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Introduction

Crop production management variables such as row spacing and seeding rates affect weed management and influence the crop's ability to compete with weeds for water and mineral resources. More rapid canopy closure can be obtained with a reduction in row spacing (Renner and Mickelson, 1997; Wax and Pendelton, 1968), increased seeding rates (Nice et al., 2001), and selection of varieties with traits that favor rapid canopy development (Bussan et al., 1977). In addition to more rapid canopy closure, narrow rows frequently have greater yields (Wax and Pendelton, 1968; Ablett et al., 1991; Oplinger and Philbrook, 1992; Shaw et al., 1991; Corrigan and Harvey, 2000; Buehring et al., 2002).

In the past, high seeding rates with conventional varieties were often established with "saved seed" and did not significantly affect soybean production costs (Kratochvil et al., 2004). But, as technology fees and seed costs increase, the economic burden of higher seeding rates may exceed the benefits of weed suppression (Nice et al., 2001; Renner and Nelson, 1999) and reduction with sequential glyphosate applications (Buehring et al., 2002). Norsworthy and Frederick (2002) reported that the recommended Roundup Ready soybean seeding rates could be lowered without negatively affecting yield. Holshouser and Whittaker (2002) found that a seeding rate of 84,211 seeds per acre was adequate for maximizing yields. Kratochvil et al. (2004) reported yields from a seeding rate of 139,676 seeds per acre were not different from a rate of 175,100 seeds per acre. Furthermore, they reported the reduced seeding rate resulted in additional profits ranging from $5.17 to $11.34 per acre because of the lower seed costs. Norsworthy and Oliver (2001) reported increased profit margins from weed management with a seeding rate of 74,899 seeds per acre. They reported that the savings in seed costs were greater than the expense for an additional glyphosate application.

However, research in Iowa indicated that yields for seeding rates higher than 75,020 seeds per acre were marginal and did not compensate for higher seed costs (De Bruin and Pedersen, 2008). In an evaluation of Roundup application time, also in Iowa, Arce et al. (2009) reported that although soybean population did not consistently affect weed populations, weed biomass at soybean harvest was inversely related to soybean population. Lower soybean yields occurred with a seeding rate of 97,667 seeds per acre compared with 170,040 seeds per acre at all locations and 121,457 seeds per acre at two locations. They indicated that to achieve consistent weed control, growers should avoid the low end of recommended seeding rates in fields where weed management is more difficult.

Improvements in planting equipment through vacuum planter technology (more uniform seed spacing), better seed placement depth control, and good seed slit closure systems has resulted in more uniform stands and fewer stand failures. These improvements also have potential to reduce seeding rates. Populations from a seeding rate of 105,000 seeds per acre planted with a vacuum planter (uniform seed spacing) produced yields equal to a rate of 140,000 seeds per acre planted with a conventional air planter (variable seed spacing) (Harrison et al., 2001; Harrison et al., 2002).

Objective

The objective of this study was to determine the effect of soybean maturity group, seeding rates, and plant populations on yield, plant height at maturity, basal stem diameter at maturity, and number of plant branches at maturity using Roundup Ready soybeans grown using narrow-row culture and good weed management practices.

Materials and Methods

A 3-year (2004–06) study was conducted on a Leeper silty clay soil at the Mississippi Agricultural and Forestry Experiment Station Northeast Branch Station at Verona. The study was conducted as a split-plot design in a randomized complete block design with four replications. Years were the main plot factor with varieties as the subplot factor and seeding rates as the sub-subplot factor.

The study included six Roundup Ready varieties commonly grown in north Mississippi — three Maturity Group (MG) IV and three MG V varieties. Four seeding rates — 60,000, 90,000, 120,000, and 150,000 seeds per acre — were planted in 15-inch rows in late April with a Monosem® vacuum planter (Monosem Inc., Lenexa, Kansas). In all 3 years of the study, seed germination was 80% for all varieties planted. Averaged over years (2004–05), seed mass (weight per seed) for all six varieties was used to calculate the average pounds of seed planted per acre for each variety and seeding rate.

Data collected were yield, planting seed weight, plant populations 4 weeks after planting, plant height at maturity, and basal stem diameter at maturity. The center four rows of each plot were harvested with a plot combine 7–10 days after each treatment matured. All data were analyzed with SAS PROC MIXED program in the Statistical Analysis Systems (SAS) software (Littell et al., 1996). When no interactions were detected, the data were pooled and reanalyzed. Means were separated using Fishers' Protected LSD at the 5% significance level. Seed cost per acre was determined for each variety/seeding rate based on the average (2004–05) planting seed weight.

Results and Discussion

The monthly average maximum and minimum air temperatures from April through September were different between years (Table 1). The April 2004 and 2005 maximum and minimum temperatures were lower than those in 2006. The maximum air temperatures in June, July, and August 2006 were higher than temperatures in June, July, and August 2004 and 2005. The maximum and minimum air temperatures in July and August 2004 were lower than those in July and August 2005 and 2006. Rainfall patterns were erratic across all 3 years. In 2004, rainfall was below the 30-year (1971–2000) average for April, July, August, and Sep-

Table 1. Monthly average maximum and minimum air temperatures for 2004, 2005, and 2006, Verona, Mississippi.

Month	Max			Min		
	2004	2005	2006	2004	2005	2006
April	72	74	80	49	49	55
May	83	81	81	63	55	59
June	86	87	91	69	68	64
July	90	91	95	70	73	69
August	88	94	96	65	72	70
September	87	90	84	63	65	62

Table 2. Monthly rainfall (inches) from April through September in 2004, 2005, and 2006, Verona, Mississippi.							
Day	**April**	**May**	**June**	**July**	**Aug.**	**Sept.**	**Total**
			2004				
1–10	0.65	0.30	1.39	1.21	0.16	0.12	3.83
11–20	1.59	3.37	1.38	1.13	0.20	3.14	10.81
21–30	0.85	2.93	2.61	0.36	2.51	0.00	9.26
Total	**3.09**	**6.60**	**5.38**	**2.70**	**2.87**	**3.26**	**23.90**
			2005				
1–10	3.79	0.03	2.12	2.31	0.33	0.00	8.58
11–20	1.12	0.82	3.52	3.26	0.18	0.47	9.37
21–30	1.13	0.69	0.00	1.17	5.47	2.60	11.1
Total	**6.08**	**1.54**	**5.64**	**6.74**	**5.98**	**3.07**	**29.05**
			2006				
1–10	3.61	4.35	1.22	2.74	0.47	0.00	12.39
11–20	0.00	1.13	1.10	0.60	0.45	4.45	7.13
21–30	1.61	0.04	0.11	0.06	1.26	2.95	6.03
Total	**5.22**	**5.52**	**2.43**	**3.40**	**2.18**	**7.40**	**26.15**
30-year avg. (1971–2000)	**5.20**	**4.84**	**4.56**	**3.58**	**3.80**	**4.09**	**26.07**

tember. Above-average rainfall in 2004 occurred in May and June. In 2005, rainfall was below average for May and September and above average for April, June, July, and August. In 2006, rainfall was below average for June, July, and August and above average for May and September.

Variety Response

There was a variety-by-year interaction for yield, basal stem diameter at maturity, branches per plant at maturity, and plant height at maturity. In 2005, Deltapine DP 5915RR [MG late (L) V] was infected with aerial web blight (*Rhizoctonia solani*) and had the lowest yield, 25.6 bushels per acre (Table 3). No aerial web blight infection occurred in 2005 and 2006. Except for DP 5915RR in 2005, yields ranged from 40–59 bushels per acre. Hornbeck HBK 4623RR [MG early (E) IV], Asgrow AG4403 (MG E IV), and Deltapine DP 5634RR [MG mid (M) V] yields in 2004 and 2006 were higher than yields in 2005. Deltapine DP 4933RR yields in 2005 and 2006 were higher than yields in 2004. DP 5915RR's yield for 2006 was higher than yields in 2004 and 2005. DP 5634RR's yield of 59.1 bushels per acre was higher than all other yields in 2004 and 2005. In 2006, DK 5366RR (MG E V) and DP 5915RR (MG L V) yields of 58 and 58.4 bushels per acre, respectively, were equal to the DP 5634RR yield.

Table 3. Soybean variety yield response in 2004–06 averaged over seeding rates, Verona, Mississippi.					
Variety	**Brand**	**Maturity group**	**2004**	**2005**	**2006**
			bu/A	*bu/A*	*bu/A*
HBK 4623RR	Hornbeck	E IV	54.7	40.4	47.1
AG4403	Asgrow	E IV	51.8	46.0	50.6
DP 4933RR	Deltapine	L IV	41.6	48.7	49.1
DK 5366RR	Delta King	E V	48.8	46.3	58.0
DP 5634RR	Deltapine	M V	59.1	54.0	58.4
DP 5915RR	Deltapine	L V	25.6 [1]	45.6	58.4
W/I year and variety LSD (0.05) 3.3					

[1]Infested with aerial web blight (*Rhizoctonia solani*).

Table 4. Variety stem diameter at maturity in 2004, 2005, and 2006 averaged over seeding rates, Verona, Mississippi.

Variety	Brand	MG	Stem diameter (inch)		
			2004	2005	2006
HBK 4623RR	Hornbeck	E IV	0.340	0.350	0.387
AG4403	Asgrow	E IV	0.351	0.340	0.396
DP 4933RR	Deltapine	L IV	0.370	0.366	0.453
DK 5366RR	Delta King	E V	0.325	0.315	0.362
DP 5634RR	Deltapine	M V	0.343	0.338	0.343
DP 5915RR	Deltapine	L V	0.390	0.365	0.415
W/I year and variety LSD (0.05) 0.022					

Basal stem diameters at maturity showed a variety-by-year interaction (Table 4). Stem diameters ranged from 0.315 to 0.453 inch. The basal stem diameter for DK 5366RR was smaller than all other varieties across years. Across years, DP 4933RR and DP 5915RR had larger basal stem diameters than all other varieties. DP 5634RR was the only variety that showed no difference between years. HBK 4623RR, AG4403, DP 4933RR, and DK 5366RR showed no stem diameter differences between years 2004 and 2005, but all had smaller diameters than those measured in 2006. DP 5915RR stem diameter was less in 2005 than 2004 and 2006.

The number of branches per plant at maturity ranged from 3.3 for HBK 4623RR in 2006 to 9.7 for DP 5915RR in 2004 (Table 5). There was a variety-by-year interaction for number of branches. The determinant varieties DP 5634RR, DP 5915RR, and DK 5366RR had a greater number of branches per plant than the indeterminant varieties HBK 4623RR, AG4403, and DP 4933RR. The indeterminant varieties showed no difference in branches per plant across years, while some determinant varieties showed differences across years. DK 5366RR showed no difference in branches per plant across years. DP 5634RR had a greater number of branches in 2004 than both 2005 and 2006; there was no difference between 2005 and 2006. DP 5915RR had fewer branches in 2006 than 2005 and 2004; there was no difference between 2004 and 2005.

Plant height at maturity ranged from 27–43 inches and showed a variety-by-year interaction (Table 6). DP 5915RR and AG4403 were the only two varieties that showed no height differences across years. DP 5634RR and HBK 4623RR plant heights for 2004 and 2006 were not different; both years, HBK 4623RR was taller than in 2005. DP 5634RR plant height in 2005 was taller than in 2006. DP 4933RR and DK 5366RR plant heights in 2005 and 2006 were not different but were taller than in 2004.

Seeding Rate Response

Since there were no interactions of variety by seeding rate or variety by seeding rate by year for yield, plant populations, basal stem diameter at maturity, branches per plant at maturity, and plant height at maturity, all seeding rate data were pooled over varieties and years and analyzed. Seeding rates significantly

Table 5. Branches per plant at maturity in 2004, 2005, and 2006 averaged over seeding rates, Verona, Mississippi.

Variety	Brand	MG	Branches per plant		
			2004	2005	2006
HBK 4623RR	Hornbeck	E IV	4.4	5.2	3.3
AG4403	Asgrow	E IV	4.5	4.4	4.9
DP 4933RR	Deltapine	L IV	4.9	5.5	4.6
DK 5366RR	Delta King	E V	8.3	6.7	7.8
DP 5634RR	Deltapine	M V	8.5	6.2	5.9
DP 5915RR	Deltapine	L V	9.7	8.1	6.7
W/I year and variety LSD (0.05) 2					

Table 6. Plant height at maturity in 2004, 2005, and 2006 averaged over seeding rates, Verona, Mississippi.

Variety	Brand	MG	Plant height (inch)		
			2004	2005	2006
HBK 4623RR	Hornbeck	E IV	33	30	35
AG4403	Asgrow	E IV	33	32	33
DP 4933RR	Deltapine	L IV	39	43	42
DK 5366RR	Delta King	E V	27	32	30
DP 5634RR	Deltapine	M V	33	34	31
DP 5915RR	Deltapine	L V	30	30	31
W/I year and variety LSD (0.05)	2[1]				

[1]Averaged over standard errors.

impacted yield, population, plant height at maturity, and branches per plant at maturity (Table 7). Averaged over years (2004–06), the 60,000-seed-per-acre treatment resulted in a population of 51,800 plants per acre; 90,000 seeds, 76,200 plants; 120,000 seeds, 97,300 plants; and 150,000 seeds, 115,500 plants. Yields ranged from 47.5 bushels per acre for 51,800 plants to 50 bushels per acre for 115,500 plants. The 51,800-plant population yield of 47.5 bushels per acre was lower than yields for plant populations of 76,200, 97,300, and 115,500. There were no yield differences between plant populations of 76,200, 97,300, and 115,500. These results were similar to those of Holshouser and Whittaker (2002) and Norsworthy and Oliver (2001), who reported that the profit margin from weed management was optimized with a population of 75,000 plants per acre. De Bruin and Peterson (2008) in Iowa found that economic returns did not differ among seeding rates between 75,000 and 225,000 seeds per acre.

Basal stem diameters at maturity ranged from 0.432 inch for the 51,800-per-acre population to 0.315 inch for the 115,500-per-acre population (Table 7). Basal stem diameters showed incremental differences among plant populations; the lowest population, 51,800 plants, had the largest stem diameter, 0.432 inch. This measurement was 0.055 inch larger than the stem diameter for the 76,200-plant population and 0.117 inch larger than the diameter for the 115,500-plant population.

Plant population had a significant impact on the number of branches per plant at maturity (Table 7). The 76,200-plant population had 6.3 branches per plant, while the 51,800-plant population had 7.4 branches per plant. Both had more branches per plant than the 97,300- and 115,500-plant populations, which demonstrated no differences in branches per plant. Plant height at maturity ranged from 31 inches for 60,000 seeds per acre to 36 inches for 150,000 seeds per acre (Table 7).

Based on the 2-year (2004–05) average planting seed weight, the pounds of seed planted per acre ranged from 14.7 pounds for DP 3933RR at 60,000 seeds per acre to 50.3 pounds for DP 5634RR at 150,000 seeds per acre (Table 8). With a seeding rate of 90,000 seeds per acre, the weight per acre of seeds for HBK 4623RR was 26.2 pounds; AG4403, 26.3 pounds; DP 4933RR, 22 pounds; DK 5366RR, 24.9 pounds; DP 5634RR,

Table 7. Seeding rate effect on plant population, yield, basal stem diameter, branches per plant, and plant height at maturity averaged over years (2004–06) and soybean varieties, Verona, Mississippi.

Seeds per acre	Plants per acre	Yield (bu/A)	Stem diameter (inch)	Branches per plant	Maturity height (inch)
60,000	51,800	47.5	0.432	7.4	31
90,000	76,200	49.4	0.377	6.3	33
120,000	97,300	49.6	0.333	5.5	34
150,000	115,500	50.0	0.315	5.2	36
LSD (0.05)	3,200	1.2	0.009	0.3	1

Table 8. Roundup Ready soybean variety seeding rates expressed as seed weight per pound and pounds of planting seed per acre, averaged over years (2004–05), Verona, Mississippi.

Variety	Brand	Maturity group	Seeds per pound	Pounds of seed per acre at four planting rates			
				60,000	90,000	120,000	150,000
HBK 4623RR	Hornbeck	E IV	3,436	17.5	26.2	34.9	43.7
AG4403	Asgrow	E IV	3,428	17.5	26.3	35.0	43.8
DP 4933RR	Deltapine	L IV	4,092	14.7	22.0	29.3	36.7
DK 5366RR	Delta King	E V	3,612	16.6	24.9	33.2	41.5
DP 5634RR	Deltapine	M V	2,982	20.1	30.2	40.2	50.3
DP 5915RR	Deltapine	L V	3,167	18.9	28.4	37.9	47.4

30.2 pounds; and DP 5915RR, 28.4 pounds. The seed cost per acre was based on each variety's seed weight, seeding rate per acre, and a seed cost of $1.00 per pound (Table 9). DP 5634RR had the largest seed mass at 2,982 seeds per pound; it also had the highest seed cost per acre, which ranged from $20 for 60,000 seeds to $50 for 150,000 seeds. DP 4933RR, which had the lowest seed mass, also had the lowest seed cost per acre, ranging from $15 for 60,000 seeds to $37 for 150,000 seeds. Varieties with a smaller seed mass offer some savings in seed cost per acre, but one should never use seed size alone for selecting an appropriate variety. Yield and resistance to known disease pests are the best criteria for selecting an appropriate variety.

Averaged over years (2004–05), based on planting seed weight and a seed cost of $1.00 per pound of seed, the cost for planting 90,000 seeds per acre was $41, compared with $69 for 150,000 seeds per acre (Table 10). This amount was $28 less than the cost for planting 150,000 seeds per acre using the seed rate yield results.

In order to take advantage of the lower seeding rates without sacrificing yield, a planter must be equipped with a uniform seed spacing system (vacuum system), a uniform seed depth placement system, and a good seed furrow closure system. The planting seed also must be of good quality and treated with a soil fungicide seed treatment.

Table 9. Roundup Ready soybean variety planting seed cost per acre at $1 per pound of seed averaged over years (2004–05), Verona, Mississippi.

Variety	Brand	Maturity group	Seeds per pound	Cost per acre ($) at four seeding rates			
				60,000	90,000	120,000	150,000
HBK 4623RR	Hornbeck	E IV	3,436	18	26	35	44
AG4403	Asgrow	E IV	3,428	18	26	35	44
DP 4933RR	Deltapine	L IV	4,092	15	22	29	37
DK 5366RR	Delta King	E V	3,612	17	25	33	42
DP 5634RR	Deltapine	M V	2,982	20	30	40	50
DP 5915RR	Deltapine	L V	3,167	19	28	38	47

Table 10. Seeding rate effect on plant population, yield, and planting seed cost averaged over years (2004–06) and varieties, Verona, Mississippi.			
Seeds per acre	**Plants per acre**	**Bushels per acre**	**Mean seed cost per acre ($)[1]**
60,000	51,800	47.5	25.0
90,000	76,200	49.4	41.0
120,000	97,300	49.6	55.0
150,000	115,500	50.0	69.0
LSD (0.05)		3.2	1.2

[1]Based on average (2004–05) planting seed weight of all varieties in the study at $1.00 per pound, which included seed cost and technology fee.

Conclusion

With good weed management, good-quality planting seed, uniform seed spacing planter technology, uniform seed depth placement, and good soil/seed furrow closure, soybean seeding rates may be reduced to about 100,000 seeds per acre with a final population of about 75,000 plants per acre planted in narrow rows without a negative impact on yield. Compared with a 140,000-seed-per-acre seeding rate, this rate is about a 30% reduction in seed cost per acre.

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