Photo courtesy of the United Soybean Board.

FEATURES

Record-Setting Soybeans: What CCAs Should Know

By Susan Winsor

What can we learn from soybean yield contest winners? Larry Purcell, University of Arkansas, has some answers based on three years of documenting how Kip Cullers, Stark City, MO, grew 160.6-bu/ac soybeans in 2010 and 139 bu/ac previously. This article addresses the controversy of adding nitrogen (N) fertilizers to soybeans, as some yield contest winners are assumed to have done, and identifies some of Cullers' important practices to increase yields and profits for more mainstream soybean growers. In addition, we examine the profitability of yield-increasing practices as verified by 60 site-years of data. Earn 0.5 CEUs in Crop Management by reading this article and taking the quiz at www.certifiedcropadviser.org/education/classroom/classes/1000.

DOI: 10.1002/crso.20130

What can we learn from soybean yield contest winners? Larry Purcell has some answers based on three years of documenting how Kip Cullers, Stark City, MO, grew 160.6-bu/ac soybeans in 2010 and 139 bu/ac previously. Purcell is a University of Arkansas soybean physiologist, Distinguished Professor of Crop Physiology, and Altheimer Chair for Soybean Research.

While recent soybean yield king Randy Dowdy, Pavo, GA, has since raised 190 bu/ac contest soybeans in 2019, there's no record of a soybean researcher independently assessing how he accomplished that yield.

Purcell replicated some of Cullers' agronomic practices on campus plots. The highest soybean yields he attained reproducing some of Cullers' practices were 118 bu/ac. He did not access every last detail of Cullers' practices but focused for three years on major variables, especially light interception.

This article addresses the controversy of adding nitrogen (N) fertilizers to soybeans, as some yield contest winners are assumed to have done, and identifies some of Cullers' important practices to increase yields and profits for more mainstream soybean growers. In addition, we examine the profitability of yield-increasing practices as verified by 60 site-years of data (see https://bit.ly/2SsbSjz).

Nix Nitrogen

Soybean nodules fix enough atmospheric N_2 to produce about 80–85 bu/ac soybeans, Purcell says. "If you apply N, it shuts down soybean N fixation. I don't know any way to apply N without shutting down N fixation."

Less than 10% of Cullers' soil N was derived from fixation, Purcell says. "We assume that most of his N came from mineralization of chicken litter; it may have accumulated during previous seasons, or from this year's application, there was no way to know. But it didn't come from N fixation," Purcell says. He used non-radioactive isotopes of N to determine Cullers' N forms. Cullers applies a lot of chicken litter—about 500 lb N/ac—to achieve 100 bu/ac soybean yields.

"Soybean yield responses to N fertilizer are very small and very unpredictable," says Seth Naeve, University of Minnesota Extension soybean agronomist who is part of a soybean agronomist team comprising the North Central Soybean Research Program. "Adding any N is unlikely to increase yield much," he adds. "So, there is no support from an economic standpoint for N application. Even with very high soybean market prices, it takes a large yield response to N to pay for itself. If N is $0.50/lb, 500 lb/ac amounts to $250. That takes 20 bu/ac of yield to recoup added N cost."

Poultry litter application is a key management practice of soybean yield winner, Kip Cullers. He applies a lot of it—about 500 lb N/ac—to achieve 100 bu/ac soybean yields. Photo by H. Tewolde (not associated with Cullers' field—originally submitted with this *Soil Science Society of America Journal* article: https://doi.org/10.1002/saj2.20184).

Shawn Conley, University of Wisconsin–Madison professor and Extension soybean and small-grain specialist and the North Central Soybean Research Program soybean agronomist, and 12 other university agronomists participated in a large collaborative research SOYA project to investigate a high-input system's impact on soybean yield and profitability (see https://bit.ly/3x3gCLO). They tested agronomic practices in 20 field locations in nine states and found 90% of high-yield practices to be unprofitable, even at $15/bu soybean prices and 75 bu/ac yields.

Although high-input management systems increased yield, the probability of breaking even was less than 10% for the yield and sale price combinations analyzed.

However unprofitable, high-input management systems significantly increased average *yield* in Iowa, Illinois, Indiana, Michigan,

Evaluating Input-Intensive Management Systems

In Table 1, the three right-hand columns tell you what percent chance you have of breaking even in three different yield categories (i.e., agronomic efficiency environment) and soybean market price by input (left-hand column). This high-yield soybean study investigated inputs' impact on yield and profits, including seed treatments; growth promoters; defoliant; soil-applied N; foliar fertilizer; N,N'-diformyl urea; foliar fungicide; and foliar insecticide. These individual inputs, as well as several high-input systems, were evaluated against university recommendations for fertilizer and weed control programs, narrow spacing (≤20 inches), optimal planting dates, and a seeding rate of 175,000 seeds/ac. The average yield for the standard practice in the Central region (Illinois, Indiana, and Iowa) across three years was 60.1 bu/ac.

Growers in the Mid-South and lower Midwest are unlikely to see positive economic returns from prophylactic use of high-input systems, especially in the absence of pest pressure, the study concludes. "Growers should ensure that basic agronomic practices, such as adequate seeding rates, adapted cultivars, proper soil fertility, and IPM principles are optimized and should not expect dramatic profitability and yield increases solely from additional inputs," the study concludes. Details are at https://bit.ly/3x3gCLO.

TABLE 1. Percent relative yield change and break-even probabilities for input treatments compared with the standard practice at multiple yield levels and soybean sale prices for studies across the Central region (Illinois, Indiana, and Iowa) between 2012 and 2014. Average yield for the standard practice in the region across all three years of the experiment was 60.1 bu/ac. Source: "Using High-Input Systems for Soybean Management Increases Yield but Not Profitability" (see https://bit.ly/3x3gCLO).

			Yield level								
			45 bu/ac			60 bu/ac			75 bu/ac		
			Soybean sale price								
Input	Cost ($/ac)	RYC (%)[a]	$9	$12	$15	$9	$12	$15	$9	$12	$15
			% probability of break-even								
Fungicide ST	$8.75	−0.5	9	16	21	16	23	28	21	28	32
Fungicide + insecticide ST	$21.25	0.5	0	1	2	1	3	6	2	6	10
Max ST	$24.25	−0.5	0	0	1	0	1	2	1	2	5
Foliar fertilizer	$19.00	−0.7	0	1	2	1	3	5	2	5	9
Defoliant (D)	$18.11	−4.7	0	0	0	0	0	0	0	0	0
Nitrogen fertilizer(N)	$44.22	1.2	0	0	0	0	0	2	0	2	6
N,N'-diformyl urea	$20.80	−0.2	0	1	2	1	3	7	2	7	11
Foliar fungicide (FF)	$38.90	2.5	0	0	2	0	4	13	2	13	28
Foliar insecticide (FI)	$13.79	1.5	19	37	49	37	53	62	49	62	69
Foliar fungicide + insecticide	$44.69	3.5	0	0	3	0	6	22	3	22	43
SOYA[b]	$152.96	5.2	0	0	0	0	0	0	0	0	0
SOYA + D	$171.07	3.2	0	0	0	0	0	0	0	0	0
SOYA - N	$108.74	3.5	0	0	0	0	0	0	0	0	0
SOYA - FF	$114.06	2.7	0	0	0	0	0	0	0	0	0
SOYA - FF and FI	$108.27	2.7	0	0	0	0	0	0	0	0	0

[a]RYC, percent relative yield change compared with the standard practice. Average yield for the standard practice in this region was 60.1 bu/ac.
[b]SOYA, high-input treatment consisting of the max ST, nitrogen fertilizer, foliar fertilizer, N,N'-diformyl urea, foliar fungicide, and foliar insecticide.

Minnesota, Wisconsin; but not in Arkansas, Kansas, and Kentucky.

The Big Picture

"High-yielding soybean practices should maximize sugars made during photosynthesis at seed set. This increases seed number and extends seed fill duration and seed weight," Purcell says. "The amount of sugars made during photosynthesis heavily determines yield potential."

The SOYA study researchers also identified "cultivar, moisture, row spacing, and soil fertility as likely yield key drivers."

Combined with Purcell's findings from Cullers, here is what they validated as being economically and agronomically effective:

Variety Selection

"Cullers uses indeterminant Group IV varieties tested on his farm to see which thrive in his conditions," Purcell says.

Minnesota's Naeve adds, "Typically, the best-yielding varieties produce between 20 and 40% greater yields than those at the bottom."

Seed Number, Weight Determine Yield

Soybean yield is determined by seed number and weight, Purcell says. "Seed number is determined during growth stages R1 to R5. Seed weight is determined by the length of stages R5 to R7. All practices should achieve optimal growing conditions from R1 to R7 to maximize sugar production from photosynthesis during seed set and to lengthen the seed-fill period in order to maximize yield.

"Stresses or gain in crop growth before R1 aren't likely to have a large impact on final yield as long as full canopy closure occurs by flowering," he says. "You want to increase the flowering period, capture that extended photoperiod at summer solstice, which results from planting early, about when you typically plant corn."

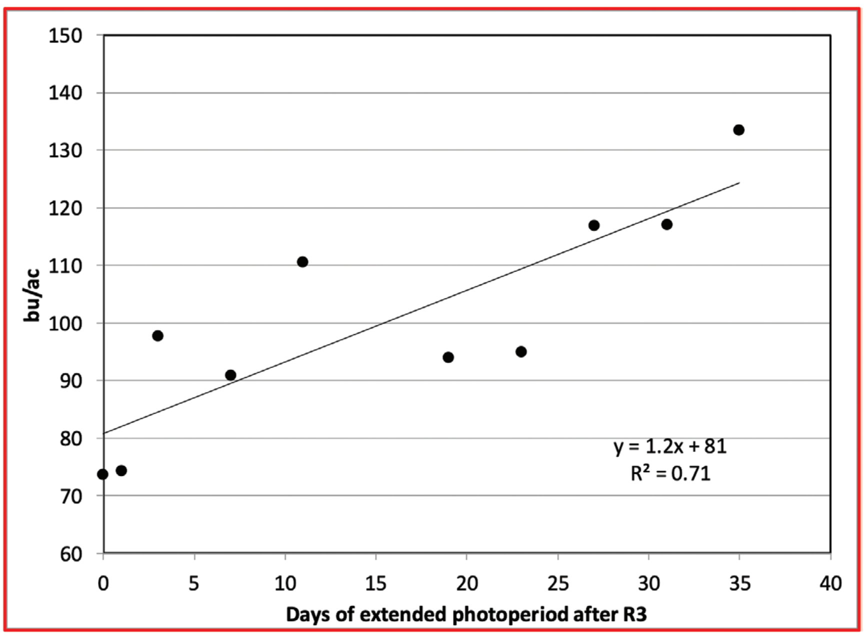
Much of Purcell's research on Cullers involved light interception. "Light is not a limiting factor for most Midwest soybean growers," he says. "We could maximize soybean yield with half the normal amount of light available during the summer in the Mid-South."

"It's critical to completely close the soybean canopy and have more than 95% light interception by the beginning of flowering," Purcell adds. "This intercepts more energy to produce more seeds and pods from photosynthesis. It often requires row spacing below 30 inches."

Naeve adds, "Canopy closure by R1 is ideal, but regions north of southern Iowa can't get there. Farther north, light interception and water limitations are equal yield limiters.

"Because light interception is so vital, narrow rows and early planting are key. You can expect approximately a 5% yield advantage for every 10 inches of narrowing, down to about 10 inches," he says. "The seed-to-seed distance is greater in narrow rows, there is less competition, and they allow higher final stands at any given seeding rate. However, seeding rate does not interact with row spacing—do not change seeding rate when you change row spacing, assuming the same planting equipment."

Fields with a history of white mold may still be planted in narrow rows, but populations should be managed carefully, Naeve says. In the SOYA high-yield research project, narrow row



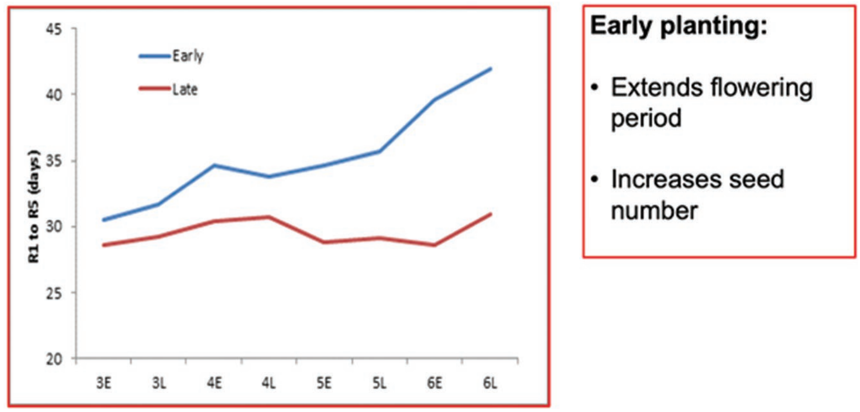
Soybean yield (vertical axis) increases with longer day length after growth stage R3 (horizontal axis). Planting early allows growers to extend the flowering period and increase yield. Kantolic & Slafter (2007; https://doi.org/10.1093/aob/mcm033) extended the photoperiod by two hours from 1 to 35 days after R3 (horizontal axis) using low-wattage, incandescent lamps. These lamps did not provide enough light energy to appreciably increase photosynthesis, but they were effective in extending the flowering period. The extended flowering period resulted in large yield increases. Data redrawn from Kantolic and Slafter (2007; see https://doi.org/10.1093/aob/mcm033).

spacing (20 inches and below) produced the highest yields.

Cullers had a plant population of 140,000/ac planted on 9-inch twin rows on 30-inch centers, Purcell says. "That planting arrangement allows more equidistant spacing."

Optimize Seeding Rates

The most profitable seeding rates vary by region and agronomic productivity category and are driven by variation in seed costs, grain prices, seed treatment use, and most importantly, your environment's productivity. You can identify your optimized rates by referring to "Agronomically Optimal Soybean Seeding Rates and Associated Risk across North America" (https://bit.ly/3jskbar).



Early planting extends the flowering period (blue line) compared with late planting (red line). 3E is Maturity Group 3 early, 3L is Maturity Group late, etc. Extended flowering period correlates with higher yields (seed number and seed weight). Source: Larry Purcell.

The optimal seeding rate average representing all of the Midwest and Canadian soybean growing areas is 179,000 seeds/ac for low-yielding environments and 150,000 seeds/ac for medium-yielding environments. The supporting research was done by a collaboration of 14 respected soybean agronomists spanning seven years in 211 field locations.

In a seeding-rate study, researchers found that soybean was able to adjust to a wide range of plant populations. Soybean plants in low populations will produce more branches, more pods, and more seeds per plant. Soybean at higher populations will grow taller and produce fewer branches, pods, and seeds per plant. Because of this flexibility, soybeans can often produce similar seed numbers per acre and similar yields over a wide range of plant populations.

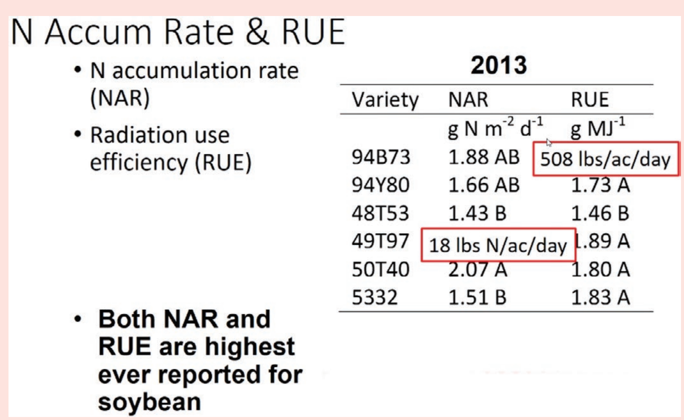
"Growers should increase seeding rates in less productive environments and decrease seeding rates in highly productive environments. These seeding-rate adjustments are more likely to be effective in the northern Corn Belt than in southern environments," the authors of the study wrote. "There was considerably more downside risk and potential yield loss with a decrease in seeding rate below the average optimal seeding rate than upside potential with an equivalent increase above the average optimal seeding rate."

Nitrogen Accumulation Rate and Radiation Use Efficiency

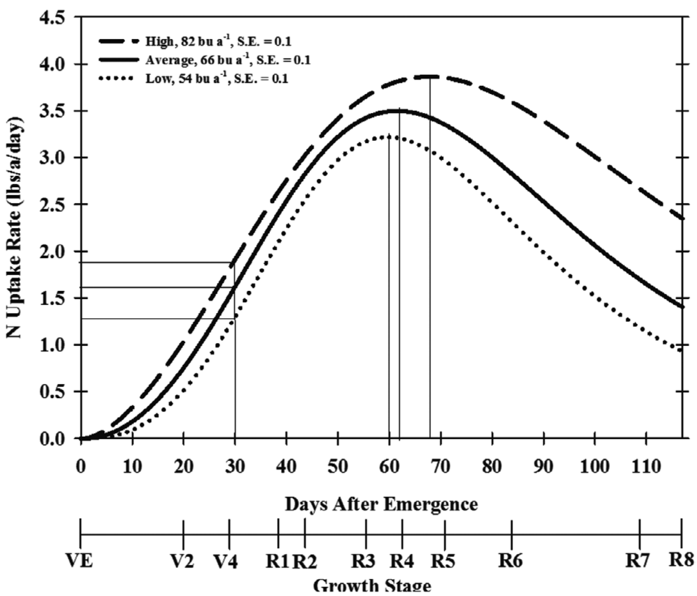
Soybean yield winner Kip Cullers' N accumulation rate (NAR) and radiation use efficiency (RUE), or photosynthesis, are higher than have ever been previously reported. "Typical RUE values under optimum conditions range between 0.8 and 1.0 g/MJ," says Larry Purcell, University of Arkansas soybean physiologist who studied this for three years. "Most researchers who've studied this would say that a high rate of N accumulation is 1 g N/m^2 per day; This comes out to be 8.9 lb N/ac per day. Compare this to Cullers' where we found N accumulation rates as high as 18 lb N/ac per day.

"The highest RUE rate (right-hand column) that I remember ever seeing is 1.2 g/MJ of intercepted light, and Cullers' comes out to equal around 1.5–1.8, or 508 lb/ac per day," Purcell says.

Purcell found Cullers' N to be mineralized N, not fixed from atmospheric N. Less than 10% of N was derived from N fixation.



Courtesy of Larry Purcell (source: *Crop Science* study by Van Roekel & Purcell, 2014, https://bit.ly/3jmoOT0).



Soybeans' N uptake peaks 60–70 days after emergence, or R3–R4, at 3-3.5 lb N/day. But N fixation is the only cost-effective way to provide that N, researchers found, because applying synthetic N shuts down all fixation. Source: University of Wisconsin.

Specific optimal seeding rates across an individual field's zones or between fields also depends upon weed control, white mold, iron deficiency chlorosis, grower risk tolerance, and seed costs.

Evaluate Soil Test Results

"Carefully evaluate soil test results," Minnesota's Naeve says. "Soybeans can typically utilize residual P and K from a well-fertilized previous corn crop, but if you're unsure about fertility levels, soil-test in the spring. Once planted, it's too late to fix deficiencies."

High applications of P and K to attain record-setting soybean yields are unaffordable practices for mainstream farmers, Naeve adds. "160 to 200 bu/ac soybeans would require a lot of P and K. A yield-contest farmer wouldn't apply 1,000 lb/ac (what is assumed to be Dowdy's approximate N application rate) without adding lots of P and K. That rate is cost prohibitive."

Besides being financially unsustainable, high rates of N, P, and K for record-breaking soybean yields "clearly have huge environmental issues," Naeve says.

Planting Early and for Even, Fast Seed Emergence

"Early planting is a huge focus for Cullers," Purcell says. Also, Cullers wants all of his seeds to emerge in 24 hours. "Soybeans don't have a planting depth requirement," Naeve says. "I'm a proponent of relatively shallow planting depth to get them out of the ground. Even a half-inch is good if there's rain in the forecast."

Seed–Soil Contact

"Pay attention to seed-to-soil contact, especially following high-residue corn," Naeve adds. "In that case, plant more deeply to ensure the seed reaches a soil substrate and not residue."

Never Let the Crop Stress

Cullers is adamant about never letting the crop stress. This includes soil moisture deficits and weed and disease pressure, Purcell says.

With regards to moisture, Cullers has a small pivot on his contest field fertigating and cooling the crop throughout the season, Purcell says. "He irrigates a tremendous amount to keep the crop cool, but it also creates an ideal environment for disease, and that might be why he focuses on fungicide use.

"It generally takes about 25 inches of annual moisture to produce a 100-bu soybean crop."

Excellent well-drained silt loam soils are also part of Cullers' success, Purcell says.

Weeds should be killed early. "Two-inch pigweed is way too long to wait before spraying," Purcell says.

Don't trust a post-emergence-only herbicide program, Naeve says. Including pre-emergence herbicides into a larger weed management strategy provides a wider window for mid-season applications and allows more control options. Use herbicides with diverse modes of action.

Inputs

"Input timing is at least as important as which inputs and their rates," Cullers says.

Cullers applies ample amounts of chicken litter before the season. Purcell speculates that it's slow-release N, high P and micronutrient content, and unidentified biologic characteristics that all contribute to Cullers' soybean yields. "At high levels, chicken litter adds some organic matter, containing biological microbes. I don't know that anyone's ever really tested it yet, but it does seem to be magic stuff," Purcell says.

Soybean inoculants aren't necessary if you plant soybeans at least every three years, Purcell says.

Purcell was unable to replicate the benefits of an herbicide that Cullers uses to shorten the soybean meristem, making for shorter plants with more branches.

Of course, there are intangibles to what Cullers and other yield winners do to set yield records. Cullers had been a very new soybean grower, Purcell says. "Curiosity and a focus on soybeans over other crops have served him well."

Resources

- Using High-Input Systems for Soybean Management Increases Yield but Not Profitability: https://bit.ly/3x3gCLO
- SoyStage (https://soystage.uark.edu) is a University of Arkansas online tool that predicts soybean developmental stages for Maturity Groups (MGs) 3 through 6 in one-half maturity group increments. SoyStage is based on development being a “photothermal” response and that MGs differ in response to photoperiod and temperature.
- The University of Wisconsin Badger Bean calculator (https://badgerbean.com/calculator) tells you how much nutrients your soybean crop removes.
- Benchmarking Soybean Production Systems in the North Central US explores yield limitations in individual states: https://bit.ly/3det0ke

SELF-STUDY CEU QUIZ

Earn 1 CEU in Crop Management by taking the quiz for the article at www.certifiedcropadviser.org/education/classroom/classes/1000. For your convenience, the quiz is printed below. The CEU can be purchased individually or you can access as part of your Online Classroom Subscription.

1. More than ________% of Cullers’ soil N was not derived from soybean N fixation.

a. 10. **c.** 60.
b. 40. **d.** 90.

2. Adding N fertilizer to soybeans predictably increases yield.

a. True. **b.** False.

3. Which of the following is a key driver of soybean yield?

a. Moisture.
b. Row spacing.
c. Sugar produced during photosynthesis.
d. Soil fertility.
e. All of the above.

4. Planting soybeans early allows growers to ________ flowering period and therefore ________ yield.

a. increase, increase. **c.** decrease, increase.
b. increase, decrease. **d.** decrease, decrease.

5. Which of the following factors is NOT important when considering adjustments to seeding rate?

a. Iron deficiency chlorosis.
b. Weed control.
c. Productivity of the environment.
d. Row spacing.
e. Seed costs.

6. Soybean plants in higher populations will

a. produce fewer branches and more seeds per plant.
b. produce more pods and grow taller.
c. grow taller and produce fewer pods and seeds per plant.
d. produce more branches, more pods, and more seeds per plant.

7. Soybeans require planting at a depth of _______ inch(es).

a. 1 **d.** 2.5
b. 1.5 **e.** None of the above.
c. 2

8. Soybean inoculants are not necessary if you plant soybeans at least every three years.

a. True.
b. False.

9. According to Table 1, applying foliar insecticide has what probability of breaking even when soybeans sell for $15 at 60 bu/ac?

a. 37%. **c.** 62%.
b. 49%. **d.** 69%.

10. According to the graph on p. 6, nitrogen uptake peaks at ________ days after emergence.

a. 55–60 **c.** 55–60
b. 60–70 **d.** 54–60