CROP INSIGHTS

Understanding and Increasing Soybean Yields

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Summary

- An understanding of the main factors influencing grain yield in soybean can provide key insights for making management decisions to increase yield.
- Seed number is determined by the amount of photosynthate produced between R1 and R5 that is allocated to the seeds, divided by the minimum amount of photosynthate needed to keep a single seed from aborting.
- Stresses or improvements in crop growth prior to flowering should not have a significant impact on final yield, provided that >95% light interception is achieved by R1.
- Seed weight is determined by the seed growth rate and the length of the seed fill period.
- Simplified, soybean yield is mainly determined by photosynthate production from R1 to R5 and the length of the seed fill period.
- Management practices should focus on maximizing photosynthate production during seed set to increase seed number and limiting stresses during seed fill to extend the seed fill duration and increase seed weight.

Introduction

Soybean yields in the United States have increased over time up to an average of 48 bu/acre in 2015. Yet, soybean yields up to 160 bu/acre have been reported in yield contests. In order to make sound management decisions that will continue to increase soybean yields, it is crucial to first understand the factors involved with grain yield determination in soybean.

Seed Number Determination

Yield is determined by the number of seeds per acre and the final seed weight. Of the two, seed number has the greatest impact on final soybean yield. Seed number is a function of the plants per acre, pods per plant, and seeds per pod. The maximum number of seeds per pod, or prevalence of 4-bean pods, is largely determined by genetics. The number of pods per plant varies drastically with the number of plants per acre and plant to plant spacing. As such, it is difficult to focus on just one component of seed number, and it is better to think of this yield component as the total number of seeds or pods per acre.

Physiologically, soybean is considered to be source limited. This assumes that a soybean plant has an inherent ability to consistently make more yield (sink) than the environment allows. This is evident by the presence of flower abortion, which still occurs at 20 to 50% even with the highest yielding crops. Because of this, a soybean crop will adjust its yield potential to match the growing conditions. Thus, seed number (per acre) determination can be simply viewed as the crop setting as many seeds as it can support. If the crop produces more photosynthate (source), it will produce more yield (sink), and the amount of photosynthate produced is what determines yield potential.

More specifically, seed number determination is closely related to photosynthate production from R1 (first flower) to R5 (beginning seed) (Van Roekel et al., 2015). Whether a pod is set or the flower is aborted depends upon if there is sufficient photosynthate available to support the demand of the developing pod and seeds. Good growing conditions during this timeframe result in more photosynthate production and more pods will be set.

The photosynthate demand of a developing seed is related to that seed's growth rate. Larger seeds usually have higher seed growth rates and higher photosynthetic demands to prevent seed abortion. However, given equal photosynthetic rates and reproductive partitioning, a large seeded variety can still produce the same amount of final grain weight as a smaller seeded variety; it will just have fewer seeds per acre. This can be visualized with Figure 1: if the big block of photosynthate is the same size but the small block of photosynthate needed per seed is bigger, you cannot divide the big block into as many small blocks to support seeds. Similarly, varieties with more seeds per pod (more 4-bean pods) will have higher photosynthate requirements per pod and often have fewer pods, but the final number of seeds per acre is usually the same.

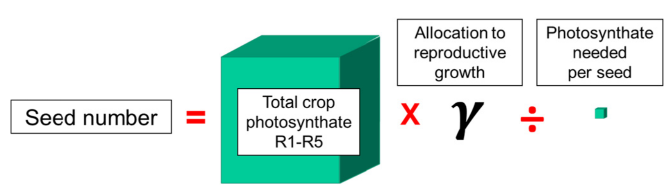

Figure 1. Total seed number is a function of the amount of photosynthate production from R1 to R5 that is allocated to reproductive growth divided by the minimum amount of photosynthate required by a seed.

Seed Weight Determination

Seed weight is a function of the seed growth rate and the length of the seed fill period (Figure 2; Van Roekel et al., 2015). As stated before, the seed growth rate is related to seed size. This is genetically controlled and generally stable throughout seed fill. Favorable late-season temperatures and rainfall can create larger seed weight by extending the seed fill duration, which does not impact seed number. Conversely, a severe late-season drought or disease like sudden death syndrome can terminate the seed fill period prematurely and reduce seed size.

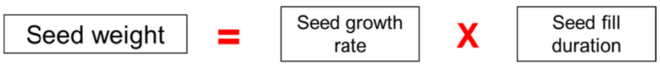

Figure 2. Final seed weight is a function of the rate of seed growth and the duration of the seed fill period.

Grain Yield Determination

When both equations for seed number and seed weight are combined, seed growth rates can be removed to simplify the equation. Also, the proportion of photosynthate allocated to reproductive growth is largely out of our control and can be essentially ignored. As such, the major physiological processes for determining final grain yield in soybean are the amount of photosynthate produced from R1 to R5 and the length of the seed fill duration (Figure 3).

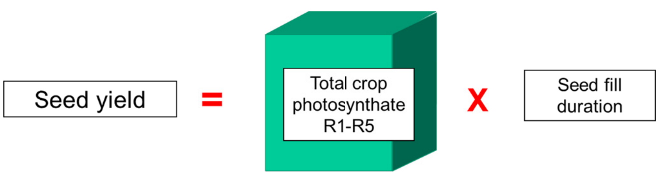

Figure 3. The main factors affecting final yield in soybean are the amount of photosynthate produced from R1 to R5 and the length of the seed fill duration.

Management Implications

While yield determination in soybean can be reduced down to this simple concept, the factors affecting crop growth and photosynthate production during these long reproductive periods are extremely complex. Maximizing yield depends upon alleviating all stresses throughout the entirety of reproductive development.

Prior to flowering, stresses do not have a large impact on final yield, provided that the stress did not severely stunt the plants. It is critical to close the rows and have >95% light interception by the beginning of flowering to maximize photosynthate production. This will often require a row spacing <30 inches.

Early planting and/or warm spring temperatures can induce earlier flowering and extend the flowering period. Soybeans initiate flowering based upon the interaction of daylength and heat unit accumulation (Lawn and James, 2011). Shorter daylengths hasten development. This can be observed with research from southern Pennsylvania in 2015 where shorter daylengths with both very early and very late planting reduced the growing degree units (GDUs) required to reach R1 (Table 1).

Parker et al. (2016) showed that soybean planted on April 15^{th} would begin flowering on June 4^{th}, while May 11^{th} planted soybean did not flower until June 30^{th} after the summer solstice and when days begin to shorten (Figure 4). Longer daylengths extend reproductive development. This is evident by the longer R1 to R6 period with earlier planting (Table 1; Figure 4). Greater GDU and solar radiation accumulation from R1 to R6 have the potential to increase photosynthate production and thus, seed number and yield.

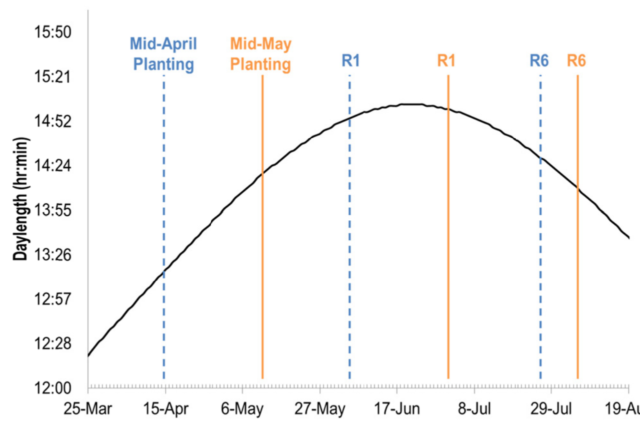

Figure 4. Daylengths during the spring and summer growing season for Pittsburg, PA, (40.4° N) with example planting, R1, and R6 dates from Parker et al. (2016).

Table 1. The duration and GDU accumulation of vegetative and reproductive growth periods for soybean maturities Late II to Mid III from Parker et al. (2016).

Planting Date	Days to R1	GDUs to R1	Days R1 to R6	GDUs R1 to R6
4/15/15	50	768	52	1198
5/4/15	41	805	45	1032
5/9/15	40	821	38	859
5/11/15	41	861	37	836
6/11/15	34	851	28	836
7/7/15	28	759	26	609

Full season varieties can have longer vegetative and reproductive periods and often have greater yield potential when planted early compared to short season varieties. In the Mid-South, short season varieties can be planted too early and have later optimum planting dates compared to fuller season varieties (Poston and Jeschke, 2015; Salmerón et al., 2016). Further north, short season varieties can be planted later with less associated yield loss (Nafziger and Vossenkemper, 2015). In both scenarios, planting full season varieties first will maximize yield potential.

After planting, growing conditions throughout reproductive development will have the greatest influence on final yield. Both too much and not enough water can have a large impact on photosynthesis and crop growth. Fertility and pH must also allow for optimal crop growth rates. This should be managed according to soil and plant analyses in conjunction with the yield goal and calculated crop demands.

While weed control is important, herbicide applications during reproductive growth should be avoided due to the potential for reduced photosynthate production and seed number. This is especially true if the herbicide causes plant injury (Kyle, 2014). In-season management of insects and diseases are also crucial to limit their impact on crop growth and yield.

All of the aforementioned practices and any others should focus on achieving optimal growing conditions from R1 through R7 to maximize photosynthate production during seed set and to lengthen the seed fill period in order to maximize yield.

Conclusions

This physiological framework for grain yield determination in soybean provides a guide for understanding the effect of management practices and growing conditions on final yield. Stresses or gains in crop growth prior to R1 are not likely to have a large impact on final yield as long as full canopy closure occurs by flowering. Factors influencing photosynthate production during the period from R1 to R5 will have a significant impact on final seed number and yield. The following seed fill period from R6 to R7 will have a major impact on seed weight, which will also influence yield. This understanding of how yield is determined in soybean is the crucial first step in making management decisions for sustainable yield increases over time.

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