturity groups and 4 replications resulted in 336 data points. Harvested yield data from ISU Research Farms are used as validation of the simulated responses of soybean yield to planting date and maturity. Additional field data will be collected and used to re-calibrate and update the decision tool. Future versions of the decision tool will be updated with additional field research data, additional geographic regions, and cultivar maturities.

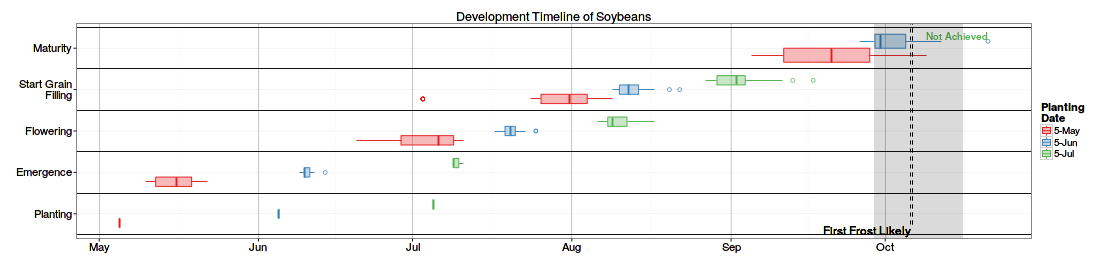
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| **Table 1:** Measured soybean data from Iowa that are included in the decision tool. | | | |
| Region | Site | Planting date | Maturity group |
| Northeast | Nashua | May 5, May 20, June 10, June 30 | 2.0, 2.5 |
| North Central | Kanawha | May 5, May 20, June 10, July 10 | 2.0, 2.5 |
| Northwest | Sutherland | May 5, May 20, June 10, July 5 | 2.0, 2.5 |
|  |  |  |  |
| Central | Ames | May 5, May 20, June 10, July 10 | 2.0, 2.5, 3.5 |
|  |  |  |  |
| Southeast | Crawfordsville | May 5, May 20, June 10, June 25 | 2.5, 3.5, 4.0 |
| South Central | Chariton | May 5, May 20, June 10, June 25 | 2.5, 3.5, 4.0 |
| Southwest | Lewis | May 5, May 20, June 5, July 5 | 2.5, 3.5, 4.0 |

How does the decision tool work?

The user can select any combination of location, planting date, or maturity and visualize maturity group selection and planting date influence on crop development and relative yield. Multi-factorial selections such as three locations and three planting dates and three maturities at the same time are not supported in version 1. Graphical illustrations of key growth stages can be viewed using box or violin plots. Graphical representation of relative yield interaction with maturity group and planting date has the option to show raw data with non-linear regressions, as well as the “optimal” planting window and maturity group for a specific location(s).The original data and prediction confidence intervals can be displayed for the user to see the range of variability that exists.

Prediction of soybean developmental stage

An important feature of the decision tool is the prediction of crop development and the occurrence of fall frost dates. The decision tool predicts date of emergence (VE; Pedersen and Licht, 2014), flowering (R1), beginning grain fill (R5), and beginning of physiological maturity (R7). The predictions refer to the date when 50% of the plants in the field have reached the stage. Figure 2 illustrates the developmental timeline of a maturity group 2.5 soybean planted on May 5th, June 5th and July 5th in central Iowa (Ames). It is noticeable from this example that as planting is delayed the risk of frost increases and the time to emergence decreases. Shorter time periods from planting to emergence results in less susceptibility to seedling and root diseases. Note that soybean requires about two additional weeks after R7 for seed drydown to reach appropriate grain moisture for harvest.



**Figure 2**. Development timeline of soybean maturity group 2.5 planted on May 5th, June 5th and July 5th in central Iowa (Ames). The decision tool output shows the 25%, median, 75% percentiles (boxplots) and the 5% and 95% percentiles (whiskers) of when emergence (VE), flowering (R1), beginning grain fill (R5) and beginning physiological maturity (R7) are likely to occur for each planting date. The frequency of the first fall frost is indicated by the gray shaded area and the median fall frost date is indicated by the vertical dashed line.

Methodology used to predict soybean development

For a detailed description of how the model calculates and predicts crop stages as well as the parameter values used in this decision tool see Archontoulis et al. (2014). Briefly, the APSIM-soybean model (Robertson et al., 2002; Keating et al., 2003) divides the soybean crop cycle into seven major phases and uses a thermal time methodology modified by photoperiod to define growth phase targets. Air temperature and photoperiod (length of daylight) are the main drivers of soybean phenology. Calculation of thermal time in the model uses a 3-hour interpolation method and a specified temperature/thermal time relationship. The base temperature for development is 50oF (10oC), the optimum is 86oF (30oC) and the maximum is 104oF (40oC). These parameters are generic for all cultivars. In contrast, the parameters describing photoperiod effects (critical [12.5–14.5 hours] and photoperiod sensitivity [0.15–0.30 hour-1]) are cultivar specific. The longer the maturity group, the more sensitive to photoperiod the plants are. In general, when soybean has entered into the photoperiod sensitive phases (floral initiation to end of grain fill; R1 to R6.5) and the daily photoperiod is above the critical photoperiod, then the phase target is increased. In other words, the crop needs more time to complete the phase. If the daily photoperiod is below the critical level, then soybean development is driven by temperature only. The ability of the APSIM soybean model to predict phenology was evaluated thoroughly by Archontoulis et al. (2014) across 280 published experimental datasets covering maturity groups from 00 to 6.0 and environments from 33oN to 46oN. The model predicted flowering and physiological maturity with a relative absolute error of about 3%. In terms of actual numbers, the model predicted flowering and physiological maturity with a root mean square error (RMSE) of 3.1d and 5.5d, respectively.

Temperature and photoperiod effects on development

To illustrate the relative importance of temperature and photoperiod on soybean development a simulation experiment was performed (Fig. 3). In this simulation, three temperature regimes (constant temperatures over the growing period of 15, 20 and 25°C) were used at three latitudes (47, 42 and 37°N) for two maturity groups (2.0 and 4.0). Different latitudes were used to generate variability in photoperiod while maturity groups have different sensitivity to photoperiod. The results show temperature has a greater impact on early vegetative development (e.g. days from planting to flowering) than photoperiod and this is more evident with the 2.0 maturity group (Fig. 3). With the 4.0 maturity group, the effect of photoperiod (e.g. latitude) was larger than that of the 2.0 maturity group, but temperature was still more important.



**Figure 3**. Days from planting to flowering for two soybean maturity groups (2.0 and 4.0) as affected by temperature and latitude with a planting date of May 5th. Horizontal green dashed lines show the time from planting to flowering using actual central Iowa, Ames, weather data (16, 21, 23, and 22oC average temperature for May, June, July and August, respectively, at 42oN latitude).

Effect of maturity group on relative yield

The most valuable piece of information for soybean growers is the economic product, grain yield. The decision tool provides the option to explore yield response to maturity group selection and planting date at eleven locations. Assuming a planting date of May 5th at three locations (Minnesota, Iowa and Missouri), the decision tool recommends a 1.0 maturity group for Minnesota, 3.0 maturity group for central Iowa and 4.5 maturity group for Missouri (Fig. 4). In addition, the peak relative yield for the three sites increases from Minnesota to Iowa to Missouri. When planting is delayed by a month from May 5th to June 5th, the decision tool automatically adjusts the maturity group selection (Fig. 4). In this example, the decision tool indicates a 0.5 to 1.0 reduction of maturity group to achieve peak yields but there is also a maturity group by location interaction from delayed planting.



**Figure 4.** Relative yield response to maturity group selection for three locations and two planting dates (top = May 5th, bottom = June 5th). The vertical dotted lines indicate the most appropriate maturity group for each location and planting date.

Relative yield response to planting date

Decision tool users can see simulated (1980 to 2013) and measured (2014) data in addition to the non-linear regression fit of the simulated data with the 95% prediction internals. In a simulation for central (Ames) and northwest (Sutherland) Iowa, the optimum planting window is wide for both locations, with an optimum to be 1st week of May for Sutherland and 2nd week of May for Ames (Fig. 5). The variability across the mean value is noticeable from the 34 historical years the model was run. On average, the relative yield for both locations with May-planted soybean was about 75% of the maximum yield attainted in these locations. The maximum yield was around 84 bu/ac for this scenario. According to the APSIM model output analysis, very early planting (April 5th to April 15th) is associated with greater yield variability due to low temperatures causing slowed emergence, growth, and development. Also, according to the 2014 field data the earliest choice for planting was May 5th but not earlier.



**Figure 5.** Relative yield response to planting date for two locations (top = Ames, bottom = Sutherland). The vertical dotted red lines indicate the optimum planting date for each location with a 2.5 maturity group selection. The non-linear regression curve (thick, red line) is a statistical fit of the simulated data (grey points). The red points represent 2014 field data.

How is relative yield calculated?

For a simple scenario where the user selects one planting date, one maturity group and one location, the relative yield is calculated as the yield of an individual year divided by the maximum yield observed during the period of 1980 to 2013. When there is a combination of maturity groups or planting dates or locations, the maximum yield found across all combinations is used as the denominator in the calculation of the relative yield. In this way, differences between treatments can be compared. In the decision tool, the soybean yields included are the simulated actual yields from the APSIM model which account for water and nitrogen limitations on crop growth. The APSIM model also simulates potential yield where water and nitrogen are not limiting crop growth. Actual yield was preferred for use in the calculation of the relative yield because is more representative of the reality. It should be noted that biotic stresses such as pest and diseases are not accounted in APSIM model simulations.

Potential yield, actual yield, and yield gap

Simulated maximum actual yields and simulated maximum potential yields were obtained for the study sites across 12 maturities and 24 planting dates are presented in Fig. 6. These yields are the maximum achieved over the period of 34 years (1980 – 2013) and should be viewed as the soybean yield upper limit that can be explained by a mechanistic model, using current technology (seeds), historical weather data, and current management practices.

Yield potential is determined by plant physiological characteristics, weather conditions, and choice of the planting date. The actual yield accounts for soil moisture and nitrogen limitations on soybean yields. Yield gaps are defined as the difference between actual and potential yield. In an effort to illustrate the magnitude of the soybean yield gap, a simulation experiment was performed for Central Iowa (Fig. 7). In this analysis 12 maturity groups were used at four planting dates and the yields were averaged over the 34 years of weather conditions. It was found that the yield gap varies from 0 to 30% in Ames and is greater at ideal planting dates or with ideal maturity groups. (e.g. 2.0 – 3.0 maturity group and mid-April to mid-May planting dates). This is because there is enough time for the plants to complete their biological cycle. When planting is delayed or a later maturity is used, the time available for plant growth is narrowed and there is not sufficient time for plant growth under potential conditions to accumulate greater yields. A longer maturity group theoretically has greater yield potential than an early maturity group. This explains why the yield gap is small at low maturity groups even if they were planted at appropriate times.

**Figure 6.** Simulated maximum actual and potential yields found across planting dates and maturity groups for 11 locations in Iowa, Minnesota and Missouri.



**Figure 7.** Simulated average actual and potential yields in Ames, Iowa from 1980 to 2013 at four planting dates and 12 maturity groups. The difference between potential and actual yield is the yield gap.

Planting date effects on crop emergence

The rule of thumb “*the earlier the planting the better*” applies to maturity groups adapted to a specific location (e.g. 2.0 to 3.5 maturity groups for Ames) up to a certain threshold date and does not cover extreme situations (e.g. very early planting). The decision tool covers a wide range of planting dates in order to evaluate the risks associated with such decisions. The base temperature for soybean growth is around 50oF (10oC; Robertson et al., 2002). The risk of planting seed in early April is very high since the number of days with temperature below 50oF the month following planting is high which translates into more days required from planting to emergence (Fig. 8). For example, a theoretical gain of 15 extra days by planting April 5th versus April 20th in central Iowa is shortened to only a 7 day difference in emergence date. Also early planting choices (before April 25) are associated with greater frost risk.



**Figure 8.** Number of days with air temperature below 50oF over the 30 days following planting (left) and simulated days from planting to emergence (right) at five regions. Each point is an average value across 34 years of data (1980–2013).

Frost Risk

Spring frost risk must be considered when selecting planting date and fall frost risk must be considered when selecting soybean maturity groups. While generally speaking, higher yield potentials can be attributed with early planting and longer maturities, reality is that frost risk and cool spring temperature bring down early planted, longer maturity soybean yields. For example, the frost risk associated with a very early planting (e.g. April 5th) is 65%, 40%, 35%, 30% and 15%, in Minnesota, northern Iowa, central Iowa, southern Iowa and Missouri, respectively (Fig. 9). Delaying planting by about 3 weeks decreases the spring frost risk to very low probabilities. Because of frost probabilities, planting early must be seriously considered to minimize the risk of crop failure due to low temperatures in the spring or killing frosts in the fall.



**Figure 9**. Probability of minimum temperature being below 29oF (frost risk) for spring (left) and fall (right) for five locations. Data points are the calculated probabilities using 34 years of weather data and lines are polynomial fits to the data (*r*2>0.99).

Crop failures

The tool has the capacity to display crop failures (i.e. relative yield being zero) due to low spring temperatures and automatically re-evaluate optimum planting date by maturity group choices. Usually crop failures are not included in the analysis of yield versus planting date because it biases the shape of the non-linear regression response curve. However, for risk analysis purposes this is important. The decision tool provides the option to include or not include crop failures in the determination of the optimum planting date. This is important, as choice of a very early planting is associated with greater frost risks. The simulated crop failures by the APSIM model are illustrated in figure 10 and clearly follow the patterns of frost risk (see previous section).



**Figure 10.** Simulated failures due to low spring temperatures by the APSIM model for three regions. Each point is the average of 34 individual years for Minnesota and Missouri. For Iowa each point is the average of 9 locations over 34 years. Lines are polynomial fits to the data.

APSIM model description

In this work, the following APSIM models were used: soybean crop model, SoilWat, SoilN, and SurfaceOM. A detailed description of all these models can be found at [www.apsim.info](http://www.apsim.info) as well as in the following publications: Keating et al. (2003) and Holzworth et al. (2014). Briefly, the APSIM-soybean crop model (Robertson et al. 2002) simulates daily crop growth rate as the minimum of two daily estimates, one limited by light (radiation use efficiency) and one limited by water (transpiration efficiency adjusted for vapor pressure deficit). The derived crop growth rate incorporates temperature, nitrogen, and soil moisture limitations. Partitioning of dry matter within the plant is phenology dependent. The crop model simulates crop phases which are driven by cultivar specific parameters (e.g. maturity group), temperature, and photoperiod values. The SoilN model simulates mineralization, immobilization, nitrification, denitrification, and urea hydrolysis at each soil layer separately. The organic matter is divided into conceptual pools each with a different decomposition rate constant. The SurfaceOM model deals with residue decomposition and affects carbon and nitrogen cycling, soil temperature and moisture.

Model availability and source code

Readers and users can freely download the APSIM simulation model as well as its source code from APSIM’s website: [www.apsim.info](http://www.apsim.info). The soybean cultivars used in the development of this decision tool are available in APSIM version 7.7 (released December 2014).

Disclaimer

By the authors: The information in the Soybean Planting Decision Tool represents current data from a working file which is updated continuously. Efforts have been made to eliminate conceptual and coding errors in the decision tool but errors may still exist and are the full responsibility of the authors. Because the decision tool is presented in an open style, errors can easily be corrected as such any comments concerning errors, functionality or suggested changes will be appreciated.

By the APSIM Initiative: to be added…..

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