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Can Soybean Seeding Rates Be Reduced Without Affecting Yields in Louisiana?

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INTRODUCTION

General Plant Population Considerations

A major agronomic objective for commercial soybean production is to reduce the minimum plant population required for optimal yield (i.e., minimal optimal plant population). This has occurred because seed cost, once a minor production expense, has become a major cost, accounting for about 42 percent of direct operating costs for an average U.S. soybean grower (U.S. Soy Crop Statistics, 2011). Current plant population recommendations in Louisiana call for a range of 80,000-120,000 plants per acre (Johnson, 2011). This costs the typical Louisiana soybean farmer $49.50 per acre (17 percent of direct operating costs, Paxton, 2011). Under good growing conditions, yield can sometimes be optimized at plant populations of 50,000-60,000 plants per acre, a level that avoids death of established plants (Board, 2000). The general rule in Louisiana, however, is to recommend a "safe" plant population of 120,000 plants per acre (Johnson, 2011). Reports from other southeastern states tell a similar story. Arkansas currently recommends an optimal plant population of 120,000-130,000 plants per acre. In contrast, for normal full-season soybeans, North Carolina recommends only 75,000 plants per acre. Although valid plant population recommendations are already available for Louisiana soybean farmers, the economic feasibility for reducing these plant populations has not been fully studied. If seeding costs can be reduced without affecting yield, profit margins would be enhanced.

Seed yield per plant increases as population declines (Carpenter and Board, 1997a,b). Previous plant population studies have shown wide differences in the minimal optimal plant population [12,120 to 200,000 plants per acre (Costa et al., 1980; Egli, 1988; Leffel and Barber, 1961; Lehman and Lambert, 1960; Lueschen and Hicks, 1977; Parks et al., 1982; Wells, 1991)]. Even for a single cultivar, grown in the same location, minimal optimal plant population can vary by 100 percent or more between years (Moore and Longer, 1987; Wells, 1991). Soybean yields demonstrate an asymptotic yield plateau as plant population increases (Edwards and Purcell, 2005; DeBruin and Pedersen, 2008). Thus, similar yields can be obtained across a range of plant populations. The most profitable strategy for a soybean farmer is to plant at the seeding rate that achieves the minimal optimal plant population.

Environmental Factors Affecting Minimal Optimal Plant Population

Studies by Wells (1991, 1993), Ball et al. (2000) and De Bruin and Pedersen (2008) have demonstrated that the minimal optimal plant population is lowest (i.e., optimal yield can be achieved with lower plant population) when growing conditions are favorable. Under favorable growing conditions (greater light, higher temperatures and more timely rainfalls), Wells (1993) reported a minimal optimal plant population of only 12,146 plants per acre. Minimal optimal plant population in a year of poor growing conditions (lower light, cooler temperatures and intermittent rainfall) was 44,534 plants per acre. Ball et al. (2000) demonstrated that at late planting dates where a shortening photoperiod and higher temperatures curtail the vegetative growing period [emergence to R5, Egli and Leggett (1973)] and reduce crop biomass, minimal optimal plant population had to be increased to 242,915 plants per acre from the typical 121,457 plants per acre grown at optimal planting dates. Working at a Midwestern United States location, De Bruin and Pedersen (2008) reported a highly negative linear correlation between yield and minimal optimal plant population (R^2=0.84, $P<0.01$), supporting previous research indicating that minimal optimal plant population declines as growing conditions improve (Wells, 1991,1993; Ball et al., 2000). An exception to this inverse relationship between growing conditions and minimal optimal plant population occurs with drought stress during reproductive growth (Devlin et al., 1995). In this case, high plant populations exhausted soil water sooner than low plant populations, resulting in a greater relative yield inhibition. Consequently, minimal optimal plant population under drought conditions was achieved with a seeding rate of only 52,272 seed per acre versus 232,000 seed per acre for plants receiving adequate water.

Yield is unaffected when crop growth rate for low plant populations equilibrates with that of higher plant populations by R1 [stages according to Fehr and Caviness (1977)] (Board, 2000). The resulting yield compensation in sparse versus normal plant populations has been attributed to greater branch dry matter per plant (Herbert and Litchfield, 1982; Hicks et al., 1969; Lehman and Lambert, 1960; Lueschen and Hicks, 1977). Specifically, greater branch dry matter per plant creates more branch nodes, branch pods and branch seeds, which results in greater yield per plant in sparse versus normal plant populations (Carpenter and Board, 1997a). This greater branch dry matter per plant derives from greater total dry matter per plant, greater partitioning of total dry matter into branches and/or a synergistic interaction between the two (Carpenter and Board, 1997a,b; Board, 2000). More favorable environmental conditions enhance this process, which explains why minimal optimal plant population generally is lower under good growing conditions. The effects of plant population on yield potential can be monitored during the growing season by observing light interception. Depending on days to R5 for a specific cultivar/planting date/latitude combination, canopy closure (95 percent light interception) must occur by a

Photo 1 illustrates a soybean canopy at closure as shown by about 95 percent shade in the inter-row area.

Photo 2 has only about 60-70 percent shade and is not at canopy closure.

certain date to optimize yield potential (Board and Kahlon, 2012). Canopy closure easily can be determined by the amount of mid-day inter-row shading. Photo 1 illustrates a soybean canopy at closure as shown by about 95 percent shade in the inter-row area. In contrast, photo 2 has only about 60-70 percent shade and is not at canopy closure. Failure to achieve canopy closure before R5 definitely would indicate plant population was too low for optimal yield.

Genetic Factors Affecting Minimal Optimal Plant Population

Genetic factors interact with environmental conditions in affecting minimal optimal plant population. Among cultivars grown at a low (38,462 plants per acre) versus normal plant population (101,215 plants per acre), yield was largely associated with factors related to branch development: percent total dry matter partitioned into branches, total dry matter per plant, branch dry matter per plant and days from R1 to R5 (Rigsby and Board, 2003). Among 14 varieties grown in this study, only two showed promise for low minimal optimal plant population (NKRA 452 and A6911). Edwards and Purcell (2005) demonstrated that across maturity group (MG) I through VI cultivars grown in the Midsouth United States, minimal optimal plant population declined as maturity lengthened. Although detailed branch development data were not reported, the authors did show that days from R1 to R5 [period for most branch development (Board and Settimi, 1986)] increased going from early to late maturing cultivars. Since cultivars were grown in the same environment, branch development probably increased as MG increased.

Recent studies have indicated the best criterion for genetic selection of minimal optimal plant population is branch dry weight per plant from a sample of four plants grown at a sparse plant population (equally spaced) of 4,000 plants per acre (Board and Kahlon, 2013). Among varieties selected from the Southern U.S. public variety germplasm collection, Gasoy 17 demonstrated the greatest yield compensation ability at sparse plant populations.

The Relationship Between Seeding Rate and Stand Establishment

A related problem pertaining to achievement of the minimal optimal plant population is determining the seeding rate necessary for stand establishment (De Bruin and Pedersen, 2008; Heatherly, 1996). Successful germination and emergence of a seedling is directly related to seedling vigor (rapid germination and seedling emergence). Seedling vigor involves two physiologically separate processes, germination and post-germination growth through the soil until emergence occurs. Hamman et al. (2002) concluded the second process probably was more important than the first in affecting seedling vigor. Delayed emergence increases the chances for seedling death largely because it enhances microbial infection of the seedling (Woodstock, 1973; Hamman et al., 2002). This increases solute leakage as membranes are degraded (Leopold, 1980) and/or halts the continued development of the seedling (Helms et al., 1996a). Impaired seedling vigor can result in a plant population that is too low for optimal yield, even when growers plant at the recommended seeding rates. Thus, when seedling vigor is poor, farmers should increase their seeding rate to compensate for increased seedling death, resulting in lower profit margins. In general, factors affecting seedling vigor are temperature, soil conditions, seed source, seed size, soil water content and cultural practices (Christmas, 2012).

Previous work has demonstrated that time from planting to emergence is best when soil temperature is in the range of 77 to 95 degrees Fahrenheit (daily average of maximum and minimum soil temperatures) (Hatfield and Egli, 1974). Days to emergence increase as temperature falls below this level. Once temperature falls below 65 F, days to emergence increases markedly. There is a two-day delay in days to emergence for every one degree reduction below 65 F (Muendal, 1986). Growers should avoid planting when average soil temperature falls below this level. No emergence occurs when soil temperature is at or below 50 F. Thus, one cultural practice that enhances seedling vigor is simply to plant at a later planting date when soil temperatures are warmer. Varietal selection for strong seed vigor under cold soil conditions is possible (Unander et al., 1986; Littlejohn and Tanner, 1976; Pinthus and Kimel, 1979; Bramlage et al., 1979; Hopper et al., 1979).

Seed size and source are other factors affecting seedling vigor. Generally, small seeds will have lower seedling vigor compared to medium and large seeds (Burris et al., 1973; Hopper et al., 1979); although Edwards and Hartwig (1971) found larger seeds to have poorer seedling vigor. Seed source also can affect seedling vigor (Unander et al., 1986). Phomopsis seed decay [caused by *Phomopsis longicolla* (T.W. Hobbs)] and purple seed stain [caused by *Cercospora kukuchii* (Matsumoto and Tomoyasu)] are two diseases, enhanced by hot and humid weather during seed filling, that affect seed vigor. Seed vigor also can be adversely affected by the mother plant being exposed to hot temperatures during seed filling (Egli et al., 2005). Even when the effect of disease infection was screened out, seed vigor declined substantially as mean maximal air temperature during seed filling rose above 86 degrees Fahrenheit. This effect varied with variety, however.

Soil conditions also affect seedling vigor (Christmas, 2012). Emergence will be impeded by cloddy, compacted or crusted soil. Yaklich et al. (1979) reported that when all other conditions are similar, seedling vigor was better on a sandy versus heavier soil. Previous research concerning the benefit of fungicide seed treatment for stand establishment has been mixed, with some reports showing benefit only for poor quality and/or diseased seed (Athow and Caldwell, 1956; Edje and Burris, 1971; Wall et al., 1983), while others recommended treatment for both high and low quality seed (Ferris et al., 1987), or when planting occurs into cool soils (Bradley, 2008). Recent studies in the Midwestern United States showed mixed results for the cost effectiveness for seed treatment to early planted soybean (Esker and Conley, 2012).

Proper stand establishment also depends on soil water content. A problem occurs when sufficient water is available for partial imbibition of the seed but not enough for germination (root appearance). This problem is greater for soybeans relative to many other crops, because of the high seed water content (50 percent of fresh weight) required for germination. Controlled studies have indicated that a soil gravimetric water content of 9 percent results in normal germination and good seed emergence (94 percent) (Helms et al., 1996a,b). Soil gravimetric water content is just the weight of water (in grams) in a soil sample as a percentage of the fresh weight of that sample. Reducing soil water content to 7 percent resulted in only partial imbibition (i.e., no germination) and poor emergence (22 percent). If soybeans are planted into a soil that sustains only partial imbibition (e.g., 7 percent gravimetric water content) and no rain or irrigation is received within six days of planting, emergence likely will be so poor (50 percent of optimum plant population) as to require replanting (Helms et al, 1997; Helms and Hla, 1991). In contrast, corn and sunflowers can endure 18 days of a comparative stress without requiring replanting. Gravimetric water content can easily be determined by first determining fresh weight of a soil sample, drying the sample in a microwave oven until constant weight and then weighing the dry sample. Weight of sample water is the difference between fresh and dry weights. Gravimetric water content is calculated as:

$$\text{Grav. } H_2O = 100 \text{ X } [(\text{weight of } H_2O)/(\text{fresh weight})]$$

Much effort has been expended on identification of a seedling vigor test and/or combination of tests that can accurately predict stand establishment. Kulik and Yaklich (1982) studied the predictability of four tests (standard germination, seedling vigor classification, seedling length and Tetrazolium test). No single test gave a satisfactory prediction of stand establishment and even combining all tests resulted in an R^2 of only 50-60 percent with stand establishment in the field. Attempts by Unander et al. (1986) to relate germination under cold conditions with stand establishment under cold conditions were not successful. TeKrony and Egli (1977) used the standard germination test, four-day germination test and accelerated aging test, each by itself and in combination with the others, to identify an accurate predictor for stand establishment. Their best predictor was an index using all three tests, but its accuracy (measured as ability to predict successful stands) was only 64 percent. Later research involving a composite of many studies conducted in Kentucky concluded that the standard germination and accelerated aging tests only gave 100 percent accuracy when soil conditions were ideal (Egli and TeKrony, 1996). As soil stress increased, accuracy of both tests declined, but the accelerated aging test was more accurate than the standard germination test. They concluded that across Kentucky conditions, using an accelerated aging percentage of 80 percent would give 80 percent predictability if a successful stand was defined as having a minimum emergence of 60 percent. This advantage of the accelerated ageing test over the standard germination test has been supported by more recent studies in Arkansas (Highhtower, 2012).

The relationship between stand establishment and seeding rate is affected by many factors. Therefore, it is necessary to determine this relationship for a given variety/environmental combination to minimize seed expenses for achieving the minimal optimal plant population. A low percentage of emergence results from either poor seed quality and/or environmental stress – and it wastes money on seed that does not result in viable plants. Determining the percentage of emergence can be done easily in producers' fields by using the line-intercept sampling method for stand analysis (Willers et al., 1998). Percentage of emergence is calculated as:

percentage emergence = [(plant population shortly after emergence)/seeding rate] X 100

Plant population using the line-intercept method is done by:

1. Dividing the area into management units of 50-100 acres based on similar crop phenology and genetics.
2. Within each management unit, place one to four sampling lines (the more lines the greater accuracy). Each line should have a length equal to the width of one to four planter passes (again, the longer the line, the greater the accuracy). Lines should run perpendicular to the field and be as straight as possible.
3. Place the sampling line at random locations within the management unit making sure it does not overlap. The starting point for a line should be halfway between the first drills for consecutive planter passes; or alternatively, half way between the last drills for consecutive planter passes.
4. Record plant numbers, once the line(s) are established, for each row traversed by the line. Counts are made for a 1- to 3-foot section of row, starting where the line crosses the row. Where plant population is consistent, the 1-foot section is sufficient. For variable plant population, however, a 3-foot section is required. For any management unit, use the same sampling length across all rows.
5. Calculate the average number of plants per square foot and then multiply by 43,560 ft^2 per acre to determine plants per acre.

Objectives:

The increased need to save on seed costs prompted the initiation of a study over three years (2009-2011) at four locations (Baton Rouge, Crowley, St. Joseph and Winnsboro) in Louisiana to:

1. Estimate economic losses from reduced seedling emergence and plant death as affected by plant population, variety and location.
2. Determine the minimal optimal plant population for soybean production.
3. Determine the economic feasibility for reducing plant population below currently recommended rates.

An ancillary objective was to also compare developmental timing as affected by MG, location and year.

MATERIALS AND METHODS

Irrigated field studies were conducted at four LSU AgCenter research locations: the Ben Hur Research Farm near Baton Rouge, the Rice Research Station at Crowley, the Northeast Research Station at St. Joseph and the Macon Ridge Research Station at Winnsboro. Specific site characteristics and cultural practices are described in Table 1. These include latitude, soil type, planting dates, soil temperatures, row spacings, plot size, fertilizer applied, harvest method and harvested area. Soil tillage operations at Baton Rouge were disking twice in the spring followed by heaping the beds and smoothing them over. At Crowley, fields were disked twice and mulched in late February. After a burn-down herbicide application, seed were planted into a flat stale seedbed. Field preparations at St. Joseph consisted of fall disking followed by a spring tillage and merging of rows to make broad 80-inch wide beds. At Winnsboro, rows were reshaped in the fall and spring, followed by smoothing of the beds with a reel and harrow. At all sites, irrigation was applied when soil moisture was 50 percent of available water (University of Arkansas Cooperative Extension, 2006). At each site, the experimental design was a randomized complete block in a split plot arrangement with four replications. Main plots were two varieties, Pioneer 94Y70 (P94Y70) (MG IV, indeterminate) and Pioneer 95Y40 (P95Y40) (MG V, determinate). These varieties were mandated to be grown

Table 1. Description of site and cultural practices for four locations of a plant population study conducted across three years in Louisiana, 2009-2011. All sites used conventional as opposed to reduced-till or no-till operations. All sites had irrigation and applied it as necessary. Recommended procedures were used for control of weeds, diseases and insects.

Location	Year	Lat.	Soil type	Soil temp.	Planting dates	Row space	Plot size	Fertilizer	Harvest method†	Harvest area
				Aver. F 10d>plt		in.	ft^2	P_2O_5-K_2O-S lb A^{-1}		ft^2
Baton Rouge	2010	30 N	Commerce silt loam	71	19 Apr	38	304	30-60-20	(harvest index) x (total dry matter)	42
Baton Rouge	2011	30 N	Commerce silt loam	78	21 Apr	38	304	30-60-20	(harvest index) x (total dry matter)	42
Crowley	2010	30 N	Crowley silt loam	82	21 May	16	213	30-60-12	Wintersteiger small plot comb.	107
Crowley	2011	30 N	Crowley silt loam	76	11 May	16	213	30-80-20	Wintersteiger small plot comb.	107
St. Joseph	2009	32 N	Sharkey clay	78	19 May	20	333	0-0-20	Massey-Ferg. 8XP comb.	167
St. Joseph	2010	32 N	Sharkey clay	80	3 May	20	333	30-30-20	Massey-Ferg. 8XP comb.	167
St. Joseph	2011	32 N	Sharkey clay	N.A.	11 May	20	333	0-0-0	Massey-Ferg. 8XP comb.	167
Winnsboro	2009	32 N	Gigger silt loam	N.A.	23 Apr	40	400	2 T poultry litter	Massey-Ferg. 8XP comb.	200
Winnsboro	2010	32 N	Gigger silt loam	N.A.	4 May	40	400	2 T poultry litter	Massey-Ferg. 8XP comb.	200
Winnsboro	2011	32 N	Gigger silt loam	N.A.	14 Apr	40	400	2 T poultry litter	Massey-Ferg. 8XP comb.	200

† harvest index = [(yield dry matter)/(total dry matter)] X 100; measured shortly after R7 and excluding leaves and petioles.
N.A. Data not available.

by the United Soybean Board grant that sponsored this research. Split plots were six targeted plant populations: 25,000 plants per acre, 75,000 plants per acre, 125,000 plants per acre, 175,000 plants per acre, 225,000 plants per acre and 275,000 plants per acre. The study was done across three years at St. Joseph and Winnsboro and across two years at Baton Rouge and Crowley. Data were analyzed within each location. Varieties and plant populations were fixed effects, with year and replication (four replications at each location) random factors. This data analysis method was suggested by Dr. Geaghan, Head of the Experimental Statistics Department at LSU, because a combined analysis across locations, varieties and populations demonstrated significant interactions for the following effects: location x plant population ($P<0.0001$), variety x population ($P<0.01$) and location x variety x plant population ($P<0.01$). Seeding rate was increased above the intended plant population according to the accelerated ageing (AA) test using the following formula:

Seeding rate = (intended plt. pop.)/ (frac. of seed germinated in AA test)

Data were taken on plant population (plants per acre) shortly after emergence [V3, stages according to Fehr and Caviness (1977)] and at the end of the growing season (R7, end of seed filling). Plant population determinations at R7 did not include infertile plants (i.e., plants with no pods). Each measurement was made by counting the number of plants in a randomly selected segment of row length equivalent to 1 m^2. In 2010 and 2011, dates for first flower (R1), pod initiation (R3), seed initiation (R5), full pod (R6) and the end of seed fill (R7) were taken. Plot yield as described in Table 1 was taken at harvest maturity. Plant population and yield were analyzed according to SAS PROC MIXED with mean separation according to Tukey's test ($P<0.05$). Data were analyzed within and not across locations. Minimal optimal plant populations at each location, or for location/year treatment combinations, were determined as the lowest plant population that resulted in yield that was not significantly different from the highest-yielding plant population according to Tukey's test at the 0.05 probability level.

RESULTS AND DISCUSSION

Initial (V3) and Final (R7) Plant Populations in Relation to Seeding Rates

Any seed planted by a grower that does not emerge, or does emerge but dies and/or becomes infertile during the growing season, represents an economic loss. Both factors result in seed loss. Awareness of this problem, as well as a concept of how much economic loss is involved, would encourage farmers to avoid and/or correct environmental stresses that impair emergence and to use seeding rates below the level at which plant death and/or infertility occur. Seedling emergence and seasonal plant death differed between the four locations. At Baton Rouge and Winnsboro, initial V3 plant populations were similar to seeding rates across almost all plant populations (Figures 1 and 2). Since similar seed stocks were used across all locations in each year of the study, this indicates environmental conditions at these two locations were favorable for seedling emergence and stand establishment. In contrast, seedling emergence at St. Joseph and Crowley generally resulted in initial plant populations significantly below that of the seeding rate (Figures 3 and 4). The only exceptions were for low seeding rates, 25,000 plants per acre at both sites and 75,000 plants per acre at Crowley. Low seedling emergence was attributed to soil moisture problems. Irrigation systems at both locations are not adapted to facilitate seedling emergence. In such cases, lack of timely rains will impair emergence.

The other source of seed loss evident in the study was plant death between V3 and R7. Previous studies indicated that significant plant death becomes apparent at plant populations of 150,000 plants per acre or greater (Board, 2000). When plants become overcrowded, interplant competition for light intensifies, resulting in self-thinning (Loomis and Connor, 1992). A significant proportion of the population dies or produces spindly nonfertile plants. Similar results occurred in this study. Significant plant death occurred at Baton Rouge, Winnsboro and St. Joseph when initial plant populations reached 140,000-180,000 plants per acre (Figs. 1, 2 and 3). In contrast, plant death did not occur at Crowley (Figure 4), even when initial plant populations rose as high as 225,000 plants per acre. This probably occurred because of the smaller plant size (i.e., lower dry matter) at Crowley compared with the other sites. Reduced dry matter at this location can be deduced by the lower yield coupled with the observation that soybean planted at an optimal planting date in Louisiana usually has a harvest index of 50 percent, unless there is a severe stress during seed filling (Carpenter and Board, 1997b). With lower levels of total dry matter per plant, interplant competition for light would be less intense

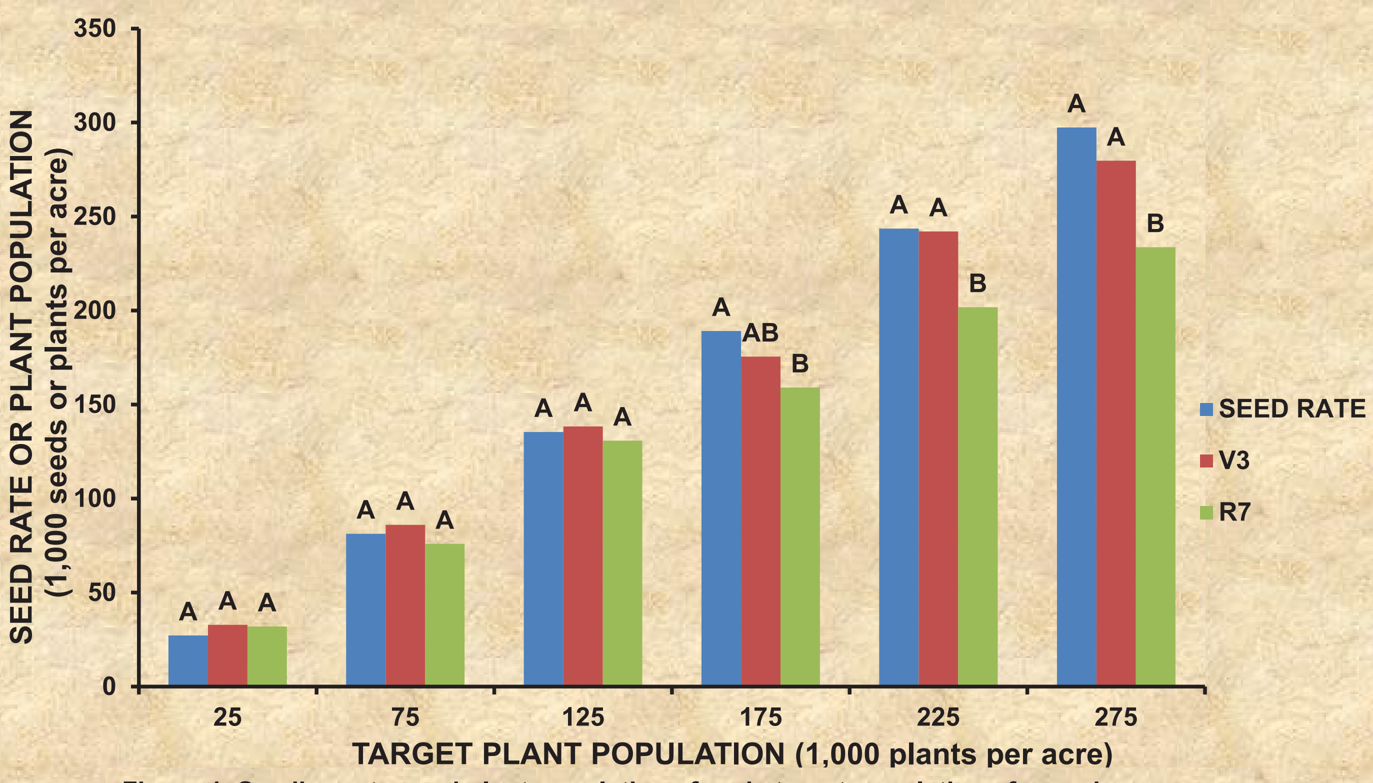

Figure 1. Seeding rates and plant populations for six target populations for soybeans grown across two years near Baton Rouge, La, averaged across 2010 and 2011. Data were pooled across varieties P94Y70 and P95Y40. Means within a plant population followed by different letters are significantly different according to Tukey's test (P<0.05).

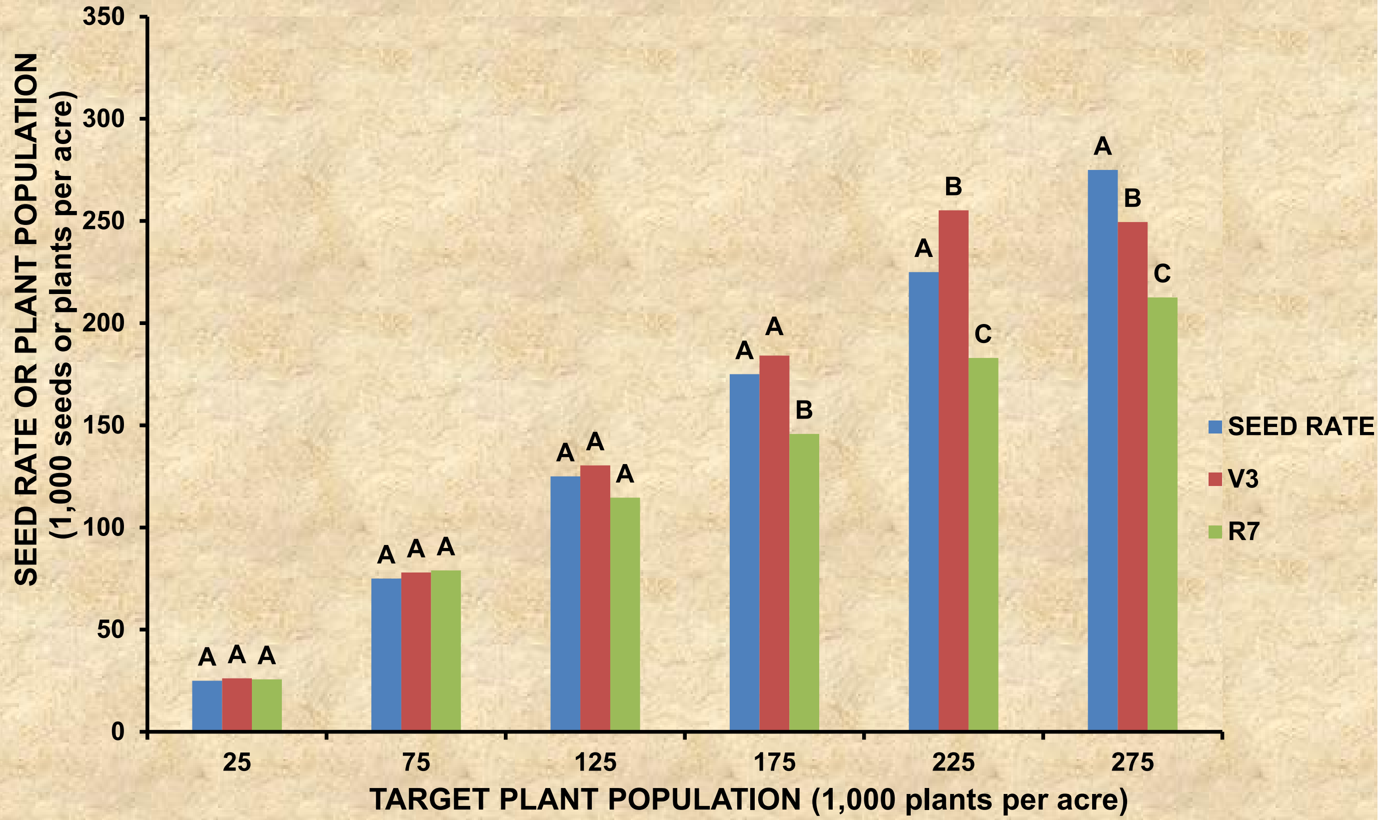

Figure 2. Seeding rates and plant populations for six target plant populations for soybeans grown across three years near Winnsboro, La. Data were pooled across varieties and years. Means within a plant population followed by different letters are significantly different according to Tukey's test (P<0.05).

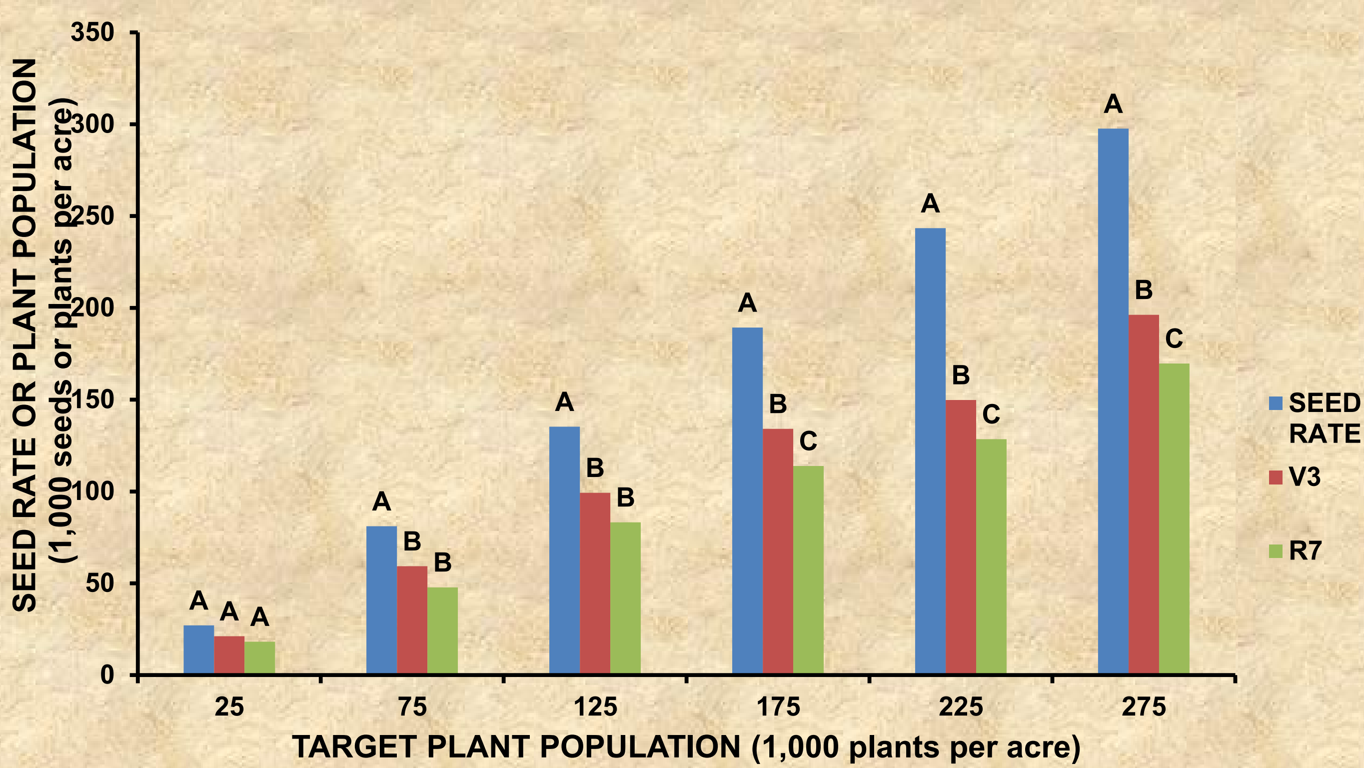

Figure 3. Seeding rates and plant populations for six target populationsof soybeans grown across three years near St. Joseph, La., during 2009, 2010 and 2011. Data were pooled across varieties P94Y70 and P95Y40. Means within a plant population followed by different letters are significantly different according to Tukey's test (P<0.05).

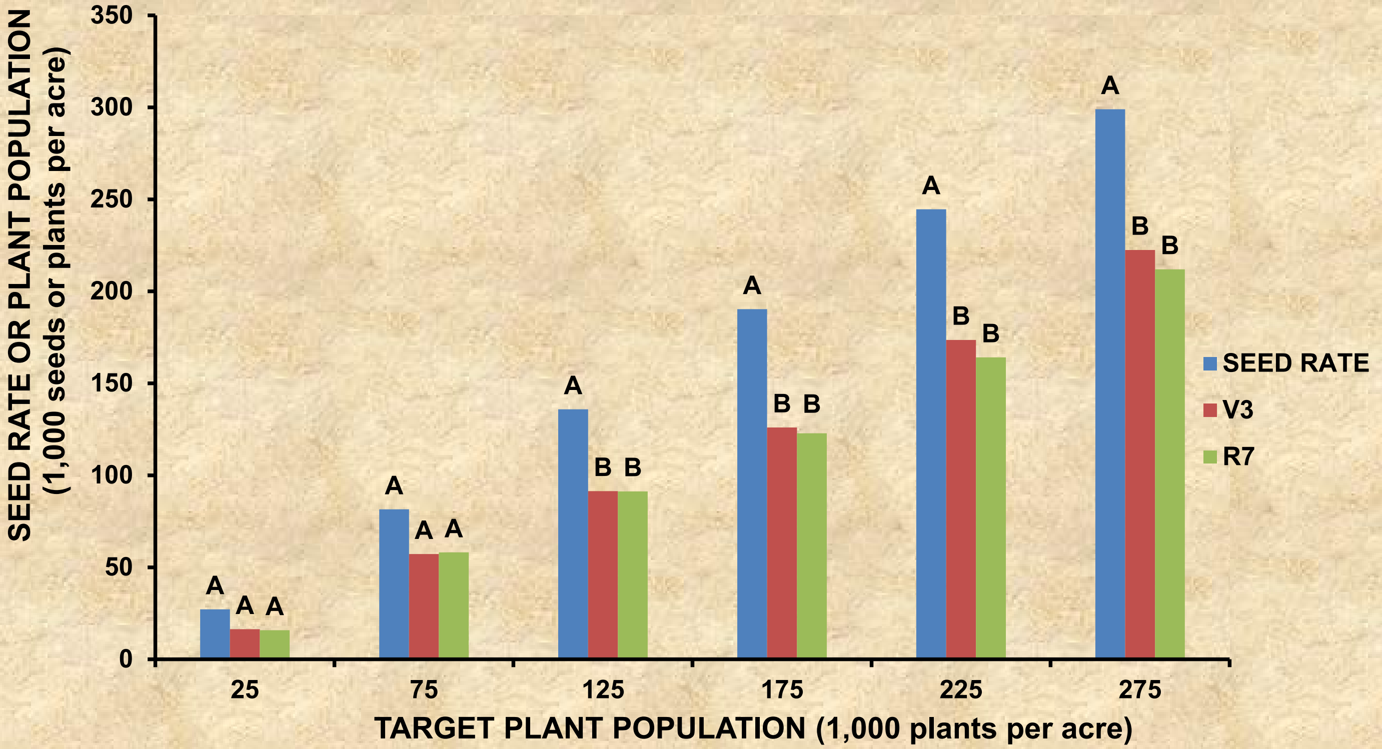

Figure 4. Seeding rates and plant populations for six target plant populations for soybeans grown near Crowley, La., during 2010 and 2011. Means were pooled across varieties P94Y70 and P95Y40. Means within a plant population followed by different letters are significantly different according to Tukey's test (P<0.05).

relative to the other locations. At Baton Rouge, Crowley and Winnsboro, no significant seed loss occurred from plant death or emergence failure until seed rates were increased above 125,000 to 135,000 seed per acre (Table 2). In contrast, relatively high seed loss (41 percent) occurred at St. Joseph at seeding rates as low as 81,100 seed per acre (Table 2). The highest percentage of seed losses were at St. Joseph (45 percent), with lowest losses at Baton Rouge (18 percent).

Economic losses paralleled the patterns of seed loss described above. Greatest losses occurred at St. Joseph, lowest at Baton Rouge and Winnsboro, with Crowley having an intermediate loss (Table 2). When averaged across the 175,000 to 275,000 plants per acre target populations, economic losses were $35.50 per acre at St. Joseph, $25.50 per acre for Crowley and about $14.80 per acre for Baton Rouge and Winnsboro. The trend at all sites was for economic losses to increase as plant population increased. Results indicate that economic losses from poor seedling emergence and/or plant death were substantial. Even for the most minor seed losses described (Winnsboro and Baton Rouge seeded at 175,000 to 189,000 seed per acre), the economic cost was $9.64 to $9.91 per acre, representing a reduced profit margin of almost $10,000 for a farmer growing 1,000 acres of soybeans. In the worst case (St. Joseph seeded at 297,600 seed per acre), the economic loss was $42.21 per acre, representing a reduced profit margin of $42,210 for a farmer growing 1,000 acres of soybean.

Because of the significant economic losses resulting from low seedling emergence and/or plant death, the following recommendations can be made:

1. Under conditions of planting in the optimal period [late March through mid-May (Levy et al., 2011)] with a recommended variety, do not seed at a rate to achieve an initial plant population of more than 125,000 plants per acre. Overseeding may result in plant death with no increase in yield.
2. Using techniques described in the introduction, determine the expected emergence rate for a particular field. Failure to achieve the expected emergence rate in any given year indicates seed vigor was poor and/or some environmental stress occurred that adversely affected crop emergence.
3. If possible, plant when soil temperature is at 77 degrees Fahrenheit or higher [mean of maximum and minimum soil temperatures at planting (Muendal, 1986)]. Do not plant if soil temperature is below 60 F (Levy et al., 2011).

Table 2. Seed, plant and economic loss for soybeans planted at four locations across six plant populations, 2009-2011.

Location	Desired plant population	Seeding rate	Percentage of seed loss	Percentage of seed loss from reduced emergence	Percentage of seed loss from plant death	Economic loss[†]
	Plants/acre	Seeds/acre	%	%	%	Dollars/acre
Baton Rouge	25,000	27,200	0	0	0	0
	75,000	81,300	0	0	0	0
	125,000	135,400	0	0	0	0
	175,000	189,100	15.9	45.0	65.0	9.91
	225,000	243,600	17.1	3.6	96.4	13.77
	275,000	297,400	21.4	27.7	72.3	21.00
Crowley	25,000	27,200	0	0	0	0
	75,000	81,500	0	0	0	0
	125,000	135,900	0	0	0	0
	175,000	190,300	35.0	95.0	5.0	22.24
	225,000	244,600	33.0	88.0	12.0	25.56
	275,000	299,000	29.0	88.0	12.0	28.71
St. Joseph	25,000	27,100	0	0	0	0
	75,000	81,100	41.1	65.5	34.5	10.99
	125,000	135,300	38.5	69.1	30.9	17.19
	175,000	189,300	39.8	73.2	26.8	24.88
	225,000	243,400	60.7	81.5	18.5	37.92
	275,000	297,600	43.0	79.3	20.7	42.21
Winnsboro	25,000	25,000	0	0	0	0
	75,000	75,000	0	0	0	0
	125,000	125,000	0	0	0	0
	175,000	175,000	16.7	0	100	9.64
	225,000	225,000	18.7	0	100	13.86
	275,000	275,000	22.7	41.0	59.0	20.59

[†] *Economic loss based on a seeding rate of one 50-pould bag of RR soybean seed per acre at a cost of $0.99 per pound. (Paxton, 2011); 1 pound of soybean seeds is assumed to have 3,000 seeds.*

4. Plant when soil gravimetric water content is 9 percent or greater.
5. Use a seed treatment if seed is of poor quality and/or diseased or if planting is done into a cool soil.
6. Choose disease-free seed that has high seed quality. Currently, the best measure of seed emergence is the accelerated ageing test.
7. Any factor that delays seed germination and/or seedling emergence potentially reduces stand establishment. Therefore, avoid deep planting of the seed unless it is necessary for adequate moisture.
8. When possible, alleviate soil conditions such as cloddiness, compaction by equipment traffic and/or soil crusting that impede seedling emergence.

Identification of the Minimal Optimal Plant Population

Plant population significantly (P<0.05) affected yield at all four locations. At three locations – Baton Rouge, Crowley and Winnsboro – no significant variety x plant population interaction occurred, thus allowing pooling of each plant population across the two varieties (Figures 5, 6 and 7). A significant variety x plant population interaction

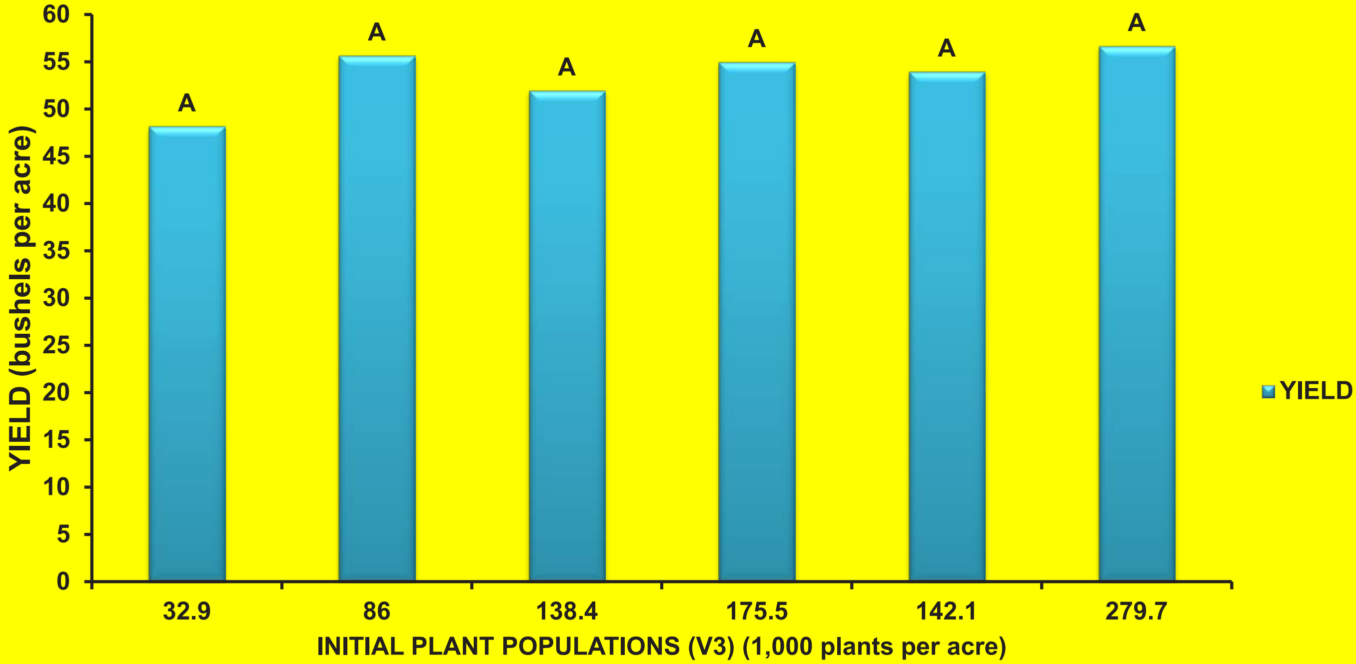

Figure 5. Soybean yields as affected by a range of sparse to dense plant populations grown near Baton Rouge, La., averaged across 2010 and 2011. Means were pooled across varieties P94Y70 and P95Y40. Yields followed by the same letter are statistically similar according to Tukey's test (P<0.05).

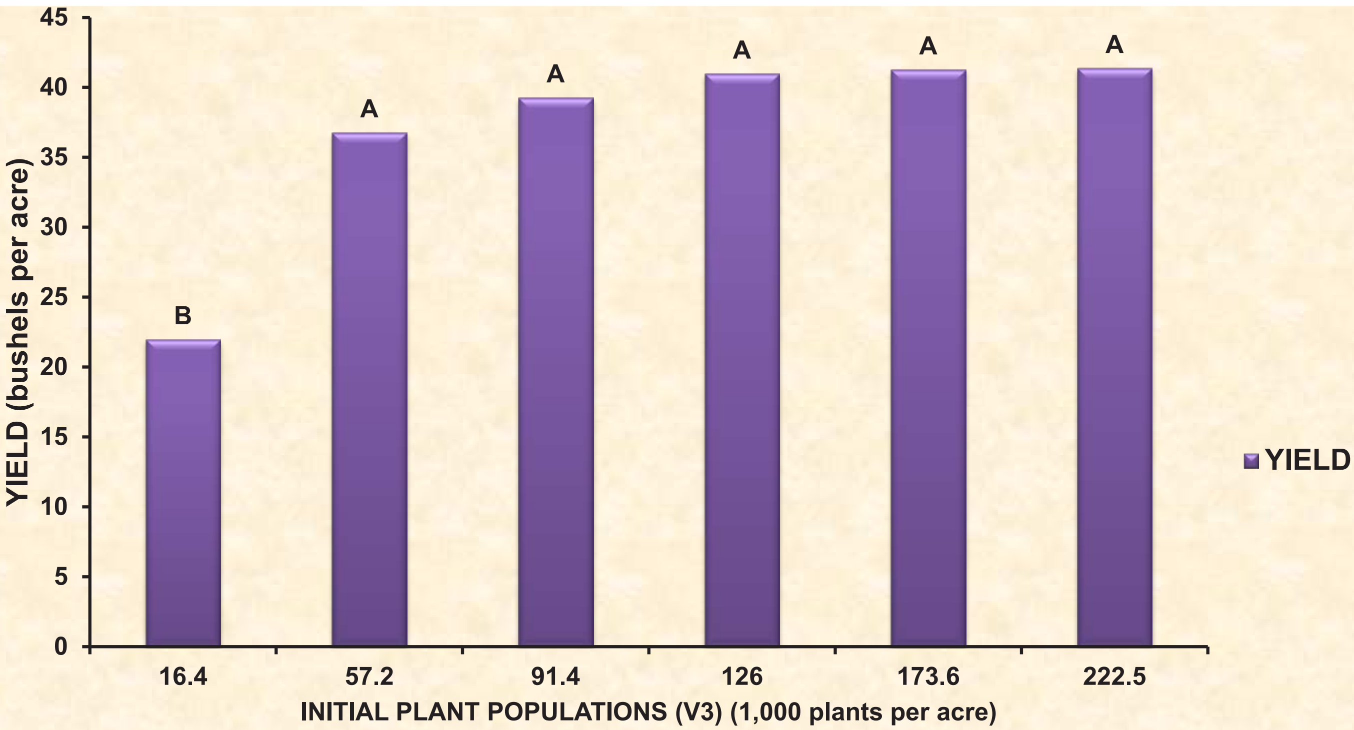

Figure 6. Soybean yields as affected by a range of sparse to dense plant populations grown near Crowley, La., averaged across 2011 and 2012. Means were pooled across varieties P94Y70 and P95Y40. Yields followed by different letters are significantly different according to Tukey's test (P<0.05).

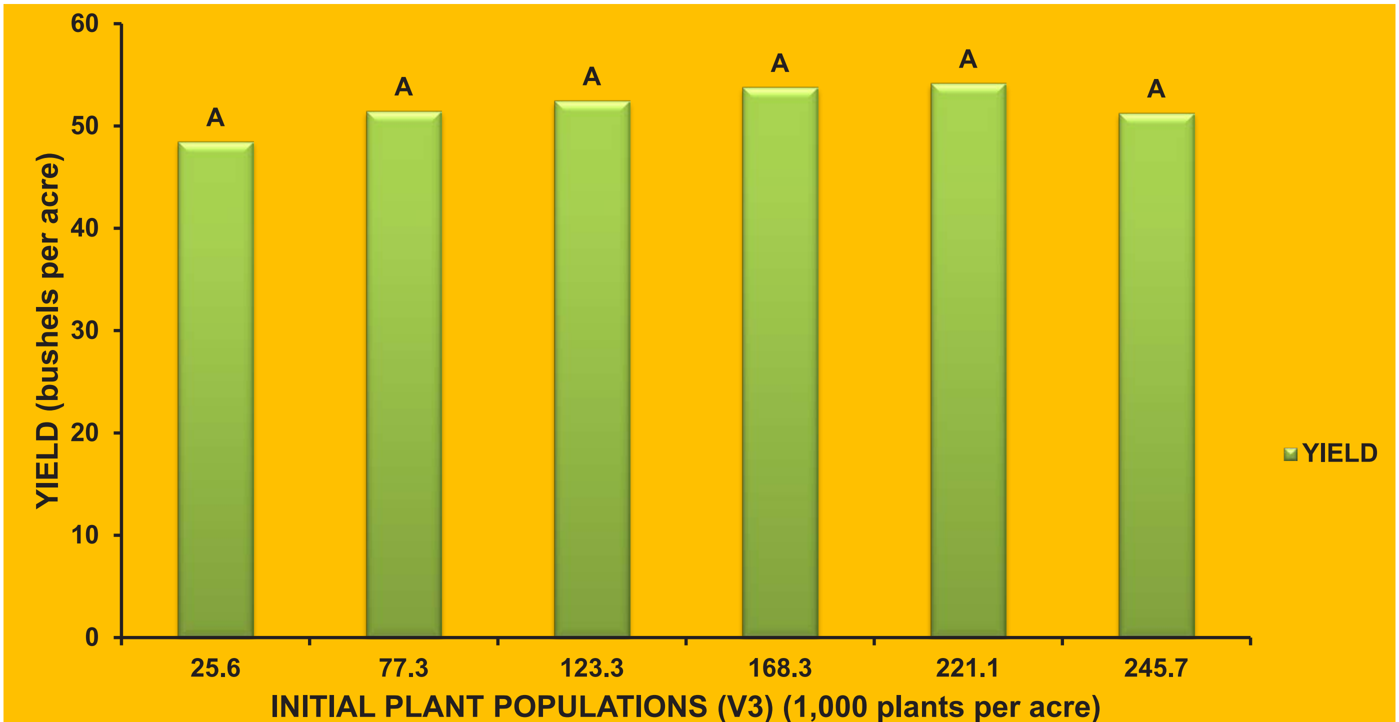

Figure 7. Soybean yields as affected by a range of sparse to dense plant populations grown at Winnsboro, La., averaged across 2009-2011. Means were pooled across varieties P94Y70 and P95Y40. Yields followed by the same letter are statistically similar according to Tukey's test (P<0.05).

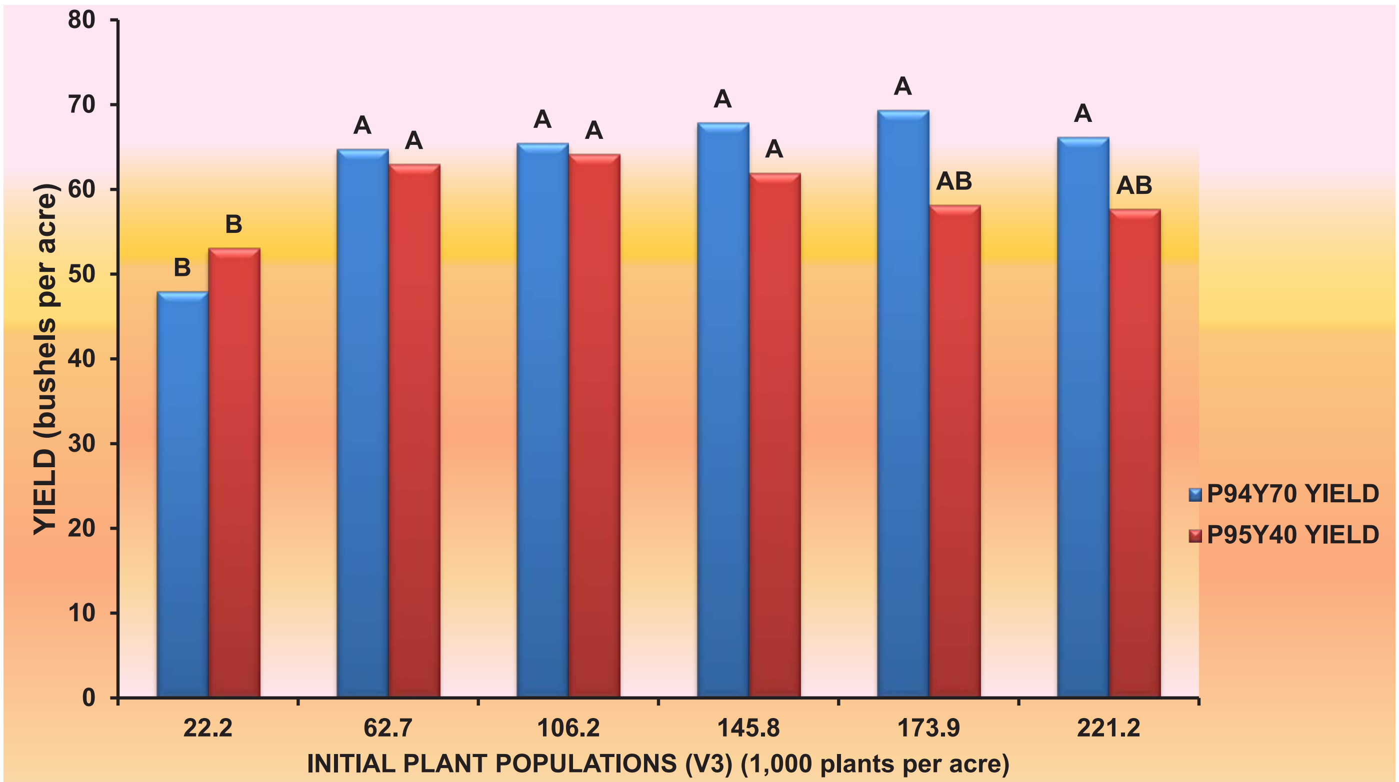

Figure 8. Soybean yields across plant populations for varieties P94Y70 and P95Y40 grown at St. Joseph, La., averaged across 2009-2011. Yields marked by different letters within varieties are statistically different according to Tukey's Test (P<0.05).

did occur at St. Joseph and variety/plant population treatment combinations were reported separately (Figure 8). At Baton Rouge and Winnsboro, yields varied between 50-60 bushels per acre across the six plant populations (Figures 5 and 7). No significant differences (P<0.05 according to Tukey's Test) occurred between any plant population at these two locations. Thus, minimal optimal plant populations for Winnsboro and Baton Rouge were 25,000 and 33,000 plants per acre, respectively. In this study, minimal optimal plant population is determined as the lowest plant population that does not show a significant yield reduction from the plant population having the greatest yield. In contrast, significant yield losses did occur at the lowest plant populations at Crowley and St. Joseph (Figures 6 and 8). At these locations, minimal optimal plant populations of 57,000 to 63,000 plants per acre achieved optimal yield. Crowley had the lowest yields of any location, with highest yield slightly above 40 bushels per acre. In contrast, St. Joseph had the greatest yield, with P94Y70 reaching almost 70 bushels per acre. The significant variety x plant population interaction at St. Joseph occurred because of different responses to increasing plant population. Variety P94Y70 demonstrated a plateau yield response to plant population above 62,700 plants per acre, while P95Y40 showed slight decreases for each incremental increase in plant population above 106,200 plants per acre.

Minimal optimal plant population was determined for each location/year/variety treatment combination in order to arrive at an overall determination of minimal optimal plant population for Louisiana (Table 3). Large variation occurred, ranging from a low of 17,400 plants per acre for P95Y40 at St. Joseph in 2011, to a high of 93,250 plants per acre for P95Y40 at Winnsboro in 2009. The overall mean across locations (mean of all year/variety treatment combinations) was 44,471 plants per acre. However, because of the high variance (C.V. = 53 percent), it would be unwise to recommend this as a minimal optimal plant population for Louisiana. Increasing minimal optimal plant population by one standard deviation unit above the mean resulted in a plant population of 67,908 plants per acre (Table 3). According to statistical probability (Bernstein, 2001), a farmer seeding to obtain this plant population would receive a significant yield reduction (due to suboptimal plant population) in one year out of six. In contrast, a farmer using a target plant population of 91,000 plants per acre (two standard deviation units above the mean), would suffer a significant yield loss due to suboptimal plant population in only one year out of 44. Thus, our data indicate that minimal optimal plant population for Louisiana should be 90,000 plants per acre. This plant population falls within the low range for the current plant population recommendations for Louisiana of 80,000 to 120,000 plants per acre (Johnson, 2011).

Table 3. Minimal optimal plant populations for two soybean cultivars grown at Baton Rouge (two years), Crowley (two years), St. Joseph (three years) and Winnsboro (three years), 2009-2011.

Location	Year	Cultivar	Minimal optimal plant population (Plt per acre) at V3	Probability of yield loss
Baton Rouge	2010	P94Y70	31,175	
Baton Rouge	2010	P95Y40	31,625	
Baton Rouge	2011	P94Y70	32,375	
Baton Rouge	2011	P95Y40	30,350	
Crowley	2010	P94Y70	77,000	
Crowley	2010	P95Y40	80,000	
Crowley	2011	P94Y70	68,250	
Crowley	2011	P95Y40	41,750	
St. Joseph	2009	P94Y70	53,225	
St. Joseph	2009	P95Y40	20,925	
St. Joseph	2010	P94Y70	60,275	
St. Joseph	2010	P95Y40	75,125	
St. Joseph	2011	P94Y70	50,775	
St. Joseph	2011	P95Y40	17,400	
Winnsboro	2009	P94Y70	29,250	
Winnsboro	2009	P95Y40	93,250	
Winnsboro	2010	P94Y70	24,750	
Winnsboro	2010	P95Y40	25,250	
Winnsboro	2011	P94Y70	23,500	
Winnsboro	2011	P95Y40	23,175	
Mean			44,471	
Std. Dev.			23,437	
C.V. (%) Mean+Std.Dev.			53% 67,908	1 year in 6
Mean+2 Std. Dev.			91,345	1 year in 44

Reducing plant population from 91,000 to 68,000 plant per acre does not appear economically justifiable. Reducing plant population by this amount would save the farmer about $56.92 per acre in seed costs across a six-year period. This calculation is based on:

1. Seed rates of 113,750 seed per acre and 85,000 seed per acre to achieve plant populations of 91,000 and 68,000 plants per acre, respectively (assuming 80 percent emergence).
2. A seed number of 3,000 per pound of seed.
3. Seed cost of $0.99 per pound of seed (Paxton, 2011).

A significant yield loss due to suboptimal plant population in one out of six years would cause a loss of anywhere from $61.60 to $172.20 per acre based on yield data from the four locations of this study. This calculation is based on an $LSD_{(0.05)}$ value for yield at each location multiplied by a price of $14 per bushel.

Thus it is not advisable to reduce plant population from 91,000 to 68,000 plants per acre. However, farmers seeding at a rate to achieve 120,000 plants per acre could save money on seeding costs by reducing plant population to about 90,000 plants per acre. Based on 80 percent emergence, this would reduce seeding rate from 150,000 to 112,500 seed per acre, resulting in a saving of $12.38 per acre or $12,380 for a farmer growing 1,000 acres of soybeans.

Developmental Stages as Affected by Variety and Location

Days to R1, R3, R5, R6 and R7 are presented in Table 4 for the four locations during 2010 and 2011. As expected, seasonal development (emergence to R7) was nine days longer for P95Y40 (MG V) compared with P94Y70 (MG IV). This maturity difference was established early in the growing season, as there was a 10-day difference between the two cultivars in days to R1 (39 versus 29 d for P95Y40 and P94Y70, respectively). This difference was maintained through to R5 (74 versus 63 d) and then onto R7. As measured by C.V., variability for developmental timing in both varieties was greatest for days to R1 (12.2 percent and 15.8 percent for P94Y70 and P95Y40, respectively) and least for days to R7 (6.4 and 9.0 percent for the same comparison). Variability for days to R3, R5 and R6 fell between these extremes. Based on the calculation of confidence intervals, days to R7 for P94Y70 and P95Y40 would fall within the ranges of 103-115 d and 109-127 d, respectively, in 19 out of 20 years. The same ranges for days to R5 were 59-67 d for P94Y70 and 67-80 d for P95Y40. This period has been shown to be especially important in yield formation, as seed number per area, the primary yield component affected by environmental stresses (Board and Modali, 2005), is largely determined by this stage (Board and Tan, 1995). In summary, developmental timing for a particular variety across years and locations was fairly consistent and did not demonstrate high variability.

Table 4. Developmental stage data for two soybean cultivars, P94Y70 and P95Y40, planted at four locations across Louisiana for two years, 2010 and 2011. Location abbreviations are: BR= Baton Rouge, CROW = Crowley, ST. JO = St. Joseph, WINN = Winnsboro.

Location	Year	Planting Date	Days to R1		Days to R3		Days to R5		Days to R6		Days to R7	
			P94	P95	P94	P95	P94	P95	P94	P95	P94	P95
			-----Days from emergence-----									
BR	2010	Apr. 19	27	35	37	52	62	69	78	83	115	126
BR	2011	Apr. 21	34	41	47	59	68	75	79	86	117	128
CROW	2010	May 21	24	31	43	51	57	62	73	73	96	96
CROW	2011	May 11	31	35	44	59	64	84	85	97	N.A.	N.A.
ST. JO	2010	May 3	25	42	N.A.[†]	N.A.	63	71	90	98	113	119
ST. JO	2011	May 16	29	51	N.A.	N.A.	67	82	92	106	108	124
WINN	2010	May 4	27	37	38	46	56	65	N.A.	N.A.	108	117
WINN	2011	Apr 14	32	43	47	57	68	81	N.A.	N.A.	106	119
MEAN			29	39	43	54	63	74	83	91	109	118
C.V. (%)			12.2	15.8	10.1	9.7	7.4	11.2	9.0	13.3	6.4	9.0
Range for 19 out of 20 yr.(d)			26-32	34-45	38-47	49-59	59-67	67-80	75-91	78-103	103-115	109-127

[†] *N.A.=data not available*

CONCLUSIONS

Based on results across four locations and three years, the following conclusions can be made:

1. Poor seedling emergence is a source of economic loss for farmers. It is recommended that farmers determine percentage of emergence for their field and use this as a guideline for identification and correction of emergence problems.
2. Under conditions of planting in the optimal period with a recommended variety, do not seed at a rate to achieve an initial plant population of more than 125,000 plants per acre. Exceeding this rate may result in plant death with no increase in yield.
3. The minimal optimal plant population was estimated at about 90,000 plants per acre for Louisiana. This level falls within the lower range of the current recommendation of 80,000-120,000 plants per acre. Farmers planting in the higher end of this range should consider reducing their target plant populations. This will reduce seed costs without lowering yield.

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Can Soybean Seeding Rates Be Reduced Without Affecting Yields in Louisiana?

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