

## **Agronomic Optimal Plant Density by Yield Environment in Soybean**

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### **Summary**

This research report presents a summary of a peer-reviewed publication: Carciochi W.D.; Schwalbert R.; Andrade F.H.; Corassa G.M.; Carter P.; Gaspar A.P.; Schmidt J.; Ciampitti I.A. 2019. Soybean seed yield response to plant density by yield environment in North America. *Agronomy Journal*.

Recent economic and productive circumstances have caused interest in within-field variation of the agronomic optimal plant density (AOPD) for soybean [*Glycine max* (L.) Merr.]. Thus, the objective of this study was to determine the AOPD by yield environment (YE) for soybean. During 2013 and 2014, nine site-years with a total of 78 yield-to-plant density responses were evaluated in different regions of the United States and Canada. A soybean database evaluating seeding rates ranging from 69,000–271,000 seeds/a was utilized, including the final number of plants and seed yield. The data were classified in YEs: low (LYE, <59.6 bu/a), medium (MYE, 59.6-64.1 bu/a), and high (HYE, >64.1 bu/a). The main outcomes for this study were: 1) AOPD decreased by 24% from LYE (127,000 plants/a) to HYE (97,000 plants/a); 2) greater AOPD in a LYE was not related to a low plant survival rate; and 3) cumulative precipitation during soybean reproductive growth period was 39% lower in LYE compared with MYE and HYE, possibly reducing its reproductive ability. This study presents the first attempt to investigate the seed yield-to-plant density relationship via understanding final plant establishment and by exploring the influence of weather defining soybean YEs in North America.

### **Introduction**

Soybean [*Glycine max* (L.) Merr] production costs in the United States increased approximately 50% over the past decade, with seed cost representing roughly 37% of the total production costs. In addition, seed price increased approximately 46% due to biotechnology advancements. Therefore, defining the agronomic optimal plant density (AOPD) for soybean is a critical decision for producers to optimize return on investment. The AOPD is defined as the minimum number of plants (in a per-unit-area basis) required to maximize yield. On the other hand, soybean plant density levels above the AOPD increase the risk of lodging and disease development without adding a yield benefit, reinforcing the need for defining the AOPD for this crop.

Soybean seed yield response to plant density has not shown consistent results. Recent studies proposed classifying each study in a yield environment (YE) based on its average

productivity. Therefore, a broad database comprised of studies evaluating soybean seed yield response to plant density in varying YEs could assist in providing an unbiased analysis focused at both local and regional levels. Thus, the objective of this study was to determine the AOPD by yield environment (YE) for soybean.

## Procedures

### *Data Description*

The data evaluated in the current analysis were obtained from trials performed during nine site-years in different regions of US (Illinois, Indiana, and Iowa) and Canada (Ontario) by DuPont Pioneer researchers during the 2013 and 2014 growing seasons. In each site-year, four different seeding rates were tested in 78 soybean studies and the data were evaluated looking at different yield levels (1,344 data points, Figure 1A and B). The experimental design used was a randomized complete block design (RCBD) with four to six replications (plot size 15 × 10 ft). Seeding rates ranged from 69,000–271,000 seeds/a, reaching final plant densities from 24,000 to 263,000 plants/a. All field studies were planted with 15- and/or 30-in. row spacing, managed with conventional till (chisel plowed or disked), in rainfed environments, and using relative maturities ranging from 2.8 to 4.2.

At physiological maturity seed yield was determined for each plot and adjusted to 130 g/kg moisture content. The final plant density was also determined and later used to calculate the ratio between achieved and target plant density (Figure 1C).

Weather data (precipitation, daily mean temperature, and solar radiation) were obtained for each site-year from the Climate Engine for the US and from the Government of Canada web page (<http://climate.weather.gc.ca>) for Canadian data. Weather data from each site-year were divided into approximate vegetative (involving from May to July) and reproductive (from August to October) periods. This analysis permitted a characterization of potential scenarios for early- versus late-season weather conditions for soybeans in each site-year in relation to the yield classification developed (YEs) (Figure 1B, D-F).

### *Statistical Analysis*

The average yield of each study was used to classify the dataset in different YEs. This method acknowledges that variations within a study are only due to the treatment (plant density). The kernel density distribution of yield data (average yield for each study) was divided into terciles (<33%, 33–66%, and >66%) (Figure 1B), obtaining 26 studies in each YE. Thus, low (LYE, <59.6 bu/a), medium (MYE, 59.6–64.1 bu/a), and high (HYE, >64.1 bu/a) YEs were defined.

Linear regression with plateau was implemented to quantify the soybean yield response to plant density. We used hierarchical Bayesian models, allowing us to calculate the most probable AOPD at each YE. Cumulative probability of AOPD and AOPD range to achieve the plateau for the seed yield-to-plant density relationship were calculated in each YE. In addition, the relationship between the achieved and the target plant density (seeding rate) was compared among YEs using Bayes inference. Lastly, weather data

(precipitation, daily mean temperatures, and solar radiation) were compared among YEs for vegetative and reproductive periods using Bayes inference.

## Results

For the pooled data, a seed yield response to plant density was not observed (Figure 1A). However, when the studies were classified by YE, significant yield responses to plant density occurred in the different YEs (Figure 2). For the LYE the most probable AOPD was 127,000 plants/a (Figure 2A), decreasing to 96,000 and 97,000 plants/a in the MYE (Figure 2B) and HYE (Figure 2C), respectively. This is a 24% decrease in AOPD from LYE to MYE and HYE.

Low plant densities in the LYE highly penalized seed yield. For example, at a plant density of 80 thousand plants/a in the LYE, seed yield decreased by 12% relative to the maximum yield (plateau) obtained for this YE (64.1 bu/a). Meanwhile, at the same abovementioned plant density level, seed yield only decreased by 5% for the MYE and by 4% for the HYE relative to their respective plateau yield levels for these YEs (plateau at 67 and 70 bu/a, respectively).

It was hypothesized that low plant establishment and survival in the LYE could be one of the potential factors affecting the differential yield response to seeding rate between YEs. However, the current work portrayed greater plant establishment (relative to the target seeding rate) for the LYE, with the plant density-to-target seeding rate ratio following the order from high to low: LYE>MYE>HYE (Figure 1C). Therefore, this study refutes the hypothesis that a greater seeding rate in the LYE is related to a lower plant survival rate relative to the HYE.

The exceedance probability of the AOPD at each YE (Figure 3A) showed a greater difference for the LYE compared with both MYE and HYE. For example, the maximum probability for reaching the AOPD with less than 100 thousand plants/a was 58% for both the MYE and HYE but was reduced to 17% for the LYE. Additionally, the probability analysis showed that the 50% interquartile range (between 25 and 75 quartiles) for the AOPD ranged between 109,000 and 144,000 plants/a for the LYE, 77,000 and 114,000 plants/a for the MYE, and 76,000 and 117,000 plants/a for the HYE (Figure 3B).

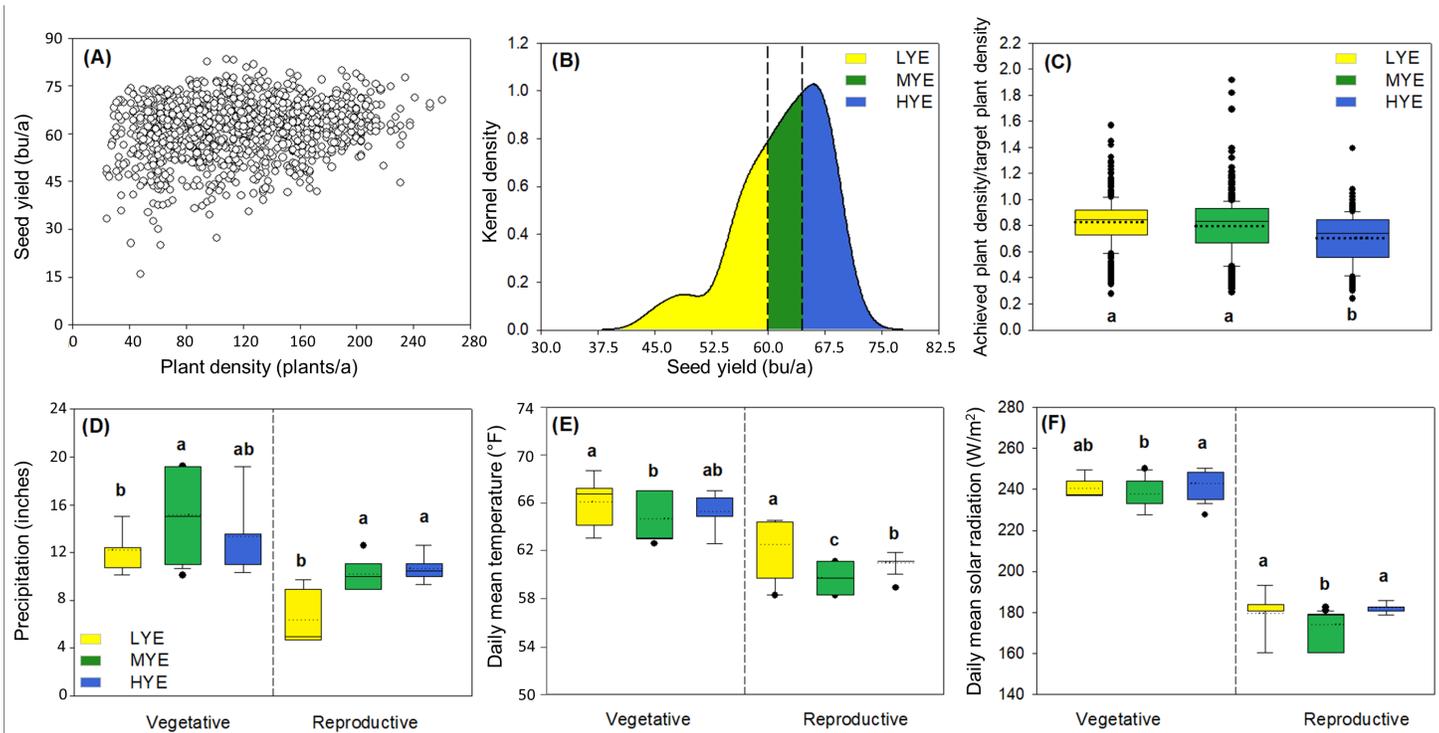
A simple analysis of the average weather conditions for the three YEs (Figure 1D-F) showed that the cumulative precipitation during the late-season soybean growth period (reproductive) was 39% lower in LYE compared with MYE and HYE (Figure 1D). Previous studies reported that drought stress during early reproductive growth stages reduced per-plant leaf area and number and length of branches, and consequently seed yield was also reduced. Moreover, average daily mean temperature for the reproductive period was 8% higher in LYE compared to MYE and HYE (Figure 1E), which could exacerbate the effect generated by the lower precipitation in the LYE.

In summary, environmental conditions (e.g., water availability, temperature, and radiation), as well as other factors such as fertility or pests, could affect soybean leaf area and branching, thus reducing crop growth rate and negatively affecting soybean's reproduc-

tive ability. Therefore, variation in environmental conditions producing different yield potential (and YEs) affects the final AOPD for soybeans.

**Conclusions**

Results of our study showed that AOPD depends on the YE so plant density could be reduced by 24% in both MYE and HYE relative to the LYE. This is valuable information for site-specific management strategies, such as variable seeding rate. Thus, within a field, yield variation could be better related to the adjustment of seeding rate for soybeans, improving both the productivity and net return for farmers. Adjusting seeding rates reduces risks of yield losses due to suboptimal densities in the LYE, while limiting higher seed costs due to supra-optimal densities, especially for MYE and HYE.



**Figure 1. Relationship between seed yield and plant density (A); density distribution of average seed yield for each study and yield environments classified by terciles (low yield environment, LYE, <59.6 bu/a; medium yield environment, MYE, 59.6-64.1 bu/a; and high yield environment, HYE, >64.1 bu/a) (B); box plots portraying the ratio between the achieved plant density and the target plant density (C); average accumulated precipitation (D); daily mean temperature (E); and daily mean solar radiation (F) for vegetative (May to July) and reproductive (August to October) periods for LYE, MYE, and HYE. The box plots portray the 5th (lower whisker), 25th (bottom edge of the box), 75th (top edge of the box), and 95th (upper whisker) percentiles. The solid line within the box represents the median, the dotted line represents the mean, and the circles referred to outliers. Different letters in the same growing period and panel indicate differences between YEs using Bayes inference.**

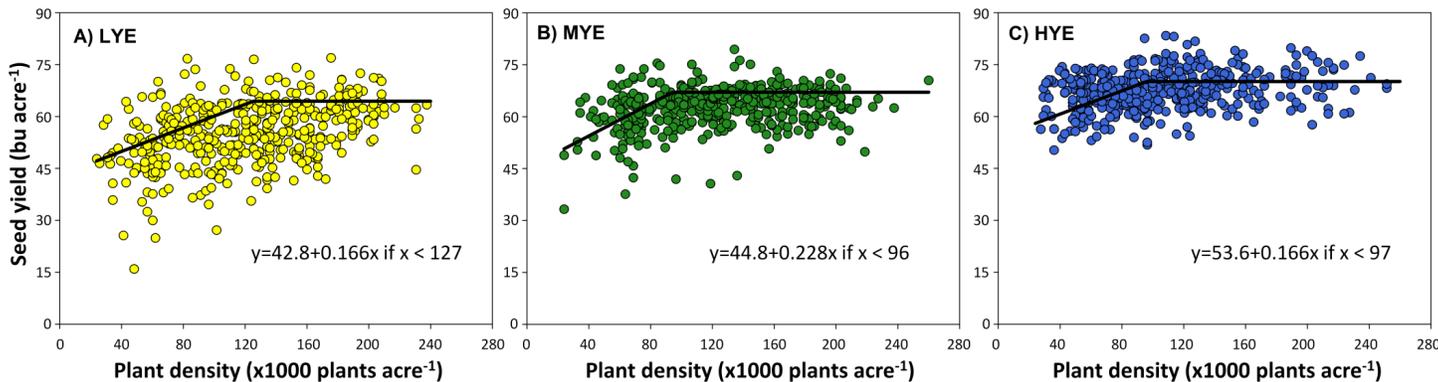


Figure 2. Relationship between seed yield and plant density for low (LYE, <59.6 bu/a; (A), medium (MYE, 59.6-64.1 bu/a; (B), and high yield environments (HYE, >64.1 bu/a; (C). Models were fitted using hierarchical Bayesian models.

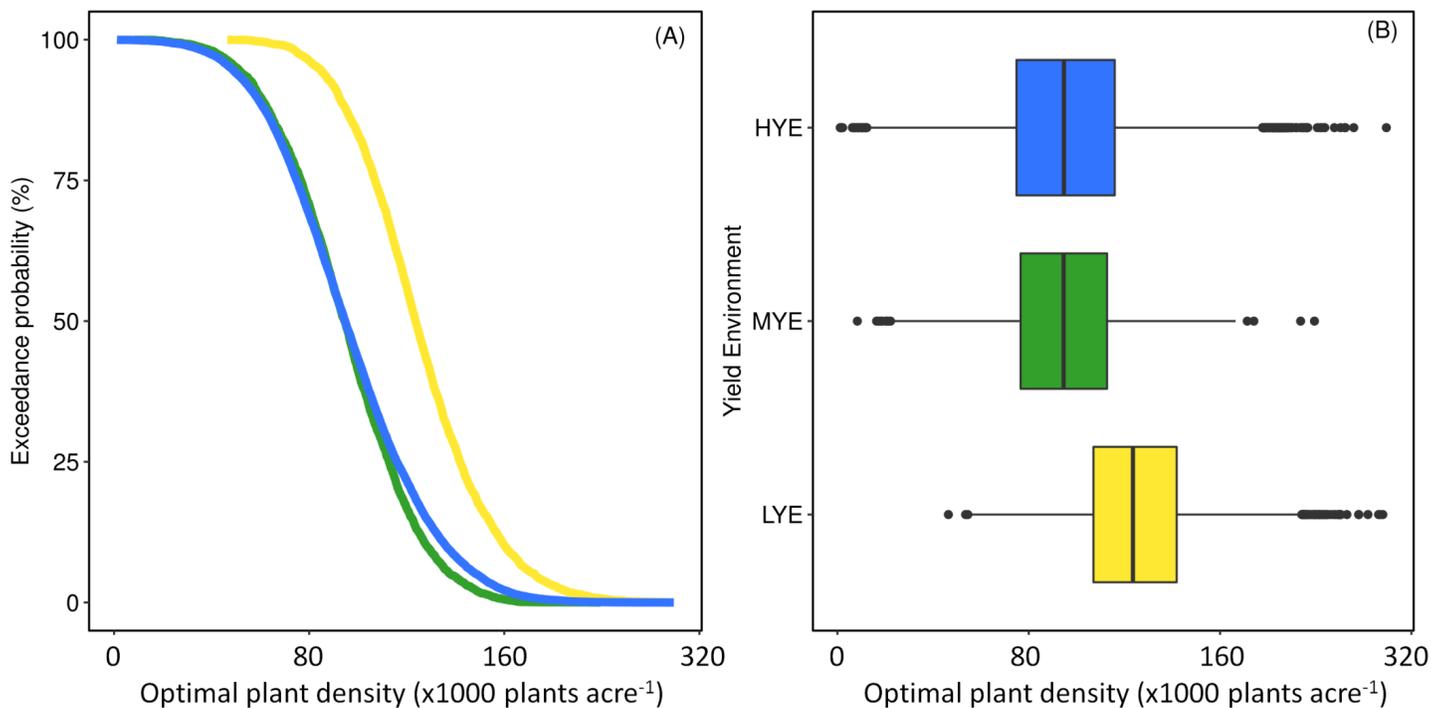


Figure 3. Exceedance probabilities (%) of agronomic optimal plant density (AOPD, plants/a) (A); and AOPD range to achieve the plateau-level for the seed yield-to-plant density relationship for the low (LYE, in yellow), medium (MYE, in green), and high yield environment (HYE, in blue) (B). For panel B, box plots portray the 25th (bottom edge of the box) and the 75th (top edge of the box). The solid line within the box represents the median and the circles referred to outliers.