Chapter

Row Spacing and Seeding Rate Effects on Soybean Seed Yield

Matthew Schutte and Thandiwe Nleya

Abstract

Soybean growers in the northern latitudes of the United States plant the crop in a wide range of row spacings although there has been a shift toward wider rows (>50 cm) in some Upper Midwest states in the last 5 years. The objective of this study was to evaluate the impact of row spacing and seeding rate on the performance of soybean and to determine whether these management practices interact to influence soybean yield. A row spacing study was conducted at Aberdeen and Beresford, South Dakota, USA, in 2014 and 2015. The study had two row spacings (19 and 76 cm), four seeding rates (247,000, 333,500, 420,000, and 506,500 seeds ha^{-1}), and two soybean varieties at each location. Soybean had greater stand establishment in 19 cm rows (6–10% higher) compared with 76 cm rows. Soybean in 19 cm rows yielded 0.8–10% more than in 76 cm rows depending on the location or year. Seed yield increased with increasing seeding rate with the highest seeding rate of 506,000 seeds ha^{-1} yielding greatest. The increase in seed yield due to the increase in seeding rate ranged from 3 to 7%. At each location, the longer duration soybean variety yielded higher than the shorter duration variety.

Keywords: soybean, *Glycine max*, row spacing, seeding rate, seed yield

1. Introduction

Soybean (*Glycine max*) is the second most planted crop after corn worldwide and is the second most important source of crop revenue in South Dakota [1]. Research conducted in the Upper Midwest of the United States documents a consistent yield advantage, in the range of 134–604 kg ha^{-1}, for soybean grown in narrow row spacings (<50 cm) when compared to those grown at wider row spacings (50–76 cm) [2–4]. Another research, however, showed no yield advantage to narrow row spacing [5]. Cox and Cherney [6] reported that soybean drilled in 19 cm rows yielded 7% more than soybeans planted with a row crop planter in 38 cm rows and 17% more than soybean planted in 76 cm rows in Northeastern United States. Even with these reports of yield advantage or no yield difference, 69% of soybean growers in South Dakota, 54% in Nebraska, and 49% in Iowa grow soybean in 76 cm row spacing or wider [1].

Lee [7] reported that in Central and Southern United States row spacing studies usually found no increase in yield in narrow rows over wider rows. This was confirmed by Thompson et al. [8] who reported that yield responses to narrow row spacing in the Mid-South United States were inconsistent and mainly influenced by weather. The increase in yield from narrow row spacings in the Northern United

States has been attributed to a shorter growing season meaning soybean has limited time to reach maximum radiation interception prior to flowering. Narrow rows therefore increase radiation interception during the critical periods for grain set resulting in earlier canopy closure and less light being usable for weeds if initial weed control is satisfactory [9–12]. Along with higher rate of light interception, less evapotranspiration was reported in narrow rows due to faster canopy closure and thus resulted in a higher water-use efficiency [13]. However, in years of drought stress, narrow rows can deplete soil water sooner by increased vegetative growth and result in insufficient soil water availability during reproductive stages and therefore no yield advantage over wider rows [2, 14].

Some studies have reported row spacing × seeding rate interactions with soybean yielding greater with higher seeding rates and narrow rows when compared to wide rows [3, 6, 15, 16]. Cox et al. [3] reported a greater profit of US$30 ha^{-1} with a seeding rate of 420,000 seeds ha^{-1} in 19 cm rows compared to 321,000 seeds ha^{-1} in 76 cm rows due to yield increase outweighing seed costs. Other studies have reported similar optimum seeding rates between narrow and wide rows and therefore no interaction between row spacing and seeding rate [17–19]. Ricks et al. [20] reported that the optimum seeding rates for South Dakota typically range between 355,000 seeds ha^{-1} and 381,000 seeds ha^{-1}. However, they also reported that higher yields have been reported with seeding rates greater than 406,000 seeds ha^{-1}.

Carpenter and Board [21] reported that soybean plants compensate for space in the canopy by adding branches, and they found no yield response to increased seeding rates. This was supported by Cox and Cherney [6] who found that not only did soybean plants compensate with biomass, pods, and seeds per plant at lower seeding rates but also found that soybean compensated for wider rows (>38 cm) as well. They also found that though soybean plants do compensate for both lower seeding rates and wider rows, they were less efficient at compensating for wider rows than for lower seeding rates, meaning that row spacing had a greater effect on yield than seeding rate. Wiatrak and Chen [22] found that increasing seeding rate may improve soybean growth at early vegetative stages, which in turn can result in increase in yield. However, they found that seeding rates above 272,000 seeds ha^{-1} did not follow this trend and did not increase vegetative growth.

White mold (also called *Sclerotinia* stem rot), a disease caused by the fungus *Sclerotinia sclerotiorum*, is a yield-limiting soybean disease in North Central United States. Management practices such as narrow row spacing, increased plant populations, early planting dates, and high-soil fertility can increase soybean yields but have the unintended consequence of increasing white mold development within the soybean canopy [23, 24]. While fungicides are available to control white mold, complete control of the disease using only chemical management is usually not possible [24]. Thus, in addition to fungicides, management strategies for controlling white mold in soybean include cultivars selection and management practices to reduce canopy density [24, 25]. Planting in wide row spacings or at lower plant populations delays canopy closer, reduces canopy density, and thus prevents favorable conditions for white mold development [24, 26].

With increase in soybean planted in wider rows (50–76 cm) in South Dakota and neighboring states in the Upper Midwest, there is a need to evaluate the value of this practice especially with recent research results suggesting that narrow rows have an advantage or at least yield the same as wider rows in the Upper Midwest. The objectives of this study were to (i) determine the effect of row spacing and seeding rate on soybean yield and (ii) measure the interactions between the two management practices.

2. Materials and methods

The study was conducted at two locations, Southeast Research Farm, Beresford, South Dakota (SD) (43.052548°N, 96.904135°W), and Aberdeen, SD (45.464698° N, 98.486483°W) in 2014 and 2015. At Beresford, the soil textural classification was Egan-Clarno-Chancellor complex, fine silty, and fine loam [27]. At Aberdeen, the soil textural classification was Great Bend fine silty, mixed, superactive, and frigid calcic Hapludolls [28]. The experimental fields were plowed in the fall and cultivated twice in the spring before planting soybean. The soybean was grown under dryland conditions. The total rainfall and mean air temperature for each growing season are shown in **Table 1**.

The experimental design was a randomized complete block in a split-plot arrangement, with four replications. The main plots were two row spacings. Subplot treatments were four seeding rates of 247,000, 333,500, 420,000, and 506,500 viable seeds ha^{-1} and two soybean varieties arranged in a factorial design. The two row spacings were 19 and 76 cm rows. The soybean varieties were different at each location based on maturity grouping ideal for the area and were also slightly different in resistance to white mold. At the Aberdeen location, the varieties were 0906R2 and 1108R2 and at Beresford were 2306R2 and 2408R2 (Channel, St. Louis, MO). At each specific location, varieties 0906R2 and 2306R2 were of shorter duration than 1108R2 and 2408R2. The rating for white mold were 3 for 0906R2, 4 for 1108R2, 3 for 2306R2, and 6 for 2408R2 on a scale of 1–9 (1 resistant and 9 susceptible) [29].

In 2014, the planting dates were June 9 and May 28 at Aberdeen and Beresford, respectively. In 2015, the planting dates were June 9 at Aberdeen and June 10 at Beresford. For the 76 cm row spacing, soybean was planted in four rows that was 6.4 m long and trimmed back to 5.5 m when they reached the V3 stage. The center

Average monthly temperature (°C)								
Location	**Year**	**May**	**June**	**July**	**August**	**September**	**October**	**Average**
Aberdeen	2014	12.89	17.53	19.61	19.58	15.33	9.14	15.68
Aberdeen	2015	12.94	20.56	22.58	20.42	18.39	10.44	17.56
30-year average		13.55	18.65	21.80	20.56	14.95	7.29	16.1
Beresford	2014	15.31	20.19	20.50	21.14	16.47	10.31	17.32
Beresford	2015	14.58	20.83	22.14	20.22	19.61	11.42	18.13
30-year average		15.03	20.53	22.81	21.56	16.58	9.41	16.2
Monthly rainfall (mm)								**Total**
Aberdeen	2014	55.37	84.07	17.78	157.23	25.40	6.60	346.46
Aberdeen	2015	162.31	53.34	103.12	74.68	9.40	41.66	444.50
30-year average		78.99	93.98	75.95	61.72	55.63	50.55	416.60
Beresford	2014	62.99	342.90	27.18	75.18	61.47	34.54	604.27
Beresford	2015	89.66	90.42	150.11	179.07	92.46	26.42	628.14
30-year average		92.46	110.74	83.31	72.39	74.42	54.61	487.90

Source: High Plains Regional Climate Center, University of Nebraska, http://xmacis.rcc-acis.org/#, last accessed 6/13/2018.

Table 1.
Monthly average air temperature and rainfall at Aberdeen and Beresford, SD, for 2014 and 2015.

two rows were harvested for yield data, while the outer two rows were buffers. For the 19 cm row spacing, soybean was planted in 16 rows that is 6.5 m long and trimmed back to 5.5 m at V3 stage. The eight center rows were harvested for yield data with eight buffer rows on either side. The data collected included the number of plants ha^{-1} at the V4 growth stage determined by counting the number of plants in the middle two rows for the 76 cm row spacing and eight rows for the 19 cm row spacing and converting to plants ha^{-1}. Seed yield was determined by harvesting two center rows (76 cm spacing) and eight center rows (19 cm spacing) with a small-plot combine (Massey Ferguson 8XP, Duluth, Georgia, USA). Seed subsamples from each plot were taken to determine moisture, protein, and oil content. Seed moisture was determined by weighing seed samples before drying at 60°C for 48 hours and reweighing the samples after drying to adjust seed moisture to 13% or 130 g kg^{-1}. Seed protein and seed oil were determined using a near-infrared transmittance (NIT) spectroscopy (Infratec 1229 Grain Analyzer, Foss Tecator AB).

Weeds were managed with a preemergent herbicide application of S-metolachlor (Dual II) (Bayer CropScience, Research Triangle Park, NC) and two in-season application of glyphosate (PowerMax) (Monsanto Company, St. Louis, MO). The insecticide Baythroid [cyano(4-fluoro-3-phenoxyphenyl)methyl-3-(2,2-dichloro-ethenyl)-2,2-dimethyl-cyclopropanecarboxylate] (Bayer CropScience, Research Triangle Park, NC) was applied when soybean aphids (*Aphis glycines*) reached economic thresholds.

Data were analyzed using PROC MIXED of SAS (SAS Research Institute, NC). Years and blocks were treated as random, and all other effects were considered fixed. Levene's test was used to test for the homogeneity of variance. After combined analysis revealed interactions between location and year, the data were split by year and then by location to analyze the significant interactions between row spacing, variety, and seeding rate within each location. Mean separation was performed using Fisher's protected LSD (0.05).

3. Results and discussion

3.1 Climate and weather

Average temperatures were slightly warmer at Beresford compared to Aberdeen, although in 2015, September was much warmer compared to 2014 at both locations (**Table 1**). Rainfall amounts and timing varied considerably for each location and each year. Aberdeen was drier (70.1 mm less rain) than long-term average in 2014 and wetter (28.1 mm more) than long-term average in 2015. Beresford was wetter than long-term average in both years with June 2014 receiving 132.1 mm more rain than average. The warmer and wetter conditions at Beresford in both years were conducive to overall better soybean growth and yield when compared to Aberdeen.

3.2 Established plant population

In 2014, the effects of row spacing on number of plants ha^{-1} and percent stand establishment (relative to seeding rate) were significant (<0.001) at both locations, while in 2015, row spacing effects were significant for the two traits ($P = 0.02$ and 0.01, respectively) only at Aberdeen (**Table 2**). Overall, plant establishment was greater in narrow rows compared with wide rows. On average, the difference in stand establishment between the two row spacings was greater at the Aberdeen location (10% points) compared to Beresford (6% points). Greater stand

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	2014				2015			
	Aberdeen		**Beresford**		**Aberdeen**		**Beresford**	
	Plants (ha^{-1})	**Percentage (%) stand**	**Plants (ha^{-1})**	**Percentage (%) stand**	**Plants (ha^{-1})**	**Percentage (%) stand**	**Plant (ha^{-1})**	**Percentage (%) stand**
Row spacing (S) (cm)								
19	352,975a*	96.7a	315,660a	85.1a	324,032a	86.2a	316,557	85.3
76	279,071b	75.7b	286,695b	76.6b	288,638b	77.1b	307,811	82.7
Seeding rate (RS) (seeds ha^{-1})								
247,000	230,821d	93.4 a	208,247d	84.4a	204,585d	82.8	220,431d	89.2a
333,500	288,003c	86.3b	281,575c	84.3a	276,940c	83.0	290,395c	87.0ab
420,000	345,634b	82.8c	334,048b	79.5b	345,335b	82.2	346,755b	82.6b
506,500	419,634a	82.2c	380,840a	75.2b	398,480a	76.7	391,155a	77.2c
Variety (V)#								
0906R2/2306R2	323,733a	87.1a	301,981	80.9	302,467	80.5	306,690	82.3
1108R2/2408R2	318,313b	85.3b	300,374	80.7	310,203	82.2	317,678	85.6
	Analysis of variance							
S	<0.001	<0.001	0.025	0.009	0.020	0.016	0.075	0.097
SR	<0.001	<0.001	<0.001	<0.001	<0.001	0.091	<0.001	<0.001
S × SR	<0.001	<0.001	0.316	0.069	0.036	0.604	0.444	0.521
V	0.048	0.028	0.811	0.850	0.141	0.091	0.079	0.053
V × S	0.748	0.688	0.539	0.560	0.086	0.062	0.243	0.232
V × SR	0.524	0.172	0.992	0.993	0.424	0.166	0.181	0.197
V × SR × S	0.758	0.722	0.451	0.538	0.946	0.928	0.631	0.512

Within each column and each treatment, means followed by the same letter are not significantly different (P 0.05).
#Soybean varieties 0906R2 and 1108R2 were grown at Aberdeen and 2306R2 and 2408R2 at Beresford.

Table 2.
Established plant population and percentage (%) established plants (relative to seeding rate) at Aberdeen and Beresford locations, SD, in 2014 and 2015.

establishment in narrow rows has been observed by others in the Upper Midwest [2, 16]. As expected increasing seeding rate increased the number of established plant ha^{-1} at both locations and in both years. Percent established plants relative to the target population, on the other hand, decreased significantly as the seeding rate increased, and this was true in three of the four location-years. The rate of decrease in percent established plants was variable among location-years ranging from a high 12% drop between the lowest and the highest seeding rates at Beresford in 2015 to the lowest drop of 6.1% at Aberdeen in 2015. The reason for this is not clear, but Bruns [30] also reported a decrease in percent established plants with increasing seeding rate. However, it is generally accepted that under optimal conditions, stand establishment is about 80% of the seeding rate [30, 31]. In this study we achieved 80% stand establishment for all seeding rates except for the highest seeding rate of 506,500 at Beresford in 2014 and 2015 and in Aberdeen in 2015.

The row spacing × seeding rate interaction effects were significant at Aberdeen in both years (**Tables 2 and 3**). The interaction was due to the fact that the decrease in the number of established plants or percent stand establishment with increase in seeding rate was lower for the 19 cm row spacing when compared to the wider row spacing in both years (4.7% vs. 17.2% in 2014; 2.4% vs. 5.9% in 2015).

3.3 Seed yield

Row spacing, seeding rate, and variety effects on seed yield were significant in both years at Aberdeen and in 2015 at Beresford (**Tables 4** and **5**). In 2014, only seeding rate significantly affected seed yield at Beresford. In all four location-years, the narrow row spacing of 19 cm outyielded the wider row spacing of 76 cm with the yield advantage ranging from 37 to 424 kg ha^{-1} or 0.8 to 10%. Our results agree with earlier finding by other researchers in the Upper Midwest [2–4]. The advantage of narrow rows in the Northern United States is attributed to a shorter growing season and related canopy development and light interception. Narrow rows speed the rate of canopy closure and hence increase light interception [11, 12]. Earlier canopy closure means less moisture loss through evapotranspiration and results in higher water-use efficiency [13]. However, it is important to note that the advantage of narrow rows can diminish under moisture stress. Soybean plants grown in

		2014		2015	
Row spacing (S) (cm)	**Seeding rate (SR) (seeds ha^{-1})**	**Plant (ha^{-1})**	**Percentage (%) stand**	**Plant (ha^{-1})**	**Percentage (%) stand**
19	247,000	246,368	99.7	215,273	87.1
	333,500	323,209	96.9	288,825	86.6
	420,000	397,359	94.6	362,975	86.4
	506,500	484,963	95.7	429,052	84.7
76	247,000	215,273	87.1	193,896	78.5
	333,500	252,786	75.8	265,055	79.4
	420,000	293,908	69.9	327,694	77.9
	506,500	354,304	69.9	367,908	72.6
SE		3759	1.08	7306	1.9

Table 3.
Interaction of row spacing and seeding rate for established plants ha^{-1} and percentage (%) stand establishment at Aberdeen, SD, in 2014 and 2015.

	Aberdeen			Beresford		
Row spacing (S) (cm)	**Yield (kg ha^{-1})**	**Seed protein (g kg^{-1})**	**Seed oil (g kg^{-1})**	**Yield (kg ha^{-1})**	**Seed protein (g kg^{-1})**	**Seed oil (g kg^{-1})**
19	4189a*	336.1	180.2	4765	347.9a	178.0
76	3765b	321.7	179.9	4728	344.3b	179.0
Seeding rate (SR) (seeds ha^{-1})						
247,000	3863b	307.8b	180.9	4542c	343.5c	179.5a
333,500	3964b	333.2ab	180.2	4743b	344.4bc	179.2ab
420,000	3986ab	336.1a	179.6	4832ab	346.6b	178.1bc
506,500	4095a	336.4a	179.6	4868a	350.0a	177.4c
Variety (V)#						
0906R2/ 2306R2	3888b	327.4	179.2b	4765	344.0b	178.8
1108R2/ 2408R2	4067a	329.3	180.9a	4727	348.2a	178.3
	Analysis of variance (P > F)					
S	<0.001	0.187	0.549	0.566	<0.001	0.121
SR	0.007	0.113	0.199	<0.001	<0.001	0.004
S × SR	0.853	0.470	0.971	0.192	0.228	0.131
V	<0.001	0.841	0.001	0.386	<0.001	0.258
V × S	0.024	0.408	0.098	0.056	0.699	0.887
V × SR	0.195	0.428	0.147	0.249	0.143	0.608
V × S × SR	0.823	0.461	0.777	0.639	0.705	0.393

**Within each column and each treatment, means followed by the same letter are not significantly different (P 0.05).*
#Soybean varieties 0906R2 and 1108R2 were grown at Aberdeen and 2306R2 and 2408R2 at Beresford.

Table 4.
Seed yield, seed protein concentration, and seed oil concentration of soybean as influenced by row spacing, seeding rate, and variety at two locations in South Dakota in 2014.

narrow rows can deplete soil water early in the growing season resulting in insufficient available water during the reproduction stages of growth [14, 20].

Seeding rate effects for seed yield were significant for both years and locations (**Tables 4** and 5). In all four location-years, the top seeding rate of 506,500 seeds ha^{-1} yielded significantly higher than the other three seeding rates, while the three lower seeding rates of 247,000, 333,500 and 420,000 had similar yields at Aberdeen in 2014 and 2015 and at Beresford in 2015. Carpenter and Board [21], Cox et al. [32], and Thompson et al. [8] reported no yield response of soybean to seeding rate and attributed this to the fact that soybean compensates for space in the canopy by adding more branches. Similarly, Cox and Cherney [6] reported that soybean compensated with more biomass, pods, and seed plant^{-1} at lower seeding rates. On the other hand, other researchers have reported that increasing seeding rate can result in greater yield [22, 31]. While the present study supports the later research findings, it is important to note that the seed yield increase observed in this study due to seeding rate was very low ranging from 3 to 7%. This supports the reported [6] compensatory power of soybean plants at lower seeding rates.

Row spacing × seeding rate interaction for seed yield was significant only at one location-year (Beresford, 2015). The interaction was due to the fact that the narrow

	Aberdeen			Beresford		
Row spacing (S) (cm)	**Yield (kg ha^{-1})**	**Seed protein (g kg^{-1})**	**Seed oil (g kg^{-1})**	**Yield (kg ha^{-1})**	**Seed protein (g kg^{-1})**	**Seed oil (g kg^{-1})**
19	4174a*	325.8	195.3b	4521a	331.4a	195.0
76	4018b	326.7	198.7a	4325b	328.4b	195.8
Seeding rate (SR) (seeds ha^{-1})						
247,000	4042b	323.2	197.7	4390b	329.4	195.4
333,500	4068b	328.3	196.8	4394b	330.1	195.8
420,000	4087b	325.4	197.1	4395b	329.8	195.5
506,500	4185a	326.2	196.6	4510a	330.3	194.9
Variety (V)#						
0906R2/ 2306R2	4058b	322.7b	197.1	4319b	328.1	195.7
1108R2/ 2408R2	4133a	328.8a	196.9	4526a	330.7	195.1
	Analysis of variance (P > F)					
S	<0.001	0.956	0.041	0.003	0.021	0.372
SR	0.003	0.097	0.605	0.008	0.965	0.774
S × SR	0.155	0.621	0.892	0.029	0.089	0.915
V	0.008	<0.001	0.839	<0.001	0.282	0.335
V × S	0.895	0.018	0.160	0.269	0.069	0.771
V × SR	0.004	0.675	0.008	<0.001	0.384	0.065
V × S × SR	0.038	0.682	0.221	0.487	0.948	0.154

**Within each column and each treatment, means followed by the same letter are not significantly different (P 0.05).*
#Soybean varieties 0906R2 and 1108R2 were grown at Aberdeen and 2306R2 and 2408R2 at Beresford.

Table 5.
Seed yield, seed protein concentration, and seed oil concentration of soybean as influenced by row spacing, seeding rate, and variety at two locations in South Dakota in 2015.

row spacing of 19 cm yielded significantly higher than the wider row spacing (76 cm) only at higher seeding rates of 420,000 (yield 5% higher) and 506,500 (yield 7% higher) (data not presented). Previous research results on row spacing × seeding rate interactions are in dispute with some researchers [3, 6] reporting row spacing × seeding rate interactions and soybean yielding greater at higher seeding rates and narrow row spacing as reported at Beresford in 2015. Other researchers have reported similar optimum seeding rates for both narrow and wider rows [8, 18, 19]. The current results are more in agreement with the later reports as 3 of 4 location-years did not show significant row spacing × seeding rate interaction.

Variety effects for seed yield were significant at Aberdeen in 2014 and 2015 and at Beresford in 2015. The varieties were chosen based on adaptation to the region but also were different in white mold ratings. At each location, the longer duration variety had a higher white mold rating (less resistant) than the shorter duration variety. In both years and in all instances, where varietal effects were significant, the longer duration variety was the higher yielding of the two. However, the difference was not considered to be related to white mold since white mold scouting showed little to no white mold infection in both years and locations. Instead, the yield difference is attributable to season length and the longer duration variety maximizing yield due to extra growing days. This was supported by the fact that variety × row spacing interaction effects on seed yield were significant only in one location-year (Aberdeen, 2014). Even then, the interaction was due to the longer duration variety (1108R2) yielding significantly higher than the shorter duration variety (0906R2) (3906 vs. 3624 kg ha^{-1}) when seeded in 76 cm row spacings, but the two varieties yielding the same (4227 vs. 4151 kg ha^{-1}) when seeded in 19 cm rows. White mold, if present, would be a bigger problem under narrow rows due to high humidity under a dense canopy [4, 24]. The fact that the row spacing × variety interaction was observed in only 1 year and under wider rows further confirms that the yield advantage of long duration varieties was related to season length.

Variety × seeding rate effects on seed yield were significant at both locations in 2015 (**Table 5**). The interactions are presented in **Table 6**. At Aberdeen the interaction was due to the fact that the longer duration variety showed an increase in seed yield with increasing seeding rate with the best yield obtained at a seeding rate of 506,500 seeds ha^{-1}. For the short duration variety, however, trends were different with the lowest seeding rate of 247,000 seeds ha^{-1} yield the same as the highest seed rate (**Table 6**). At Beresford, the variety × row spacing interaction was, again, due to inconsistent performance of varieties at different seeding rates with the longer duration variety yielding highest at the lowest seeding rate. These results are not surprising as soybean plants respond to environmental conditions and can compensate for lower plant populations by producing more branches [32].

3.4 Seed protein and seed oil concentration

Row spacing, seeding rate, and variety effects for seed protein concentration were significant at Beresford in 2014 (**Table 4**). Seed from narrow rows had higher protein than from wider rows, while protein concentration increased with increasing seeding rate, and the longer duration soybean variety had higher seed protein

	Yield (kg ha^{-1})	
Seeding rate (seeds ha^{-1})	**0906R2**	**1108R2**
	Aberdeen (2015)	
247,000	4103a*	4034b
333,500	3985b	4099ab
420,000	3980b	4196a
506,500	4166a	4204a
	Beresford (2015)	
	2306R2	2408R2
247,00	4178b	4602a
333,500	4326a	4464b
420,000	4352a	4439b
506,500	4420a	4601a

**Within each column and year, means followed by the same letter are not significantly different (P 0.05).*

Table 6.
Seed yield of soybean as influenced by seeding rate and variety at two locations in South Dakota in 2015.

than the shorter duration variety. In 2015, variety × row spacing effects were significant for protein at Aberdeen, while row spacing effects were significant at Beresford (**Tables 4** and **5**). The longer duration variety had higher seed protein at Aberdeen in 2015, while the narrow row spacing, again, had higher seed protein than the wider rows at Beresford in 2015. In 2014, variety effects were significant for seed oil concentration at Aberdeen, while seeding rate effects were significant at Beresford. The longer duration variety, 1108R2, had higher seed oil concentration than the shorter duration variety, 180.9 and 179.2 g kg^{-1}, respectively. At Beresford, seed oil concentration decreased with increasing seeding rate with the highest seeding rate of 506,500 seed ha^{-1} having 2.1 g kg^{-1} lower oil concentration than the lowest seeding rate. In 2015, row spacing and variety × seeding rate effects for seed oil concentration were significant at Aberdeen (**Table 5**). The wider row spacing had significantly higher seed oil concentration than the narrow row spacing (198.7 vs. 195.3 g kg^{-1}). There were no clear trends to explain the variety × seeding rate interaction for seed oil concentration rather than that oil concentrations for both varieties were inconsistent from one seeding rate to the other. Research results on the effects of row spacing or seeding rate on protein content and seed oil concentration are not readily available. One consistent relationship, among studies, has been a negative correlation between seed protein and seed oil concentration. This negative correlation can be attributed to various genetic and environmental factors [33]. One possible explanation for the inconsistent relationship between row spacing and seeding rate and grain quality could be explained by water availability during seed filling. Rotundo and Westgate [34] found that water stress during seed filling (R5–R7) reduced protein and oil accumulation in soybean. Accounting for differences in water availability during seed filling and season could explain the major differences in research results for the row spacing and seeding rate studies. For example, longer duration varieties have prolonged seed maturation period resulting in greater oil or protein accumulation. Wider rows may preserve soil moisture making soil moisture conditions more favorable during the seed filling period and therefore greater oil concentration in the seed.

4. Conclusions

A considerable number of growers in the Upper Midwest continue to grow soybean in wide row spacings (50–76 cm). Results from the present study and others indicate that soybean planted in narrow rows of 19 cm have higher yield potential when compared to soybean planted in wider rows. Soybean yield responded to seeding rate with maximum yield obtained at a seeding rate of 506,500 seeds ha^{-1} with no significant interaction between row spacing and seeding rate. In terms of soybean variety, the longer duration variety at each location had higher yield. Although the current results indicate that the best soybean yield can be obtained when the crop is seeded in row spacings of 19 cm at seeding rates of 506,500 seeds ha^{-1}, it must be noted that management choices for growers are influenced by a number of factors. In addition to yield potential, growers consider equipment costs associated with changing row spacings and disease and lodging problems associated with narrow rows or high seeding rates. And because of high costs of soybean seed, economic optimum seeding rates are usually less than seeding rates that result in highest yields. However, it is important that growers in the Upper Midwest consider seeding soybean in narrower rows as the current results and many others show that soybean planted with such row spacings have higher yield potential than soybean planted in wider rows.

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Author details

Matthew Schutte[2] and Thandiwe Nleya[1]*

1 Agronomy, Horticulture, and Plant Science Department, South Dakota State University, Brookings, SD, USA

2 Business Development Representative, Bioverse Natural Solutions, Rushmore, MN, USA

*Address all correspondence to: thandiwe.nleya@sdstate.edu

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