Soybean radiation-use efficiency in high yield production environments

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Background and objective

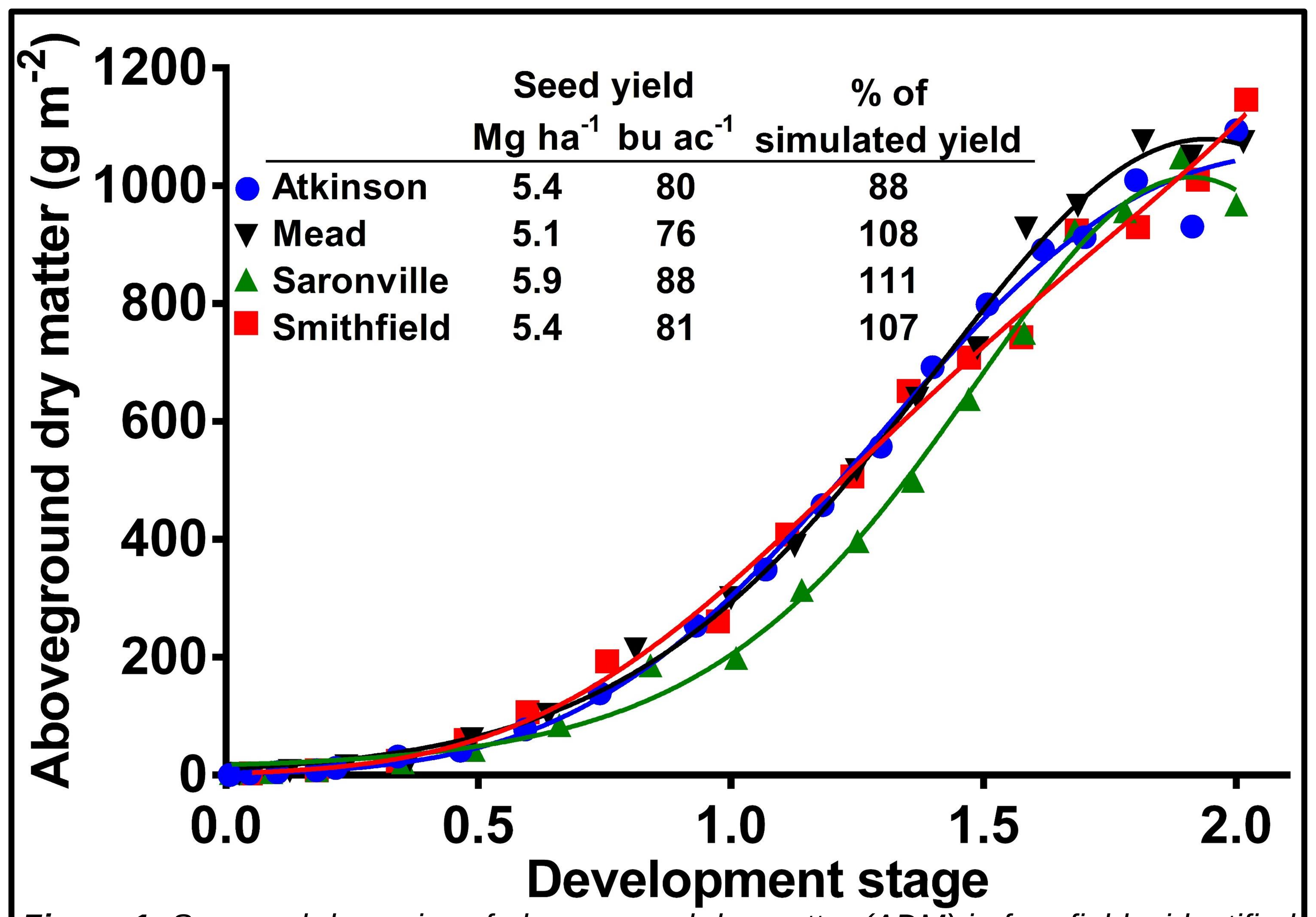
- ✓ Soybean is a key component of global food security because of the use of its seeds for protein and oil for food and feed, accounting for 56% of global oilseed production.
- ✓ Efficiency in the capture and use of seasonal solar radiation to produce biomass and seed yield has not been studied in soybean crops that approach yield potential.
- ✓ Analysis of radiation-use efficiency (RUE) in soybean is very difficult due to its high synthesis of protein and lipids during the seed filling phase.
- ✓ The objective of this study is to determine the efficiency of capture and use of solar radiation in producer soybean fields that approach the yield potential.

Materials and methods

- ✓ Replicated experiments were installed in four producer irrigated fields in Nebraska (USA) planted with soybean in 2015. These fields had consistently achieved yields >5 Mg ha^{-1} (75 bu ac^{-1}) in previous years, equivalent to >90% of their yield potential.
- ✓ Sensors were installed to measure incident, absorbed, transmitted, and reflected photosynthetically active radiation (PAR). Measurements were taken every second during the entire crop season, from emergence (VE) to physiological maturity (R7).
- ✓ Plant samples were collected weekly to determine phenology, aboveground dry matter (ADM), and green leaf area index (LAI).
- ✓ Heat of combustion of each plant organ was measured with a bomb calorimeter to calculate energy-corrected ADM.
- ✓ Comparison among locations was made possible by defining three developmental stages (DS = 0, 1, and 2, corresponding to VE, beginning of pod setting [R3], and physiological maturity [R7]), based on thermal units accumulated between stages.
- ✓ Seasonal dynamics of LAI, ADM, and fraction of absorbed PAR (*f*APAR) were described using exponential cubic models ($R^2 \geq 0.96$)
- ✓ ADM and APAR derived from fitted curves were used to determine RUE between sampling times and for the whole season.

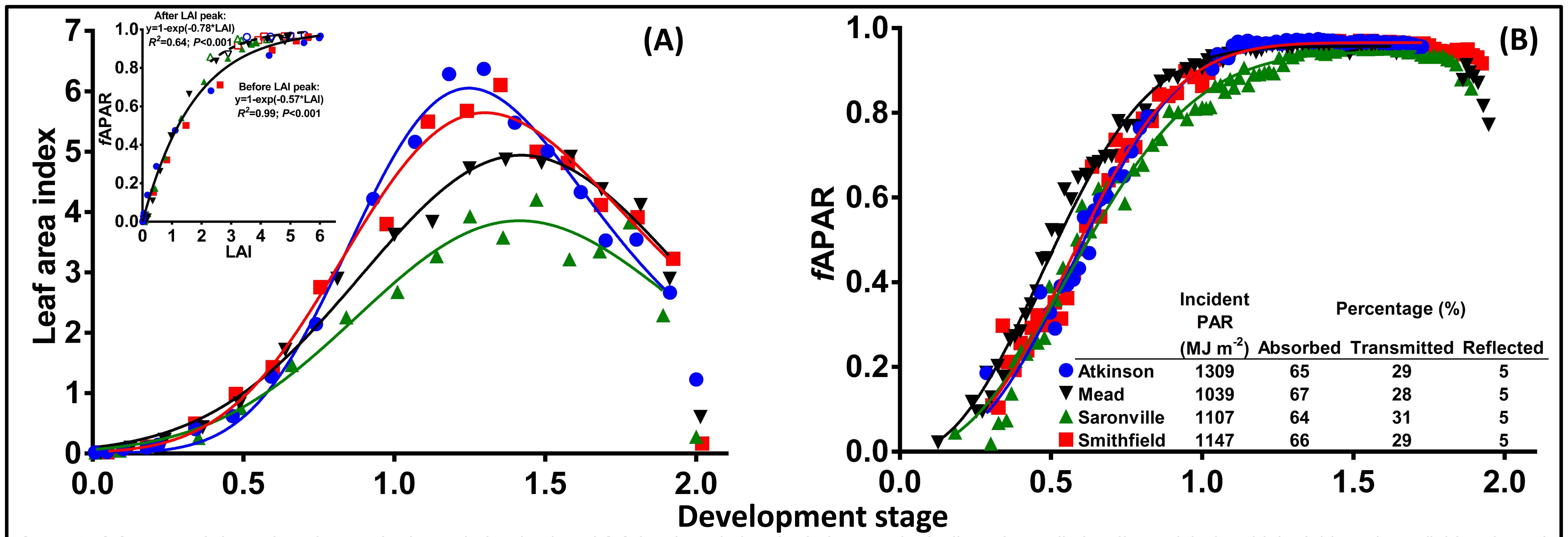
Results

- ✓ Seed yield ranged from 5.1 to 5.9 Mg ha^{-1} across fields, which were within ±15% of their respective simulated yield potential based on site-specific weather. (***Figure 1***)
- ✓ Soybean crops absorbed 2/3 of cumulative incident PAR between emergence and physiological maturity. (***Figure 2***)



	Seed yield Mg ha^{-1}	Seed yield bu ac^{-1}	% of simulated yield
Atkinson	5.4	80	88
Mead	5.1	76	108
Saronville	5.9	88	111
Smithfield	5.4	81	107

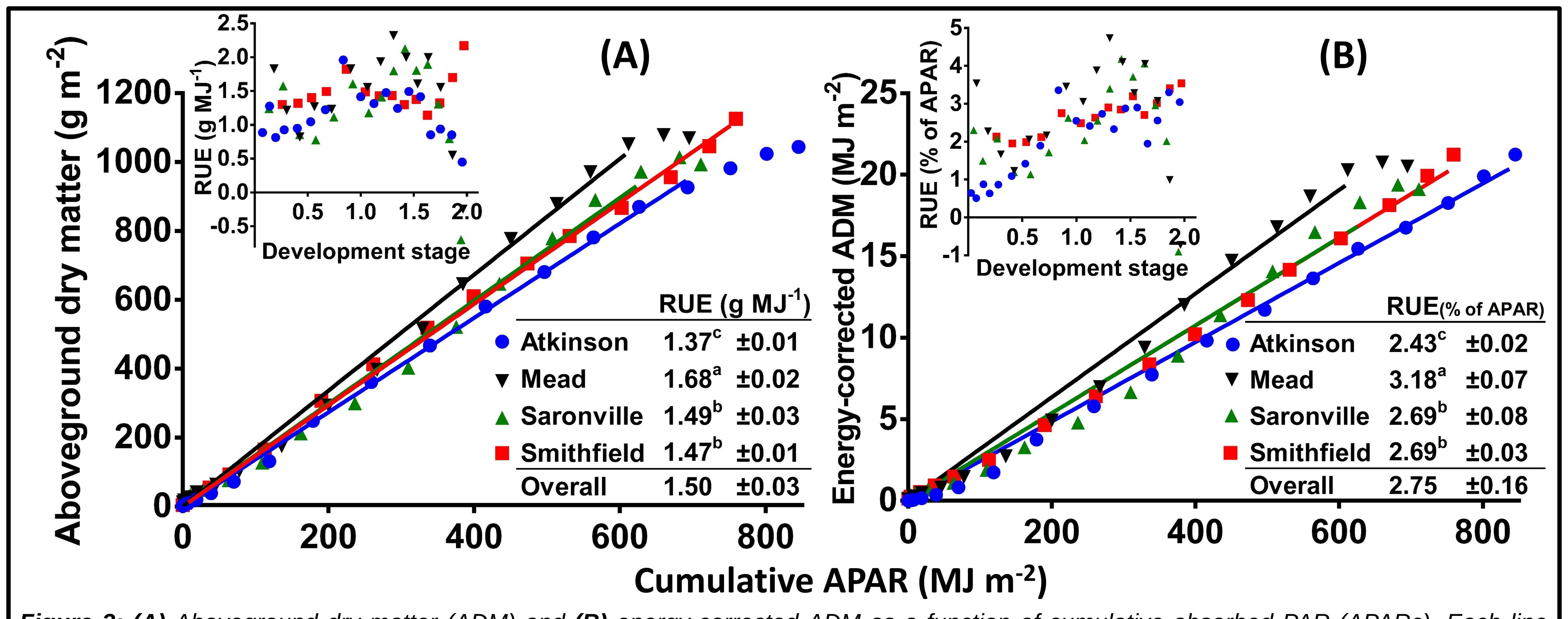
Figure 1: *Seasonal dynamics of aboveground dry matter (ADM) in four fields, identified with names of nearby locations. Table indicates seed yields (13% moisture content) and their % of simulated yield potential using SoySim model.*



	Incident PAR (MJ m^{-2})	Percentage (%) Absorbed	Transmitted	Reflected
Atkinson	1309	65	29	5
Mead	1039	67	28	5
Saronville	1107	64	31	5
Smithfield	1147	66	29	5

Figure 2: ***(A)****Seasonal dynamics of green leaf area index (LAI) and* ***(B)*** *fraction of absorbed photosynthetically active radiation (fAPAR) in four high-yield producer fields. Figure in the inset shows the fAPAR as a function of LAI. Table shows cumulative absorbed, transmitted, and reflected PAR, expressed as percentage of the cumulative incident PAR between emergence and physiological maturity.*

- ✓ Seasonal RUE, derived from plots of cumulative ADM versus cumulative APAR, ranged from 1.37 to 1.68 g MJ^{-1} across locations. (***Figure 3A***)
- ✓ Our RUE values fall within the mid-range of RUE values previously reported in the literature (1.09 to 2.95 g MJ^{-1}).
- ✓ Decline in RUE during the seed-filling was not fully explained by seed oil and protein synthesis.(***Figure 3B***)



	RUE (g MJ^{-1})	
Atkinson	1.37^c	±0.01
Mead	1.68^a	±0.02
Saronville	1.49^b	±0.03
Smithfield	1.47^b	±0.01
Overall	1.50	±0.03

	RUE (% of APAR)	
Atkinson	2.43^c	±0.02
Mead	3.18^a	±0.07
Saronville	2.69^b	±0.08
Smithfield	2.69^b	±0.03
Overall	2.75	±0.16

Figure 3: ***(A)*** *Aboveground dry matter (ADM) and* ***(B)*** *energy-corrected ADM as a function of cumulative absorbed PAR (APARc). Each line represents a linear regression fitted for each location over the range of APARc in which biomass was responsive to increasing levels of APARc. Tables indicate seasonal radiation-use efficiency (RUE), derived from the slope of fitted linear regressions ($R^2 \geq 0.96$, $P<0.001$), with different letters indicating statistically significant differences between locations. In (B), RUE was estimated as: ADM energy content / APARc x 100. Figures in insets show the seasonal dynamic in RUE, with the latter calculated for the time intervals between biomass sampling times.*

- ✓ Seasonal trends in RUE, calculated for the time intervals between sampling dates, indicate changes with ontogeny. (***insets in Figure 3***)
- ✓ Measured energy in end-of-season ADM and seed yield represented, on average, 2% and 1% of the total incident PAR during the crop season (assuming root biomass to represent 15% of ADM).

Conclusions

- ✓ Measured RUE in high-yield soybean crops (5-6 Mg ha^{-1}) did not exceed RUE values reported in the literature.
- ✓ Instead, high-yield soybean exhibited a very high capture (*ca.* 66%) of incident solar radiation during the growing season.
- ✓ Energy-corrected biomass helped to explain part, but not all, of the decline in RUE during the seed filling, suggesting that other factors may be involved, such as declining leaf N content and respiratory load associated with biomass remobilization from vegetative organs to seed.
- ✓ Efficiency of converting incident PAR to phytoenergy in high-yield soybean systems was, on average, 1% (seed-yield basis) and 2% (total-biomass basis).
- ✓ These efficiencies represent benchmarks for maximum productivity in well-managed, high-input soybean systems.

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