Soybean Yield and Yield Component Response to Plant Density in Narrow Row Systems

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Epler, M., and Staggenborg, S. 2008. Soybean yield and yield component response to plant density in narrow row systems. Crop Management doi:10.1094/CM-2008-0925-01-RS.

Accepted for publication 7 July 2008. Published 25 September 2008.

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ABSTRACT

Soybean (Glycine max) yield is responsive to changes in plant population and row spacing under dryland conditions. Soybean seeding rate recommendations in many states were developed prior to the release of herbicide tolerant varieties when soybean seed costs were lower. As a result, many recommendations are high, and soybean performance at low plant densities in narrow rows needs to be reevaluated. This study was conducted to evaluate soybean yield response to plant density in narrow row, drilled systems (7.5 and 15 in) and evaluate the effects of plant population on yield components. The study was conducted in six environments with optimum plant populations ranging from 80 000 to 140 000 plants acre^{-1}. The two yield components responsible for the yield optimization were pods plant^{-1} and pods acre^{-1}. As plant population increased, pods plant^{-1} decreased steadily; however, yield was not reduced either year of the study by the loss of pods plant^{-1} because pods acre^{-1} increased as plant population increased. The optimum seeding rates for each year of the study were below the 150 000 to 160 000 plants acre^{-1} seeding rate normally recommended in the region. The decreased optimum plant populations in both years did not adversely affect yield and might be useful in reducing input costs in dryland soybean production.

Soybean yield responses to plant density and row spacing have been studied extensively during the past two decades. Many studies examined physiological responses to narrow row spacing (7.5 in or less) as this management system evolved (Board and Harville, 1992; Buhler et al., 1990; Bullock et al., 1998; Duncan, 1986; Egli et al., 1987; Ethredge et al., 1989; Safo-Katanka and Lawson, 1980). Early seeding rate recommendations for soybean grown in narrow rows were quite high (~ 200,000 seed acre^{-1}), but seed costs were quite low prior to the release of herbicide tolerant varieties (Staggenborg et al., 1996).

Early narrow row soybean research was conducted under conventionally tilled systems with grain drills designed for wheat seed metering and placement. The combination of this tillage system and planting equipment often resulted in low emergence rates. This, combined with low seed costs is likely the genesis of high seeding rate recommendations.

The ability of soybean to compensate for low population has resulted in little or no response to changes in plant population from 70 000 up to more than 400 000 seed acre^{-1} (Ablett et al. (1991); Adams and Weaver, 1998; Beuerlein, 1988; Costa et al., 1980; Kratochvil et al., 2004; Lehman and Lambert, 1960; Riess and Sherwood, 1965). Devlin et al. (1995) found that yields in Kansas are normally affected by water availability, planting date, and soil type. This illustrates that environmental conditions can contribute to the non-response of soybean yields to increasing seeding rates.

Soybean responds to row spacing and population shifts through yield component adjustments. Carpenter and Board (1997) attributed soybean yield compensation at low densities to increased branching, while others reported that pods plant^{-1} and seeds plant^{-1} were the source of compensation (Ball et al., 2000; Board et al., 1990; Boquet, 1990; Lehman and Lambert, 1960; Norsworthy and Shipe, 2005; Weber et al., 1966). Board et al. (1990) and Bullock et al.

(1998) reported that early season light interception was the reason for narrow row soybean having higher yields than those grown in wide rows. In wider rows, decreased light interception led to decreased branching, pods plant^{-1}, and seeds plant^{-1} which provided the yield advantage in narrow row soybean. These researchers also reported decreased pods plant^{-1}, and Bullock et al. (1998) reported decreased branching as row width increased, which suggests that added inter-row space does not always translate into increased branches and pods plant^{-1}.

Because soybean has the ability to adjust yield components at low plant densities to maintain yield levels, it is possible that soybean seeding rates in narrow row systems can be reduced without reducing grain yields. Therefore, our objectives were to: 1) evaluate yield, yield component, and plant characteristic responses to plant population and row spacing and 2) determine the minimum soybean plant population that can be achieved in Kansas without decreasing yields.

Field Studies

This study was conducted in 2005 and 2006. Plots were planted at Manhattan, KS, Ottawa, KS, and Rossville, KS in 2005 and 2006. Table 1 shows the soil series and taxonomic description for each of the locations and years included in the study.

All small plots were sowed with a no-till drill (Model 3P605NT, Great Plains Mfg., Salina, KS) with 7.5 in row spacing. In 2005 and 2006 treatments consisted of five seeding rates: 60-, 100-, 140-, 180-, and 220 000 seeds acre^{-1}. In 2005, plots had 7.5 in row spacings and in 2006, a 15 in row spacing treatment was added at all locations. At all three locations in 2005, the experimental design was a randomized complete block with four replications. In 2006, a split plot within a randomized complete block design with row spacing as the main plot and seeding rate as the sub-plots was used at all locations. Plot size was 6 by 30 ft at all locations. The tillage system at the 2005 and 2006 Manhattan and Ottawa locations was no-till, while the 2005 and 2006 Rossville locations were planted into a conventional–till system. Table 2 shows the planting date, row spacing, previous crop, and variety of seed used for all locations in 2005 and 2006.

At all locations and both years, final plant population was determined approximately 30 days after planting. To determine plant population, plants were counted on both sides of a 10 ft pipe that was randomly placed between two non-border rows. Pods plant $^{-1}$, with respect to origin on plant (branches or mainstem), plant height, and height of the lowest pod were determined at approximately growth stage R7 by randomly selecting two plants from each plot for measurement. The yield components seeds pod^{-1} and pods acre^{-1} were calculated using the plant populations and the pods plant^{-1}, and 200 seeds were counted from every plot to determine seed weight. All 2005 locations were combined for analysis using GLM (SAS v 9.1) after variance testing indicated the variances were equal from each location. In 2006, the Manhattan, Ottawa, and Rossville locations were combined for analysis using GLM (SAS v 9.1).

Yield Responses to Narrow Rows

In this study, the soybean planting dates and seeding rates used included the normal ranges used in Kansas. Across both years, yields ranged from 24 to 64 bu acre^{-1} which was attributed to the wide variation in temperature, soil quality, and rainfall throughout the two years of the study.

In 2005, adequate rainfall was received for much of the growing season, which contributed to the moderately high yields found at all three locations (Fig 1). The adequate rainfall across the region resulted in yield variances that were equal for each of the three locations, so the data were combined for analysis and only plant population affected yields (Table 3). Across all three locations, yields increased as plant population increased until reaching a plateau at 80 000 plants acre^{-1} (Fig. 2A).

In 2006, rainfall was not as abundant in the region, and yields were lower than 2005. Locations, location X population and location X row spacing affected yields (Table 3). The 7.5 in row spacing produced higher yields at all locations in 2006, and Manhattan and Ottawa both yielded higher than Rossville in 2006 (Table 4). As plant population increased, yield increased in a quadratic manner at Manhattan and Ottawa with optimum yields occurring at plant populations 136 000 and 140 000 plants acre^{-1}, respectively (Fig. 2B). A severe hailstorm at Rossville in 2006 at approximately the V2 growth stage decreased the final plant population and delayed the crop (Table 4). The lower plant densities at Rossville contributed to the significant location X row spacing interaction in 2006 (Table 3). The lower plant densities and delayed development at Rossville in 2006 resulted in a similar yield response to increasing plant populations as the other locations. Based on the regression analysis and extrapolation beyond the data, the optimum plant population at Rossville in 2006 was approximately 150 000 plants acre^{-1}. This is not an unreasonable conclusion, as the physical hail damage and delayed development might require more plants to develop adequate pods and grain to reach the yield potential compared with the other two locations where hail was not a factor.

Optimum plant densities of 80 000 and 140 000 plants acre^{-1} (2005 and 2006, respectively) are below the recommended seeding rates for Kansas (Fjell et al., 1997) and Nebraska (Elmore and Specht, 2000) who recommend 180 000 and 150 000, respectively and in agreement with seeding rates for 30 inch rows in Missouri (Helsel and Minor, 1993). However, our results are reported in plants acre^{-1} and seeding recommendations are made in seed acre^{-1} meaning that emergence rates must be considered. This creates the greatest challenge associated with the seeding rate decision as seeding equipment (drill vs. planter), weather (rain at planting) and seed quality can play an important role in emergence rates.

Pods Plant^{-1} and Pods acre^{-1}

Yield components responded similarly across locations and years. In 2005 and 2006 plant population affected pods plant^{-1} (Table 3). Pods plant^{-1} were different at each location in both 2005 and 2006 (Table 5). Throughout the study, as population increased, pods plant^{-1} decreased in a polynomial manner, reaching minimums from 150 000 to 190 000 plants acre^{-1} (Fig. 3A). The negative response in pods plant $^{-1}$ to increasing plant population agree with the findings of several other researchers (Ball et al. 2000; Boquet 1990; Lehman and Lambert 1960; Norsworthy and Shipe 2005; Weber et al. 1966).

In 2005 and 2006, pods acre^{-1} were affected by location and plant population (Table 3). Pods acre^{-1} were different across locations both years (Table 5). It appears that the lower plant densities and damage to the plants from the hail at Rossville in 2006 had less impact on the plants' ability to compensate than might be expected. Pods plant^{-1} at Rossville were equal to those at Ottawa and greater than at Manhattan. Pods acre^{-1} at Rossville were lower than at the other two locations. As population increased, pods acre^{-1} increased in a linear manner (Fig. 3B). Pods plant^{-1} was not correlated to yield ($r = 0.02$), but pods acre^{-1} was correlated to yield ($r = 0.72$). These results agree with the findings of Parvez et al. (1989), but conflict with those of Ethredge et al. (1989).

Branch Contribution to Total Pods Plant^{-1}

In 2005 and 2006, pods plant^{-1} on branches were affected by plant density (Table 3). As population increased in both years, the percent of branch pods on each plant decreased (Fig. 3C). It was apparent that increased competition within the rows caused the plants to branch less, and therefore receive less of the total yield from branches. Branch pod contribution had a low correlation to yield ($r = 0.25$) but had a larger influence on pods acre^{-1} ($r = 0.67$). These findings agree with work done by Probst (1945) and Carpenter and Board (1997), who showed the compensatory ability of soybeans as they react to increases and decreases in available space.

Plant Height

In 2005, plant height was affected by plant density at all locations (Table 3). As plant density increased, plant height increased in a quadratic manner, reaching a maximum at plant population of approximately 195 000 plant acre^{-1} (Fig. 4). In 2006, plant height was affected by location, plant density, and row spacing as indicated by significant location X population and location X row spacing interactions for the three combined locations (Table 3). Plant heights were not different when comparing the two row spacings at Manhattan and Rossville in 2006 (Table 6). At Ottawa in 2006, plants in the 7.5 in rows were shorter than plants in the 15 in rows.

Plant height was not affected by plant population to the same degree at Manhattan and Ottawa in 2006 as in 2005. In 2005, plant heights across all locations had a range of 4 in, whereas at these two locations in 2006, the range was less than 2 in. In 2006, only at Rossville did plant height increase as rapidly as plant density increased. Plant height in narrow row soybean is often a concern to producers, as taller plants are believed to have greater risk of lodging.

Height of First Pod

Of greater interest to producers than plant height is the location of the first pod from the soil surface. Across all locations each year, height of first pod was affected by plant population (Table 3). The location main effect was also significant in 2006. In 2005, height to the first pod increased linearly and reached a plateau at approximately 110 000 plants acre^{-1} (Fig. 5). In 2006, average height of the lowest pod increased as plant population increased and reached a maximum at approximately 140 000 plants acre^{-1}(Fig. 5). These observations agree with the findings of Lueschen and Hicks (1977), who reported similar responses of first pod height to plant population.

Seeds Pod^{-1} and Seed Weight

Population affected seeds pod^{-1} in 2006 (Table 3) but seeds pod^{-1} were not affected by any treatments in 2005. As population increased, seeds pod^{-1} decreased in a linear manner (seeds pod^{-1} = 2.71 – 3.21x10^{-6}*plant population) with the data ranging from 2.3 to 1.5 seeds pod^{-1} (data not shown). In both 2005 and 2006, growing conditions at each location affected seed weights differently (Table 3). In 2005, seed weights were different at each location (Table 5). In 2006, the delayed development because of the hail damage at Rossville reduced the time available for grain fill and seed weights at Rossville were lower than those measured at Manhattan and Ottawa. This illustrates that the yield component most affected by the hail damage was seed weight compared with pod plant^{-1} and pods acre^{-1}. As discussed earlier, pod acre^{-1} were approximately 10% lower at Rossville than Manhattan, whereas seed weights are approximately 20% lower at Rossville compared with the other two locations in 2006.

Seed weight influenced grain yield (r = 0.79), but seeds pod^{-1} did not influence yield (r = -0.06). Seed weight and seeds pod^{-1} yield responses were mainly affected by rainfall and high temperatures late in the growing season after growth stage R5. These findings agree with those of Board et al. (1990) and Lehman and Lambert (1960), who both reported that seeds pod^{-1} and seed weight typically do not display as large of a response to plant density as do the yield components pods plant^{-1} and pods acre^{-1}.

Summary

Row spacing had little effect on soybean yield and yield components, but population and environment played major roles in dictating yield responses. Yields were maintained across changing plant densities due to the compensatory abilities of soybean to fluctuate yield components in response to intra- and inter-row competition. The 2005 plots failed to increase in yield above 80 000 plants acre^{-1} and the 2006 plots had optimum plant populations below the currently recommended seeding rates for Kansas and Nebraska and were in agreement with those from Missouri. Therefore, it is likely that the recommended soybean seeding rates for dryland environments can be safely lowered by at least 20-25%.

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Figures and Tables

Table 1. Soil series and taxonomic descriptions for all 2005 and 2006 plot locations.

Year	Location	Soil Series	Taxonomic Description
2005	Manhattan	Reading silt loam	Fine-silty, mixed, superactive, mesic Pachic Argiudolls
2005	Ottawa	Woodson silt loam	Fine, smectitic, thermic Abruptic Argiaquolls
2005	Rossville	Eudora silt loam	Coarse-silty, mixed, superactive, mesic Fluventic Hapludolls
2006	Manhattan	Smolan silt loam	Fine, smectitic, mesic Pachic Argiustolls
2006	Ottawa	Woodson silt loam	Fine, smectitic, thermic Abruptic Argiaquolls
2006	Rossville	Eudora silt loam	Coarse-silty, mixed, superactive, mesic Fluventic Hapludolls

Table 2. Planting dates, row spacing, previous crop, and soybean variety for 2005 and 2006 soybean plots.

Year	Location	Planting Date	Row Spacing (in)	Previous Crop	Soybean Variety
2005	Manhattan	17-May	7.5	soybean	Asgrow brand 3701 RR
2005	Ottawa	27-May	7.5	sorghum	Asgrow brand 3701 RR
2005	Rossville	20-May	7.5	corn	Asgrow brand 3701 RR
2006	Manhattan	16-May	7.5 & 15	sorghum	Garst brand 3824 RR
2006	Ottawa	19-May	7.5 & 15	sorghum	Garst brand 3824 RR
2006	Rossville	8-Jun	7.5 & 15	corn	Garst brand 3824 RR

Table 3. Significance levels for soybean plots in 2005 and 2006 at Manhattan, Ottawa, Rossville, and Parsons KS.

	Seed Yield	Plants acre^{-1}	Pods Plant^{-1}	Pods acre^{-1}	Branch Pod Percent	Plant Height	First Pod Height	Seeds Pod^{-1}	Seed Weight
					2005				
Rep	*	NS	*	NS	NS	*	*	NS	NS
location	NS	*	*	*	NS	NS	NS	NS	*
population	*	*	*	*	*	*	*	NS	NS
loc x pop	NS	NS	NS	NS	NS	NS	NS	NS	NS
					2006				
Rep	*	*	NS	NS	NS	*	*	NS	*
location	*	*	*	*	NS	*	*	NS	*
population	*	*	*	*	*	*	*	*	NS
row spacing	NS	NS	NS	NS	NS	*	NS	NS	NS
rs*pop	NS	NS	NS	NS	NS	NS	NS	NS	NS
loc*pop	*	*	NS	NS	NS	*	NS	NS	NS
Loc*rs	*	*	NS	NS	NS	*	NS	NS	NS
loc*rs*pop	NS	NS	NS	NS	NS	NS	NS	NS	NS

* Significant at α = 0.05 level.

Table 4. Soybean yield for two row spacings at three locations in Kansas in 2006.

	Row Spacing				
	7.5 in		15 in		
Location	- - - - - - - - Yield (bu acre^{-1}) - - - - - - - -				Avg.
Manhattan	36	c†	35	cd	36
Ottawa	44	a	41	b	42
Rossville	29	e	33	d	31
Avg.	36		36		36
	- - - - - - - - - Plants acre^{-1} - - - - - - - - -				Avg.
Manhattan	124 487	a†	112 084	b	118 186
Ottawa	105 809	b	93 868	c	99 838
Rossville	79 611	e	82 189	d	75 434
Avg.	102 009		98 533		100 271

† Means within a column or row for the same variable followed by a different letter differ at $\alpha = 0.05$.

Table 5. Soybean yield components and plant characteristics at Manhattan, Ottawa, and Rossville, KS in 2005 and 2006.

Location	Year	Pods plant^{-1}	Pods acre $^{-1}$ (x 10^{-6})	First Pod Height (in)	Seed Weight (mg seed^{-1})
Manhattan	2005	59.3 a †	6.3 b	4.3 c	140 a
Ottawa	2005	37.7 b	4.4 c	6.7 a	133 b
Rossville	2005	67.0 a	7.6 a	4.8 b	128 c
Manhattan	2006	38.2 b †	4.2 b	4.5 a	158 a
Ottawa	2006	50.9 a	4.7 a	3.8 a	159 a
Rossville	2006	52.4 a	3.8 c	3.8 a	130 b

† Means within a column followed by a different letter differ at 0.05.

Table 6. Soybean plant heights for two row spacings at three locations in Kansas in 2006.

Row Spacing	Manhattan	Ottawa	Rossville	Avg.
		(in)		
7.5	20.4 de†	27.4 b	20.2 e	22.7
15	20.2 e	29.4 a	20.9 de	23.5
	20.3	28.3	20.6	

† Means followed by a different letter differ at α = 0.05 for Manhattan, Ottawa, and Rossville.