COOL BEAN
University of Wisconsin-Madison | UW Extension
WWW.COOLBEAN.INFO

Agronomically optimal soybean seeding rates and associated risk across North America

Mourtzinis, S, L. E. Lindsey, H. J. Kandel, P. Schmitz, J. Stanley, D. S. Mueller, E. D. Nafziger, J. Ross, A. J. Varenhorst, K. A. Wise, I. A. Ciampitti, M. I. Chilvers, A. U. Tenuta, and S. P. Conley

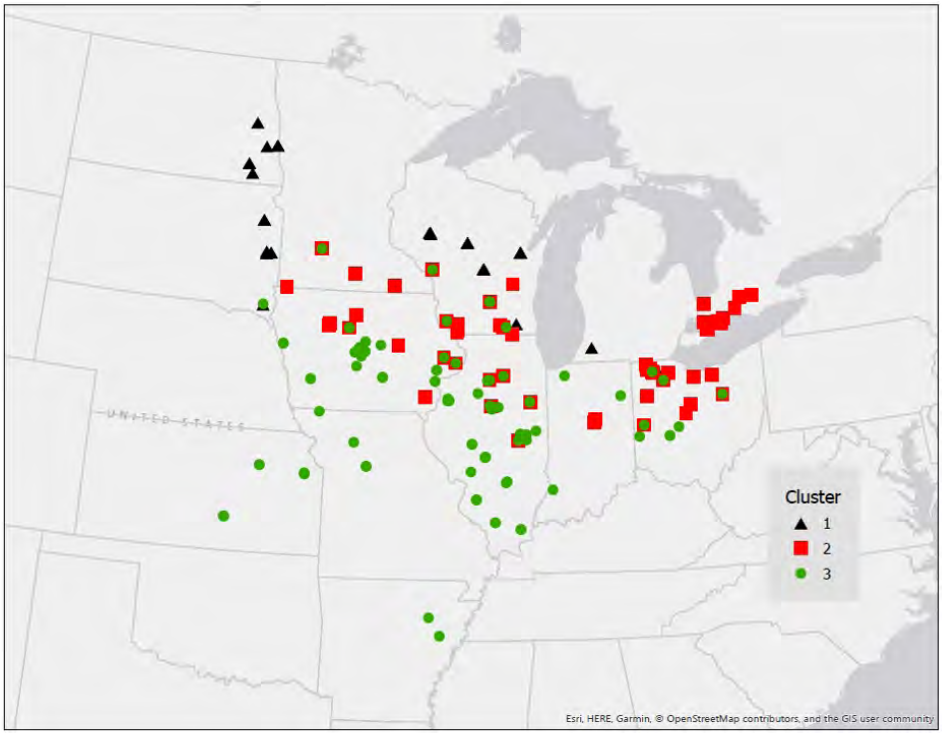
In a bean pod

- 211 field studies were grouped into similar environmental (soil × climate) clusters and into high (HYL), medium (MYL), and low (LYL) yield levels.
- Within the two northern most clusters, the agronomically optimal seeding rates (AOSR) were higher in the LYL followed by the MYL then HYL.
- Within the farthest south cluster, a relatively small (+/-6,000 seeds/ac) change in seeding rate from the MYL was required to reach the AOSR of the LYL and HYL, respectively.
- The increase in seeding rate to reach the LYL AOSR was relatively greater (5x) than the decrease to reach the HYL AOSR within the northern most cluster.
- Seeding rates below the AOSR presented a small potential yield loss, while seeding rates above provided slight yield increases.
- Specific to LYLs and MYLs, establishing and maintaining an adequate plant stand until harvest maximized yield regardless of the seeding rate.
- The economic optimal soybean seeding rate (EOSR) will be below the AOSR and are based on seed input costs and commodity price.

Introduction

Soybean [*Glycine max* (L.) Merr.] seeding rates have been declining over the past two decades in North America due to a switch from drills to row crop planting (>80%), seed treatment adoption, better seed handling and cleaning equipment, and adoption of soybean cultivars with herbicide resistance traits. A primary driver for seeding rate decline is the 295% increase in seed costs per acre since 1997 (USDA-ERS, 2018), and justified in part due to increased genetic yield potential, improved pest tolerance (Rincker et al., 2014), and new technology options (e.g., herbicide traits) (Shi, 2009). Additionally, various studies have determined that 100,000 plants/ac at harvest are required to maximize yield (Gaspar and Conley, 2015) while others have determined that 75,000 seeds/ac maximize profit (De Bruin and Pedersen, 2008). In comparison to the aforementioned studies, others have suggested plant stands as high as 243,000 plants/ac are needed in drought-prone environments (Holshouser and Whittaker, 2002) while economically optimal seeding rates can be as high as 130,000 seeds/ac (Gaspar et al., 2017). Thus, there are a wide range of agronomically and economically optimal seeding rates and plant stands driven by variation in seed costs, grain prices, seed treatment use, and most importantly, the productivity of the environment.

Figure 1. Location of 211 trial site-years that are included in the database and their respective environmental cluster classifications.



The main objective of this study was to quantify the production risk associated with soybean seed yield response to seeding rate and plant density across a range of environments varying in levels of productivity across North America. Secondary objectives were to (i) identify and quantify the subsequent yield components driving these different responses and (ii) quantify natural in-season plant attrition. With the rapid adoption of geo-spatial tools such as yield maps and variable rate seeding over the past decade, these findings will help growers better manage (agronomically and economically) their annual seed investment by spatially adjusting seeding rates based upon the productivity of the environment and its underlying environmental factors (Smidt et al., 2016). This is applicable at both within- and between-field levels.

Materials and Methods

Database Components

Soybean seed yield data and complementary yield component data were assembled for this study from 211 randomized and replicated field studies, which were conducted specifically to evaluate the effect of seeding rate on soybean seed yield at sites within each of 12 states (Arkansas, Iowa, Illinois, Indiana, Kansas, Michigan, Minnesota, Missouri, North Dakota, Ohio, South Dakota, and Wisconsin) and Ontario Canada from 2005 to 2007 and 2012 through 2017 (Fig. 1). Individual field studies were grouped into similar growing environments (clusters which were based on weather and soil parameters) and three yield levels based on their average yield. The lower 30% were considered low yield levels (<58 bu/ac), the middle 30-70% were considered medium (58-71 bu/ac), and the upper 30% were considered as high yield levels (>71 bu/ac). Site and trial specific management practices, such as cultivar, row spacing, and soil fertility are likely key drivers explaining the yield differences between each yield level and each individual trial but were not fully available for analysis in this study. However, seeding rate does not consistently interact with cultivar or row spacing (Cox and Cherney, 2011) and a seeding rate × soil fertility interaction has not been documented to date.

Results & Discussion

Environmental Cluster × Yield Level Characteristics

There was a clear latitudinal separation of clusters (Fig. 1). Cluster 1 mainly represented the northern corn belt, while cluster 3 represented the Midwest and south. Cluster 2 was primarily intermixed between both clusters 1 and 2 geographically. Cluster 1 was the lowest average yielding environment (61 bu/ac). Average yields for clusters 2 and 3 were higher (64 and 65 bu/ac, respectively) than cluster 1. The small separation in yield between clusters 2 and 3 is likely due to similar soil and climatic characteristics. The wide yield range present in this data set allowed separation of testing environments within each cluster into high (HYL), medium (MYL), and low (LYL) yield levels.

Agronomically optimal seeding rate

The agronomically optimal seeding rate (AOSR) varied between clusters and yield levels (Table 1). When averaged across yield levels, the AOSR for cluster's 1, 2 and 3 were 186,000, 148,000, and 136,000 seeds/ac, respectively. When averaged across all clusters, and therefore representing the entire Midwest

Table 1. Agronomically optimal seeding rates (AOSR) for each cluster by yield level combination (9) with the resulting yield increase probabilities and average delta yields from the agronomic risk analysis at seeding rates surrounding each AOSR.

		Cluster 1			Cluster 2			Cluster 3		
Yield level	**Seeding rate**	**Yield increase probability[†]**	**Average delta yield[‡]**	**Standard deviation**	**Yield increase probability**	**Average delta yield**	**Standard deviation**	**Yield increase probability**	**Average delta yield**	**Standard deviation**
	Seeds/ac		bu/ac			bu/ac			bu/ac	
Low	+30%	0.53	0.04	0.49	0.56	0.05	0.32	0.60	0.05	0.19
	+20%	0.53	0.03	0.48	0.55	0.04	0.31	0.60	0.05	0.19
	+10%	0.52	0.02	0.48	0.53	0.02	0.31	0.59	0.04	0.19
	AOSR		(237,000)[§]			(170,000)			(130,000)	
	-10%	0.46	-0.05	0.46	0.43	-0.06	0.30	0.46	-0.004	0.18
	-20%	0.37	-0.15	0.44	0.29	-0.17	0.29	0.39	-0.05	0.18
	-30%	0.21	-0.33	0.41	0.09	-0.37	0.28	0.18	-0.17	0.18
Medium	+30%	0.60	0.06	0.23	0.59	0.04	0.16	0.68	0.06	0.14
	+20%	0.58	0.05	0.23	0.55	0.02	0.16	0.67	0.06	0.14
	+10%	0.56	0.03	0.23	0.52	0.003	0.16	0.65	0.05	0.14
	AOSR		(168,000)			(146,000)			(136,000)	
	-10%	0.39	-0.07	0.22	0.06	-0.22	0.15	0.42	-0.009	0.13
	-20%	0.18	-0.19	0.21	0.00	-0.46	0.14	0.33	-0.06	0.13
	-30%	0.01	-0.45	0.19	0.00	-0.89	0.14	0.06	-0.2	0.13
High	+30%	0.58	0.07	0.34	0.64	0.07	0.19	0.59	0.07	0.29
	+20%	0.57	0.06	0.34	0.62	0.06	0.19	0.58	0.06	0.29
	+10%	0.54	0.04	0.34	0.58	0.04	0.19	0.55	0.04	0.29
	AOSR		(154,000)			(128,000)			(142,000)	
	-10%	0.40	-0.08	0.33	0.34	-0.07	0.18	0.38	-0.09	0.27
	-20%	0.22	-0.24	0.31	0.10	-0.22	0.17	0.17	-0.25	0.26
	-30%	0.03	-0.55	0.29	0.00	-0.52	0.17	0.01	-0.57	0.25

[†] Yield increase probability is the probability that a seeding rate will at least provide the same yield as the agronomically optimal seeding rate (AOSR) within each cluster by yield level combination.
[‡] Average delta yield compared to the agronomically optimal seeding rate (AOSR) within each cluster by yield level combination.
[§] The agronomically optimal seeding rate (seeds/ac) for each cluster by yield level combination is displayed in parenthesis.

and soybean growing areas of Canada, the AOSR was greatest for the LYL (179,000 seeds/ac) and lowest for the HYL (141,000 seeds/ac). Compared to the MYL's AOSR (150,000 seeds/ac), AOSR was 19% higher for the LYL, but 6% lower for the HYL. The average yields representing the HYL, MYL, and LYL were 76, 64, and 48 bu/ac, respectively. These results suggest that in relation to the MYL, the increase in seeding rate within LYLs should be approximately 3x the decrease in seeding rate within HYLs, on average.

Relative to the MYL (168,000 seeds/ac), the increase in seeding rate to reach the AOSR of the LYL (+41%) was approximately 5x the decrease in seeding rate for the HYL (-8%) or a separation of 83,000 seeds/ac. Relative to the AOSR of the MYL (146,000 seeds/ac) within cluster 2, there was not a large absolute difference in the seeding rate increase (+17%) or decrease (-13%) required to reach the AOSR of the LYL and HYL, respectively. Yet, both clusters 1 and 2 demonstrated the same trend of higher AOSRs in LYLs and lower AOSRs in HYLs compared to the MYLs. This was reversed in cluster 3 with higher AOSRs in HYLs and lower AOSRs in LYLs compared to the MYL. However, the separation between these yield levels was much smaller with only a +/-4% increase (+/-6,000 seeds/ac) and decrease from the AOSR of the MYL. In summary, based on the results of this analysis, growers should increase seeding rates in lower productivity environments and decrease seeding rates in higher productivity environments. Moreover, these adjustments in soybean seeding rates are likely to be more effective in the northern corn belt compared to more southern environments.

Plant stand

Early and late season stand was evaluated with yield levels combined across clusters and as a percentage (%) of survival (plants/seeding rate x100). In Figure 2 we show the effect of stand x yield level interaction on yield. Seeding rate, yield level, and their interaction did not affect early % season stand (V2).

Table 2. Analysis of covariance for early (V2) and late season plant stand (R8).

	% Early season stand†	% Late season stand†
Source	——P > F——	
Seeding rate (SR)	0.627	<0.001
Yield level (YL)	0.976	0.607
SR*YL	0.263	0.334

†Percent early season stand and % late season stand were analyzed as a percentage of seeding rate (plants/seeding rate).

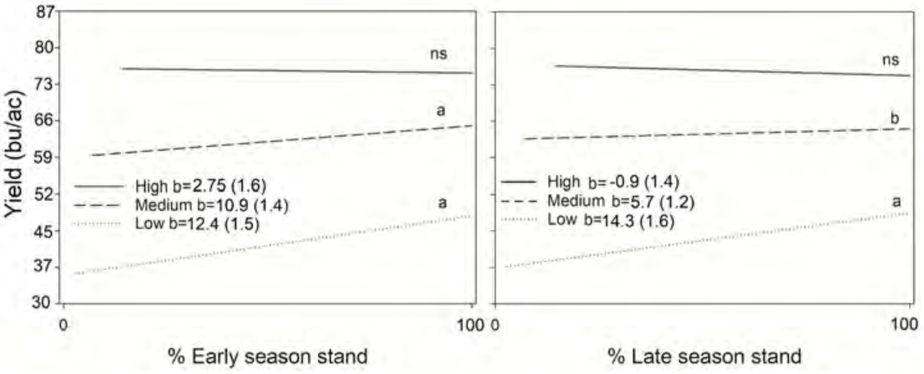


Figure 2. Relationship between % early (V2) and late (R8) season stand with yield. Clusters were combined within each yield level. Percent early and late season stand were calculated by dividing the plant stand at each time by seeding rate. Slope coefficients are reported for each line followed by the standard error of the slope (in parenthesis). Different letters signify statistically different slopes at alpha=0.05 within each separate graph whereas, "ns" denotes that the slope was not significantly different from zero.

Late season stand (R8) was affected by seeding rate ($P<0.001$) but not by yield level or the seeding rate by yield level interaction (Table 2). As seeding rate increased, percent late season stand decreased (data not shown). Therefore, because early season stand was not affected by seeding rate ($P=0.627$), but late season stand was ($P<0.001$), one can conclude that in-season plant attrition increased as seeding rate increased.

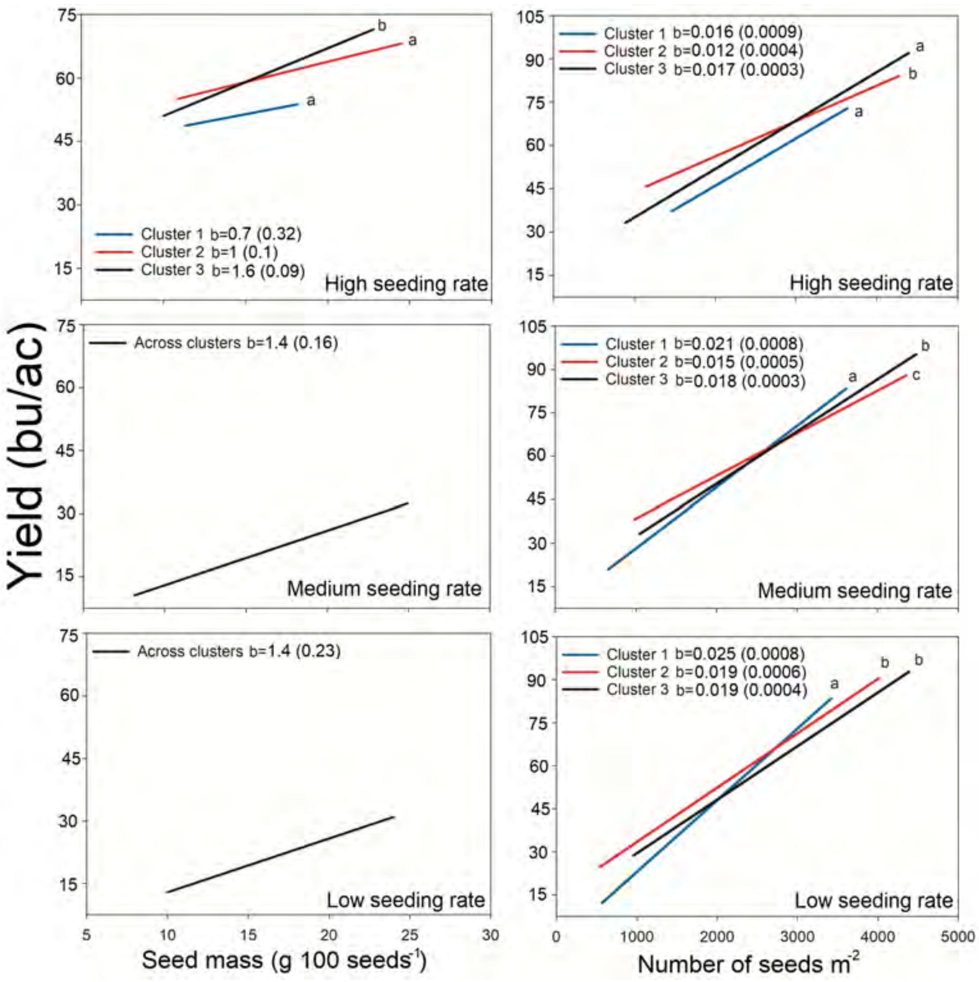
The early and late season stand covariates both interacted with yield (productivity) level, meaning their relationship with yield differed between yield levels ($P<0.05$) (Fig. 2). The slope coefficients describing this relationship as the increase in yield (bu/ac) per unit increase in stand (%) were similar for early season stand within the LYL (12.4) and MYL (10.9). However, for late season stand the slope coefficient was more than double in the LYL (14.3) compared to the MYL (5.7). The HYL displayed non-significant ($P>0.05$) slope coefficients for both early and late season stand, suggesting that maintaining stand through the whole growing season had no effect on yield within this yield level.

It has been hypothesized that early and late season stand (measured as a percentage of seeding rate) in areas of lower productivity is often reduced to a greater extent than in higher productivity areas. Therefore, one could conclude that reduced stand is a driving principal of why seeding rates should be increased in low yield levels. However, we found that early and late season stand was not affected by yield level across the entire region (Table 2). Thus, yield level and stand are mutually exclusive and early and late season stand are not driving factors behind the relatively higher seeding rates required in lower productivity environments. However, within each yield (productivity) level there was a differential effect of early and late season stand on yield (Fig. 2). Greater early season stand positively affected yield similarly within the MYL and LYL, while greater late season stand positively affected yield within the MYL and, to an even greater extent LYL. In contrast, yield within the HYL was not affected by early or late season stand. However, regardless of yield level we did find that higher seeding rates resulted in greater amounts of in-season plant attrition. Therefore, within MYLs and to an even greater extent LYLs (which displayed higher AOSRs), establishing an adequate stand at planting and maintaining this increased stand until harvest is critical to maximize yield within these yield levels. In contrast, HYLs can maximize yield across a much wider range of plant stands and attrition rates. The use of seed treatments (Gaspar et al., 2014), appropriate tillage and planting practices (Oplinger and Philbrook, 1992), narrow rows (Andrade et al., 2019), and adequate fertility are all components which can maximize early season stand and minimize in season plant attrition to ensure adequate late season stands are achieved which is particularly important in medium and low yield levels. Yet, growers will continually encounter greater attrition rates as seeding rate increases, further supporting the limited yield and risk benefits from increasing seeding rates above the AOSR.

Seed mass and seed number

The effect of cluster on the yield components and seed yield relationships within low, medium, and high seeding rate groups are displayed in Fig. 3. The covariate, seed mass interacted with cluster in the high seeding rate group ($P<0.05$), but not in the medium and low seeding rate groups whereas, the seed number covariate interacted with cluster in all three seeding rate groups. The slope coefficients, quantifying the yield (bu/ac) increase per unit increase in seed mass (g 100 seeds^{-1}), were the same for the medium and low

Figure 3. Relationship between seed mass (g 100 seeds^{-1}) and seed number (seed $^{m-2}$) with yield derived from an analysis of covariance. Each cluster is compared within low, medium, and high seeding rates groups. The lower 30% of seeding rates were considered low, the middle 30-70% of seeding rates were considered medium, and the upper 30% of seeding rates were considered high. Slope coefficients are reported for each line followed by the standard error of the slope (in parenthesis). Different letters signify statistically different slopes at alpha=0.05 within each graph.



(1.4) seeding rate groups. Within the high seeding rate group, yield was more responsive to changes in seed mass for cluster 3, with a slope of 1.6, compared to clusters 1 and 2, which displayed similar slope coefficients of 0.7 and 1, respectively. The slope coefficients, quantifying the yield (bu/ac) increase per unit increase in seed number (seeds m^{-2}), were always positive regardless of the seeding rate group or cluster but demonstrated more complex interactions with the environment within all three seeding rate groups. Even though the interactions were more complex for the effect of cluster on the seed number and yield relationship, this relationship was much stronger than seed mass and yield.

Others have also demonstrated the importance of seed number and its strong relationship with yield (Gaspar and Conley, 2015). However, this study also suggests that there are differential environments where one (seed mass vs. seed number) may be increasingly important. (Fig. 3). For instance, in the low (40,000 – 100,000 seeds/ac) and medium (100,000 – 160,000 seeds/ac) seeding rate groups, the relationship between seed mass and yield was not affected by the environment. In contrast, within the more northern and less productive environments represented by cluster 1, increasing seed number was a more efficient way to increase yield compared to the more southern and higher productivity environments (cluster 2 and 3). This differential response may be driven by the condensed growing season and earlier maturity group cultivars planted in the northern corn belt which have a shorter seed filling period, placing more reliance on seed number to maximize yield. However, this trend for seed number was not seen within the high seeding rate group (160,000 – 270,000 seeds/ac) where yield was much more responsive

to seed mass within cluster 3. This may be a result of greater seed set due to improved environmental characteristics, subsequently allowing changes in seed mass to have a magnified effect on yield with higher seeding rates. In summary, emphasis should be placed on increasing seed number where low to moderate seeding rates are planted within northern environments, while seed mass may deserve more attention with higher seeding rates in more southern and highly productive environments. Ultimately, further testing is needed to better understand the differential effects of seeding rate within various environments on these two key yield components as identified by this study.

Seeding rate risk analysis

The Monte Carlo analysis of risk provided a yield increase probability (the probability that a seeding rate will at least provide either the same yield or a higher yield than the AOSR) and average delta yield (the average yield increase or decrease compared to the AOSR) (Table 1). For example, within the MYL of cluster 1, a 20% decrease in seeding rate from the AOSR had a 0.18 (18% chance) probability of either maintaining or increasing yield over the AOSR and on average decreased yield by 0.19 bu/ac with a standard deviation of 0.21 bu/ac. In comparison, a 20% increase in seeding rate over the AOSR displayed a 0.58 probability of either maintaining or increasing yield over the AOSR with an average yield increase of 0.05 bu/ac and standard deviation of 0.23 bu/ac.

Risk aversion is a common component in farm level soybean seeding rate decisions and many times results in growers inflating seeding rates. Across all nine cluster × yield level combinations, seeding rates above the AOSR always resulted in a yield increase probability above 0.5 (0.52 to 0.68), while decreasing the seeding rate below the AOSR resulted in lower probabilities of yield increase (0 – 0.46). Thus, decreasing the seeding rate below the AOSR resulted in a change in the yield increase probability of greater magnitude compared to a seeding rate increase above the AOSR. For instance, within the HYL of cluster 1, a 30% increase in seeding rate above the AOSR resulted in a yield increase probability of 0.58, which is a rise in probability of 0.07, compared to a probability decline of 0.47 from a 30% decrease in seeding rate from the AOSR (154,000 seeds/ac). A similar trend was observed for the average delta yield, where increasing the seeding rate above the AOSR resulted in small yield increases of 0.04 – 0.07 bu/ac. In comparison, larger decreases in yield were observed with seeding rates below the AOSR, which in some cases reached an average delta yield of -0.89 bu/ac. Therefore, the magnitude of change in the average delta yield was greater when seeding rates were below, not above, the AOSR. However, for both the yield increase probability and average delta yield, the magnitude of change due to seeding rate was cluster × yield level dependent.

Ultimately, risk-averse growers may choose to increase seeding rates slightly above the AOSR to ensure yield is maximized, but should not expect substantial yield increases, while growers who are comfortable with additional risk may choose to decrease seeding rates below the AOSR. However, there was considerably more downside risk and potential yield loss with a decrease in seeding rate below the AOSR than upside potential with an equivalent increase above the AOSR. Furthermore, the balance of risk vs. yield stability was different within each cluster × yield level combination, meaning growers must understand this dynamic specific to their geography and risk tolerance in combination with farm level economics (Gaspar et al., 2017).

Adapted from: Gaspar et al., 2020. Defining optimal soybean seeding rates and associated risk across North America (in review).

References

Andrade, J., J. I. Rattalino Edreira, S. Mourtzinis, S. Conley, I. Ciampitti, J. Dunphy, J. Gaska, D. Holshouser, H. Kandel, P. Kyveryga, M. Licht, L. Lindsey, A. McClure, S. Naeve, E.D. Nafziger, J. Orlowsky, J. Ross, K. Glewen, L. T., M. Staton, J. Specht, and P. Grassini. 2019. Assessing the influence of row spacing on soybean yield using experimental and producer survey data. Field Crops Research 230:98-106.

Cox, W. J. and J.H. Cherney. 2011. Growth and yield responses of soybean to row spacing and seeding rate. Agron. J. 103:123-128.

De Bruin, J.L. and P. Pedersen. 2008. Soybean seed yield response to planting date and seeding rate in the upper Midwest. Agron. J. 100:696-703.

Gaspar, A.P. and S.P. Conley. 2015. Responses of canopy reflectance, light interception, and soybean seed yield to replanting suboptimal stands. Crop Sci. 15:377-385.

Gaspar, A.P., D.A. Marburger, S. Mourtzinis, and S.P. Conley. 2014. Soybean seed yield response to multiple seed treatment components across diverse environments. Agron J. 106: 1955-1962.

Gaspar., A.P., D.S. Mueller, K.A. Wise, M.I. Chilvers, A.U. Tenuta, and S.P. Conley. 2017. Response of broad-spectrum and target-specific seed treatments and seeding rate on soybean yield, profitability, and economic risk. Crop Sci. 56:2251-2262.

Holshouser, D.L., and J.P. Whittaker. 2002. Plant population and row spacing effects on early soybean production systems in the Mid-Atlantic USA. Agron. J. 94: 603–611.

Oplinger, E.S., and B.D. Philbrook. 1992. Soybean planting date, row width, and seeding rate response in three tillage systems. J. Prod. Agric. 5:94-99.

Rincker, K., R. Nelson, J. Specht, D. Sleper, T. Cary, S.R. Cianzio, S. Casteel, S. Conley, P. Chen, V. Davis, C. Fox, G. Graef, C. Godsey, D. Holshouser, G. Jaing, S.K. Kantartzi, W. Kenworthy, C. Lee, R. Mian, L. McHale, S. Naeve, J. Orf, V. Poysa, W. Schapaugh, G. Shannon, R. Uniatowski, D. Wang, and B. Diers. 2014. Genetic improvement of U.S. soybean in maturity groups II, III, and IV. Crop Sci. 54:1419-1432.

Shi, G., J.P. Chavas, and K.W. Stiegert. 2009. Pricing of herbicide-tolerant soybean seeds: A market-sturcture approach. AgBioForum. 12:326-333.

USDA-ERS. 2018. Recent US soybean production costs and returns. Accessed September 14, 2018 from <www.ers.usda.gov>. Confirmed on Oct. 20, 2018.

Conclusions

This work suggests that there is an opportunity for growers to adjust seeding rates at both the between- and within-field level based upon the environment's historical productivity to maximize yield, particularly in more northern environments. Growers can utilize current variable rate seeding planter technology to better manage their soybean seed investment, by following the strategy of increasing seeding rates in environments of lower productivity and decreasing seeding rates in environments of higher productivity. Furthermore, the AOSR should be targeted within each environment (cluster × yield level). From a risk perspective, this is critical, as seeding rates increasingly below the AOSR increase potential yield loss, while seeding rates above the AOSR provided slight risk reduction, a negligible potential yield increases but also increased seed cost. Particularly in northern environments, the increase in seeding rate to reach the AOSR within lower productivity environments should be relatively greater than the decrease in seeding rate to reach the AOSR within higher productivity environments. Furthermore, the absolute difference in AOSR between the HYL and LYL will likely be greater in northern vs. southern environments. Ultimately, the specific seeding rates for the varying levels of productivity across an individual field or between fields will be based upon local agronomic recommendations (e.g., weed control, white mold (Sclerotinia sclerotiorum), iron deficiency chlorosis), grower risk tolerance, and economics (e.g., seed costs), but should follow the aforementioned strategy. Regardless of the seeding rate implemented, growers should strive to establish an optimal stand at planting and maintain this stand until harvest to maximize yield, specifically within low and moderate yield levels.

The authors wish to thank Adam Roth and John Gaska of UW-Madison, Laura Wolf and Eric Egan of Corteva Agriscience, Adam Byrne and John Boyse of MSU, Jeffrey Ravellette, Nolan Anderson, and Jon Leuck of Purdue University, Yuba Kandel and Stith Wiggs of ISU, Joshua Vonk and Jason Niekamp of the University of IL, and Osler Ortez and Luiz Moro Rosso of KSU. Furthermore, the support from Joe Davlin, Matt Davis, Lynn Ault, Philip Rozeboom, and Cole Dierks as on-farm collaborators was appreciated. The authors would also like to thank Corteva Agriscience for providing data and review of the submitted manuscript. We would also like to thank the Wisconsin Soybean Marketing Board, University of Wisconsin-Madison, North Dakota State University, North Dakota Soybean Council, Ohio Soybean Council, Foundational and Applied Science Program grant no. 20186800828356 USDA-NIFA, South Dakota Soybean Research and Promotion Council, USDA-NIFA Hatch Project SD00H610-16, Michigan Soybean Promotion Committee, Indian Soybean Alliance, Kansas Soybean Commission, Kansas State Research and Extension, USDA Hatch Project IOWA3908, and Corteva Agriscience.