**A Public-private Partnership to Use Drone-acquired Metrics to Increase Accuracy of Yield Estimation in Multi-environment Yield Trials of Soybeans**

While farmers and agronomists are well aware that canopy development is critical to yield in soybean, it had never before been quantified for selection of new soybean varieties until the Purdue soybean breeding lab, led by Dr. Katy Martin Rainey, began doing so in 2015. Quantifying soybean canopy development has been made possible with recent advances in drone technology (or unmanned aerial systems; UAS). To accelerate the impact of precision phenotyping technology on farmers, we sought to extend our capabilities to seed companies, so for this project, we established a public-private partnership with Beck's Hybrids. Our objectives were to 1- Test the efficacy of image-based parameters acquired with drones to increase the accuracy of yield estimation in multi-environment yield trials of soybeans; 2- Develop methods to determine custom plant populations for all soybean varieties using UAS imagery.

**Objective 1:**

One our goals was to use UAS canopy measurements to increase the accuracy of yield estimation in Beck's replicated soybean yield trials, with a focus on measuring canopy development in advanced lines that are being considered for sale to farmers as varieties. The idea is that any yield trial has a margin of error that we can improve with UAS data. In 2017 and 2018, we have conducted 27 flights over Beck's on-farm research trials (MG 2 - 3.9) in Remington and Lafayette, IN, acquiring hundreds of RBG images each flight. We completed automatic extraction of plot images of equal pixel dimensions from drone imagery of each plot, including quantification of canopy coverage (CC) and two values for row length (RL). The first around 40 days after planting (DAP; RL_early) and the second around 60 DAP (RL_late). We fitted a logistic growth curve for the CC data to calculate average canopy coverage (ACC), ranging from 20 to 80 DAP. We also computed the average growth rate (Av_GR) and maximum growth rate (Max_GR) using the fitted CC. Beck's has shared yield data for both locations and both years, as well as their yield raking for all their test location in Indiana (Bourbon, New Haven, Atlanta, and Greensburg). Becks divided the trials in conventional lines MG-2.4-2.9

(C2429), MG-3.0-3.4 (C3034) and MG-3.5-3.9 (C3539). We conduct statistical analysis combining both locations (Lafayette and Remington) using a base model for randomized complete block design and included the image-based parameters as a covariate in this base model one by one to test their efficiency to improve yield estimates compared with the Indiana location rankings. We also included a yield spatial adjustment covariate (SPC_yield) to the model alone and in combination with all image-based parameters. The analyses were done by 2017 and 2018 separately and combined.

As expected, there were changes in the line's rankings between the different models in all the trials. Table 1 summarizes the best model for each trial in 2017, 2018 and combining years analysis based on ranking correlation with the Indiana locations. Ranking correlations coefficient of 1 means that both rankings are the same, so the closest the coefficient is to 1 more similar are the rankings. For all trials adding an image-based parameter covariate improved the ranking correlation with Indiana locations when compared with the base model. This indicates that image-based parameters can improve the accuracy of yield estimation in advanced yield trials. For trial C3034 combined analysis the ranking correlation coefficient was 0.89, indicating that using only two locations of yield data complemented with row length at 60 DAP resulted in almost 90% of similarly with the multi-environment trial. In this case, the breeder can reevaluate the return on investment of testing extra location beside Remington and Lafayette.

*Table 1: Summary of the best model based on ranking correlations (in parenthesis) for all trials. ACC: Average canopy coverage; SPC_yield: Yield spatial adjustment covariate; RL_late: Row length late; RL_early: Row length early; Av_GR: Average growth rate.*

| Year | C2429 | C3034 | C3539 |
|---|---|---|---|
| **2017** | ACC + SPC_yield (0.38) | RL_early and RL_late (0.48) | ACC + SPC_yield (0.68) |
| **2018** | Av_GR (0.67) | RL_late (0.76) | ACC + SPC_yield and RL_early + SPC_yield (0.55) |
| **Combined** | RL_early (0.48) | RL_late (0.89) | Av_GR (0.73) |

We believe drones can reduce error and improve efficiency so that better products may come to market more quickly. Our results show that there is potential to make drone RGB images a standard procedure in breeding trials, as it can be used to improve yield estimates. Further studies are necessary to narrow down to one or two parameters that are consistently improving yield estimations in any given trial.

**Objective 2:**

During 2017 and 2018 a set of experiments evaluating the effect of seeding rates and planting dates in five different soybean cultivars were carried out at the Purdue's Agronomy Center for Research and Education (ACRE). The main goal of this study was to evaluate the feasibility of establishing customized seeding rates for soybean based on canopy development parameters monitored through drone imagery. In 2017, three seeding rates were considered: 60,000; 110,000; and 160,000 seeds per acre, while in 2018 the study was expanded to five seeding rates: 50,000; 100,000; 150,000; 200,000; and 250,000 seeds per acre. The five cultivars considered in this study correspond to BECKS-338L4, BECKS-314L4, BECKS-3091X2, BECKS-3353X2, and BECKS-315R4. Remote imagery collected each ~12 days through a UAS were used to track the canopy cover (CC) dynamic during the growing season.

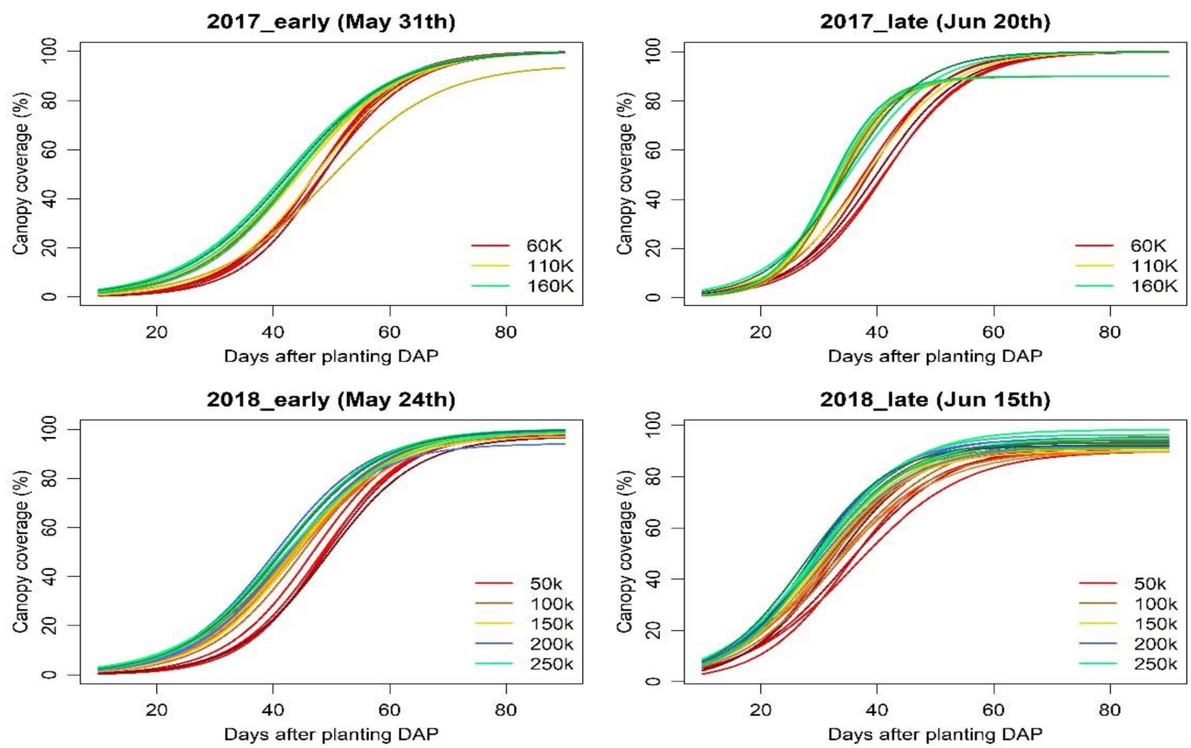


*Figure 1: Canopy coverage (CC) dynamic in soybean as a function of seeding rate and planting date*

Results indicate seeding rate and planting date influence the CC regardless of the cultivar selected (Figure 1). Although retraced planting induced 1.5% faster canopy development per every 10 days of delay, late planting yielded 5-25% less than earlier sowing. Planting 100,000 extra seeds per ACRE in early dates (May) increases the CC measured at 30 DAP in 7-11%, while the same increase in seeding rate in late planting represents an improvement in CC 30 DAP of 11-13%. Seeding rates lower than 100,000 seeds/acre are not recommendable since they yielded consistently 10-20% less than seeding rate in the range 100,000 to 200,000 seeds/acre. Likewise, seeding rate higher than 200,000 seed/acre did not show a clear advantage in canopy coverage or yield in this study. The range between 100,000-150,000 seeds/acre promoted an optimum canopy development to strongly compete with weeds, without limiting high yields.