Interplanting of a Deficient Soybean Stand

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LITERATURE REVIEW

Introduction

Soybean [*Glycine max* (L.) Merr.] is an economically important grain crop in the United States and Missouri and is grown primarily for oil and protein. In 2007, 25.75 million hectares in the United States and 1.86 million hectares in Missouri were planted to soybean. The production value of the soybean crop was estimated to be $26,752,197,000 in the United States and $1,767,675,000 in Missouri (USDA, 2007). Since the release of glyphosate resistant soybean cultivars in 1996, soybean production systems have changed dramatically. In 2007, glyphosate resistant soybeans accounted for 91% of the planted soybean area in the United States (USDA, 2007). The majority of agricultural commodities are produced by larger producers. The United States Department of Agriculture Economic Research Service (2002) reports that farms with at least $500,000 in gross receipts accounted for 43.9% of production in 2002, which is up from 28.9% in 1989. In the United States, there were 64 000 farms in this class in 2002, an increase from 32 000 in 1989.

With this shift to larger farms and the rise in operating expenses, especially seed cost, timely management techniques that minimize operating costs are important to keep United States soybean producers economically viable. Larger producers need to plant more acres in a timely fashion in spring, there is pressure to plant soybeans earlier or into marginal soil conditions. Planting soybean into cool or otherwise marginal soil conditions can lead to emergence problems and plant stand deficiencies.

Soybean Germination and Emergence

The process of soybean germination and emergence begins with the imbibition of water. Imbibition includes an initial wetting of seed tissues and the establishment of a sharp wetting front. The seed swells as seed water potential increases (McDonald et al., 1988). The seed coat hydrates first, followed by the embryo axis, and finally the cotyledons. Water absorption occurs over the entire seed coat and at the micropyle. Imbibition first causes wrinkles in the seed coat on the side of the seed distal to the hilum, but water is taken up at a greater rate through the hilum area (McDonald et al., 1988). In order for soybean seeds to germinate, a minimum moisture content of approximately one-half of their seed weight on a dry weight basis needs to be absorbed (Hunter and Erickson, 1952).

Once the soybean seed is hydrated, enzymatic activity, including respiration, begins, which leads to an increasing demand for oxygen (Al-Ani et al., 1985). Stored lipids are hydrolyzed into fatty acids and glycerol, which are transported with water to the embryo axis. The next step is the initiation of cell division and the growth of the embryo. During these initial steps of germination, the seed coat thins and becomes translucent, which permits the outline of the imbibed embryonic radical to be seen through the seed coat (Muthiah et al., 1994).

Imbibition of water softens the seed coat as well as enlarges the radical. The enlargement of the radical creates physical pressure on the seed coat, which will eventually split. This split will occur between the hilum and radical region near the microphle. Muthiah et al. (1994) reported that under ideal conditions (22 to 26 ºC, adequate soil moisture, and sterile soil) 18 to 30 hours is required from initial water absorption to radical emergence through the seed coat. After breaking through the seed coat, the radical continues elongation and anchors itself in the soil. The elongating radical begins to curve downward in response to gravity. Visible radical growth and downward movement occurs within 24 to 48 hours after planting (Hicks, 1978). After the radical reaches an elongation of approximately 10mm, the root cap is easily distinguishable (Muthiah et al., 1994). When the radical reaches 2 to 3 cm in length, branch roots begin to develop (Hicks, 1978).

Hydration of the cells in the embryonic axis and cotyledons allows them to attain full turgor. Associated with this hydration, subcellular organelles and cellular membranes reorganize and return to fully viable status (Noggle and Fritz, 1983).

Stored food reserves in the cotyledons are mobilized to provide energy for growth of the embryonic axis (Noggle and Fritz, 1983). These food reserves in soybean consist of three major groups: protein, fat, and carbohydrate (Gardner et al., 1985).

Muthiah et al. (1994) reported that between 72 and 108 hours after planting, the developing seedlings begin to discard the seed coat as the cotyledons expand in a longitudinal fashion. At this stage the hypocotyl forms a hook and is positioned to pull the cotyledons out of the soil. Emergence of the soybean from the soil occurs when the hypocotyl arch straightness and pulls the cotyledons upwards.

Requirements of Germination and Emergence

The soil environment of including water, oxygen, and temperature plays a direct role in the process of soybean seed germination and emergence. In most instances, seeds are planted into soils with less than optimal conditions for rapid emergence. These environmental factors can slow down the emergence process or result in seedling death.

Water

The imbibition of water by the soybean seed can be affected by both the lack of sufficient water and excessive soil water. As stated earlier, the seed moisture content required for soybean germination is approximately 50% on a dry weight basis. Soil moisture requirements for soybean germination are greater than requirements for the germination of rice, sugar beet, and corn (Hunter and Erickson, 1952). For example, Pendleton and Hartwig (1973) expressed soil moisture requirements for germination as soil moisture tensions. Corn germinated at a tension of 12.5 atm, whereas soybean failed to germinate at tensions greater than 6.6 atm.

Planting soybean seeds into soil with adequate soil moisture is not always possible. Seeds planted into moisture deficient soils might imbibe enough water to exhibit swelling, but not enough to complete germination and emergence. Senaratna and McKersie (1983) studied the effects on germination of imbibing soybean seeds followed by a dry down. They found that both the length of the imbibition period and the moisture content following drying affected germination percentage. Imbibing soybean seeds for 6 hours followed by drying to 10% moisture did not exhibit a significant statistical difference in germination percentage than the nondehydrated control, which had a germination percentage of 93%. Water imbibitions for 12, 18, and 24 hours resulted in germination percentages of 60, 65, and 65%, respectively, after the seeds were dried to 10% moisture. When the soybean seeds was imbibed for a period of 36 hours then dehydrated to moisture levels of 60, 40, and 20%, germination percentages were 90% or greater. However when the 36 hour imbibed seeds were dehydrated to 10% moisture, seed germination percentage dropped to 0%. Senaratna and McKersie (1983) concluded that soybean seed viability after an imbibition-dehydration treatment was influenced by the severity of dehydration and the length of the germination period prior to dehydration.

Research by Helms et al. (1996) concluded that if the radical had emerged from the seed coat and the soil water content was reduced below the initial soil water content due to drying, emergence percentage was reduced. In addition, if seed imbibition occurred, but the initial soil moisture was too dry for the radical to emerge from the seed coat, emergence percentage decreased as the number of days of this stress increased.

Initial lack of soil moisture and subsequent wetting and dehydration cycles both affect soybean germination, but so does excessive amounts of water. The effect of flooding duration and temperature on soybean seed germination was studied by Wuebker et al. (2001). During this lab experiment, soybean seeds were flooded for a duration ranging from 1 to 48 hours and flooding occurred 1, 2, and 3 days after the start of imbibition. They also used temperature treatments of 15 and 25 °C. Percent germination was measured after each treatment ended. Flooding at any time and for any duration lowered germination percentage compared to nonflooded seeds. The average decrease in germination percentage after one hour of flooding was 15 percentage points. For seeds flooded 2 or 3 days after the start of imbibition for a duration of 1, 6, 12, and 24 hours, germination percentages were 47, 48, 48, and 44% respectively, but the 48 hour flood duration resulted in a significantly lower germination percentage of 29%.

The interaction between germination temperature and the timing of flooding was significant for germination percentage. The greatest flooding injury occurred with the 15

°C germination temperature. Flooding of seeds 1 day after the start of imbibition at 15 °C reduced germination by 18 percentage points compared with an 11 percentage point decline for the 25 °C treatment. Seeds that were flooded for 3 days after the start of imbibition were more susceptible to flooding injury regardless of germination temperature. Wuebker et al. (2001) concluded that as seeds progressed further into the germination process when flooding occurred, susceptibility to flooding stress increased. Their data indicated that the duration of flooding is an important consideration in anticipated losses due to flooding. The results suggest that flooding for as briefly as one hour has the potential to cause significant losses in germinability. However, when the duration of flooding increased to 48 hours, the potential loss in seedling germinability was much greater. Previous studies have suggested many potential physiological mechanisms, including ethanol toxicity, oxygen deprivation, and carbon dioxide accumulation could be the cause for loss of germination percentage due to flooding (Wuebker et al., 2001; Woodstock and Taylorson, 1981).

Oxygen

The imbibition of water converts the seed from a quiescent state to a body capable of active respiration, biosynthesis, and growth. These life processes greatly increase oxygen demand. All life processes in the developing seedling depend on aerobic respiration, which consumes O_2 and liberates CO_2. Flooding and high soil water content excludes oxygen from soil. Low oxygen environments restrict seed respiration, and germinating seeds under hypoxia often produce toxic substances (Tain et al., 2005).

In a study conducted by Raymond et al. (1985), germinating seeds of twelve species, including soybean, were placed in aerobic and anaerobic conditions, and adenosine triphosphate (ATP) production was estimated. Seeds were first subjected to imbibition for 6 hours at 25 °C for measurements under aerobic conditions. After the aerobic data were collected, the seeds were placed in a closed vessel with an N_2 atmosphere for up to 48 hours to produce anaerobic conditions.

In the aerobic conditions, ethanol was found in large amounts in pea, maize and soybean and in smaller amounts in wheat, sunflower, and radish. The authors also observed that ethanol content of the seeds was increased under conditions, such as excess water, which limited gaseous exchange or ethanol evaporation. From the O_2 data they concluded that alcohol fermentation accounted for only 5% of the ATP regeneration in aerobic conditions.

Under anaerobic conditions, an accumulation of ethanol was observed in seeds of all the species. The rate of ATP generation under anoxia was smaller than in ambient air. During the first 4 hours, soybean reached only 20% of the rate of ATP generation observed in aerobic conditions. In summary, Raymond et al. (1985) showed that during anaerobic conditions ATP production in soybean is reduced dramatically and accumulation of ethanol occurs.

Woodstock and Taylorson (1981) examined the production of ethanol and acetaldehyde during respiration and the effects of these compounds on high vigor compared to low vigor soybean seeds. Their study focused on the interaction between the glycolytic pathway and the tricarboxylic acid cycle electron transport chain. Soybean seeds were imbibed for 4 hours at 25 ºC in anaerobic conditions and measurements of pyruvate, acetaldehyde, and ethanol production were made. Submerging the seeds in water created anaerobic conditions and pyruvate was converted to acetaldehyde and ethanol. This accumulation occurred in both high vigor and low vigor soybean seeds, but accumulation in low vigor seeds was greatly enhanced due to a decline in mitochondrial activity. The accumulation of ethanol and acetaldehyde in low vigor seed could be due to a breakdown in the integration between glycloysis and the TCA cycle. Although a slight increase in ethanol and acetaldehyde might be tolerated and could even be a frequent occurrence in high vigor seeds, an intensification of ethanol accumulation in low vigor seeds will lead to adverse effects on seedling growth.

Temperature

Soybean emergence percentage and the speed of emergence are both affected by temperature. In a field study, Hatfield and Egli (1974) found that the optimum range of soil temperatures for emergence of soybean was 25 to 35 °C. They also found that hypocotyl elongation was extremely slow at 10 °C and that seeds did not germinate at 40 °C. They also studied the length of time between planting and emergence of soybean. At 15 °C, the time from planting to emergence was approximately 500 hours, and the time decreased to a minimum of 100 hours at 30 °C.

Cool temperatures during imbibition of water can damage seeds. Bramlage et al. (1978) established that imbibition temperatures that cause chilling injury might be attributed to disruptive effects on the reorganization of membranes and are associated with increased solute leakiness from soybean cotyledons. Leopold (1980) found that solute leakage rates were 10-fold greater from living soybean cotyledons than from dead ones at 20 °C and concluded that this leakage may be a consequence of the disruption of membrane reorganization at the temperature associated with chilling injury.

The rate of imbibition and the amount of water weight gain that occurs during imbibition are both temperature sensitive. Duke et al. (1977) conducted a study to examine low temperature effects on soybean during imbibition and germination. In their study, soybean seeds were submerged for 6 hours at 10 and 23 °C at the start of imbibition. For 6 hours the seeds were kept at their respective temperatures and then placed on water-saturated tissue paper. Weight gain of the total seed was measured at 0, 3, 6, 12, and 24 hours followed by measurements of weight gain of the removed embryonic axes at 48 hours. After 3 hours of being submerged, imbibition at 23 °C had increased in fresh wt/hr by 8% more than the seeds imbibed at 10 °C. The rates of gain for both temperature treatments were somewhat equal during the 3 through12 hour period. At 48 hours, embryonic axes of the 10 °C treatment weighed about 40% of those of the 23 °C treatment. This study also measured the amount of time needed for germination of the 10 and 23 °C temperature treatments. At 23 °C, 72% of the seeds had germinated at 36 hours, whereas at 10 °C this percentage was not achieved until after 144 hours. After germination at 10 °C, hypocotyl extension was severely depressed and growth was slow and abnormal.

Seedling Diseases

Soil pathogens can affect seedling health and emergence percentage. The most common soybean seedling diseases in the USA are caused by *H. glycines, Phytophthora sojae, Macrophomina phaseolina, Fusarium solani, Rhizoctonia solani, Pythium spp.*, and *Fusarium spp.* (Wrather et al., 2001). These seedling diseases can cause less than optimal plant populations and reduced seedling vigor that can lead to reduced yield and higher weed control cost (Poag et al., 2005). It would be expected that environmental conditions that limit general metabolic activity of the host might also limit its ability to respond to pathogens. Shortening the period of the pathogen attack should logically result in a lower probability that pathogens will adversely affect the seedling. In a greenhouse study, Hamman et al. (2002) found that final emergence percentage of soybean was reduced by pathogens, but the pathogens also tended to increase the time it took for the seedlings to emerge. They also found that the destruction of the seed by the pathogen before or immediately after germination was the significant cause of small emergence percentage.

Environmental factors can also affect the ability of the pathogen to infect a host. For example, *Phytophthora sojae* germination and development of oospores and sporangia are favored by saturated soil conditions. The highest economic loss from *Phytophthora* occurs when soils were saturated with water just after soybean planting (Dorrance, 2001). *Pyhthium* spp. are the most important fungi associated with poor stand when soybean is planted in cold soils (Zhang and Yang, 2000). *Phomopsis longicolla* is damaging to soybean when seeds are planted in a low moisture soil (Ferriss et al., 1987). The conclusion of Dorrance et al. (2003) in a study of temperature and moisture effects on *Rhizoconia solani* in soybean production was inconclusive and suggested that management measures aimed at influencing the soil temperature and moisture are unlikely to be successful due to the ability of the *R. solani* pathogen to infect soybean seeds over broad temperature and moisture ranges.

Another factor in pathogen interactions with soybean is the quality of the seed. Cracks in the seed coat are potential sites of pathogen invasion, so the quality of the soybean seeds is important (McDonald, 1985). Senaranta and McKersie (1983) found that solute leakage can occur when soybean seeds are stressed due to dehydration injury. Schrotch and Cook (1964) found that cracked seed coats result in greater exudation and greater susceptibility to preemergence damping-off caused by *Rhizoctonia solani* and *Pythium ultimum*. Their data suggest that increased preemergence damping-off resulting from cracked seeds is not due to increased exudates and that uninjured seed exudates were sufficient to stimulate germination of the chlamydospores.

Seed Quality

The environmental effects of moisture, temperature, and pathogens are important in the process of soybean germination and emergence, but starting with high quality seed is the basis for establishing an adequate final stand. Seed quality and seed vigor are closely related. Muendel (1986) defines vigor as the potential of seeds to give rapid, uniform emergence under a wide variety of conditions. There are several factors that influence soybean seed vigor. The first step in germination is the imbibition of water through the seed coat. Changes in the seed coat can alter the imbibition process. Seed quality at planting results from the integrated effects of the environment during seed production and the conditions to which the seeds were exposed during harvest, conditioning, and storage (Egli et al., 2005). Physical damage to the seed coat due to improper harvesting and handling and its consequential effect on seed coat integrity is a leading cause of seed deterioration. (McDonald et al., 1988) Often, this damage results in cracks in the seed coat, which leads to a decrease in field emergence (Luedders and Burris, 1979).

In an effort to understand seed coat damage, Burchett et al. (1985) studied what is called etched seed. Etched seeds have been referred to as defective, cracked, and physiologically cracked seeds. They found that etched seed coats are inferior to non-etched seeds in both germination and vigor and that seed coat etching reduced warm germination by about 18%.

The environment in which soybean seeds develop can also affect seedling vigor. Temperature and drought stress during critical growth stages of soybean can cause variations in seed quality. Warm and moist conditions during late reproductive stages may increase infection of seeds by *Phomopsis longicolla*, which can reduce quality (Spears et al. 1997). Spears et al. (1997) found that temperatures of 33 and 38 °C during seed filling reduced seed germination and vigor compared to seed filling at 27 °C. Water stress during seed maturity can also decrease seed vigor. Results from the work of Dornbos et al. (1988) demonstrated the germination ability of soybean seed can be reduced by drought that occurs during seed fill if the intensity of stress is sufficiently severe. As the severity of drought increased, germination percentages decreased significantly by 6% when compared with irrigated plots.

Stand Assessment and Management Options

The establishment of an adequate soybean plant density is an essential part of profitable soybean production. Reduced emergence and less than optimal plant density can lead to less yield at the end of the growing season. The management of less than ideal soybean plant stands starts with the assessment of the existing stand.

First, the cause of the reduced stand needs to be determined to ensure that future management options are not adversely affected by an existing stand reducing problem. Those factors that produce sparse soybean stands can include poor seed quality, improper seeding practices, low moisture availability, soil crusting, soil temperatures, hail, saturated soils, herbicide injury, insect feeding, disease infections, frost, and animal feeding.

The second step in evaluating a soybean stand is to determine existing plant densities. Soybean plant densities can be determined by counting plants in several areas of the affected field and calculating the number of plants per given area. When evaluating the existing soybean stand, attention should be given to the health and general appearance of the existing plants. Plants that have been damaged or are weak need to be assessed for their ability to recover and contribute to overall yield. Other factors to consider during the stand determination are the uniformity of the existing stand and the presence of large gaps in the stand.

After stand density of the existing stand is determined, the yield potential of the weak stand needs to be assessed. Research on soybean plant density related to yield is somewhat inconclusive. For example, Ball et al. (2000) examined two cultivars at planting densities ranging from 60 000 to 1 340 000 plants/ha. They found increases in yield with increases in plant densities through the entire range of plant density treatments. Norsworthy and Frederick (2002) found that seeding rates of 620 000 seeds/ha and 40% of that rate were not significantly different for yield. Holshouser and Whitaker (2002) compared seeding rates ranging from 103 000 to 850 000 seeds/ha for soybean yield. They determine that 208 880 seeds/ha was the optimum seeding rate when little drought stress occurred, but 600 000 seeds/ha were required to maximize yield in drought stress situations. Kratochvil et al. (2004) compared seeding rates of 432,250 seeds/ha with rates at 20% and 40% less than 432 250 seeds/ha. They concluded that a 20% reduction in seeding rate did not reduce yield, but a 40% reduction consistently yielded less than the 432,500 seeds/ha rate.

Boquet (1990) reported that at optimal planting dates, plant density of 100 000 plants/ha showed no reduction in yield compared with optimal plant population density of 250 000 plants/ha. Norsworthy and Oliver (2001) approached the question of seeding rates in glyphosate resistant soybean from a different perspective. They studied 12 different seeding rates ranging from 185 000 to 1 482 000 seeds/ha and also determined the herbicide cost needed to keep these plots 90% weed free during the growing season. Their comparison of gross profit margins included the seed cost, herbicide cost and yields. They concluded the best gross profit margins were obtained at the lowest seeding rate tested of 185 000 seeds/ha. As soybean seeding rate increased, glyphosate and application costs were less influential on total cost than seeding cost; thus, seeding rates producing the highest yield did not result in maximum gross profit margin.

Soybean plants have the ability to compensate for less than optimum stand densities, which could explain these research results. Soybean plants will grow into open areas in the field to maximize the light interception in a given area. Soybean can allocate more resources to branching and seed yield on branches when needed. Rigsby and Board (2003) conducted research on 14 different cultivars and two plant populations of 90 000 and 250 000 seeds/ha. They found that some cultivars were better suited for the smaller plant population and yielded the same for both plant densities. Results also indicated that partitioning of total vegetative dry matter into branches plays a leading role in the determination of yield in lower than optimum plant populations. Vasilas et al. (1990) studied the effect of stand reduction by imposing gaps in soybeans. Their study removed 33% of the soybean stand and found no reduction in yield, illustrating that soybean plants have the ability to compensate for sub-optimal plant densities.

After the yield potential of the weak stand has been estimated, the expected yield from replanting needs to be determined. In most instances, stands are assessed two or more weeks after the initial planting date so the effect of planting date on yield is an important consideration. Delayed planting can have an adverse effect on soybean yield and the later the planting date from optimal, the greater the decreases in seed yield. For example, Walker (1983) compared responses of four soybean cultivars to planting dates in central Illinois. Early June and late June planting dates yielded 90% and 65%, respectively, of the May planting dates. Oplinger and Philbrook (1992) found similar results when comparing 30 May plantings to 13 July planting. The July planting yielding a significantly 15% less than the May planting. Boquet (1990) found that a planting delay of just 14 days from a June date to a July date resulted in smaller seed yields in Louisiana. Heatherly (1988) also observed planting date effects in irrigated soybean production when comparing mid May to mid June planting dates. In this research the 3-year average yields for the June planting was significantly 928 kg/ha lower than the May planting date.

Once the yield potentials of a sparse stand and replanting have been estimated, weighing the management options for the deficient stand occurs. Most previous research has focused on two options available: leave the existing stand until harvest or destroy the existing stand and replant. If the existing deficient stand is left, additional applications of herbicide may be needed, which would add to the cost of production. Another concern with leaving the existing stand is its ability to yield as well as an optimum plant stand. The replant option is contingent on planting date effects and also the added cost associated with replanting. With the advent of glyphosate resistant soybean seed adoption, input expenses for soybean seed has increased dramatically since its introduction in 1996. The cost of replanting a hectare of glyphosate resistant soybeans with a no-till planter is over $114 which is a sizable increase in the operating expense for the producer (Plain et al., 2006).

With the uncertainty of leaving the existing stand and the added cost of replanting, a third option should be investigated. This third option is the interplanting of soybean into the existing deficient stand in an effort to increase the plant population density without destroying the existing stand. The interplanting option would require fewer seeds per hectare than replanting thereby costing less. This interplanting option has not been explored in research and should be considered to increase the producer's options.

Objectives

The objectives of this study were to:

1. determine if planting date influences the response of soybean yield to plant density and
2. evaluate interplanting as a cost effective management strategy for correcting sparse soybean stands.

MATERIALS AND METHODS

This experiment was conducted in 2002, 2003, and 2004 at the Bradford Research and Extension Center near Columbia, Missouri. The predominant soil type for the plot area was a Mexico silt loam (Montorillonitic, mesic, aeric, Vertic Epiaqualfs). The previous crop for each year was corn (*Zea mays* L.)

The field plot design was a split plot with whole plots arranged as a randomized complete block and replicated four times. Whole plots were five planting treatments: “Let Be”, “Interplant V1”, “Interplant V3”, “Replant V1”, and “Replant V3”. The split plots were six seeding rates: 74 100, 148 200, 222 300, 296 400, 370 500, and 444 600 seeds/ha. The “Let Be” treatment consisted of planting the appropriate seeding rates followed by no additional planting related actions. ”Let Be” plots were planted without tillage using an Almaco no-till drill. Row spacing was 0.19 meters. Each plot was 16 rows wide (two drill widths) for a total of 3 meters and 7.6 meters long. The “Let Be” treatments were planted on 31 May, 23 May, and 4 June in 2002, 2003, and 2004, respectively. At the V1 growth stage, all plants were counted in three 0.9-meter quadrants randomly placed within the plot. These counts were used to calculate stand densities.

For the “Interplant” treatments, two sets of plots were planted on the same planting date and using the same planting rates as the “Let Be” treatments. Stand densities were calculated using stand counts collected as described for the “Let Be” treatment. The number of seeds required to increase stand density to 395 280 plants/ha (assuming 90% emergence) were determined for each plot. At the V1 stage of growth, the “Interplant V1” treatment was applied to one set of plots by planting the calculated number of seeds into the existing stands with a Kinze 4-row planter. Row spacing was 0.76 meter. Planting dates for “Interplant V1” were 18 June, 17 June, and 22 June in 2002, 2003, and 2004, respectively. At the V3 stage of growth, the “Interplant V3" treatment was applied to the second set of plots in a manner identical to “Interplant V1”. Planting dates for “Interplant V3” were 27 June, 25 June, and 28 June in 2002, 2003 and 2004, respectively.

To simulate replanting situations for the “Replant V1” and Replant V3” treatments, two sets of plots were planted using a non-glyphosate resistant variety (Williams 82) at a rate of 59 974 seeds/ha. The planting dates and techniques were identical to those used for the “Let Be” treatment. Prior to the V1 stage of development, existing plants were sprayed with glyphosate to kill the stands. On the same planting dates used for the “Interplant V1” treatment, the plots that had been assigned to the “Replant V1” treatment were planted using the same six seeding rates and techniques as the “Let Be” treatment. Similarly, plots assigned to the “Replant V3” treatment were planted using the same six seeding rates as the “Let Be” treatment, but on the dates that coincided with the “Interplant V3” treatment.

The soybean variety used in all years was DeKalb brand 38-52, a glyphosate resistant variety. Herbicides applied at labeled rates prior to planting in 2002 were glyphosate [N-(phosphonomethyl)glycine] , S-metolachlor [2-chloro-N-(2-ethyl-6-methylphenyl)-N-[(1S)-2-methoxy-1-methylethyl] acetamide], metribuzin [4-amino-6-(1,1-dimethlethyl1)-3-(methylthio)-1,2,4 triazin-5(4H)-one], and chloriumuron ethyl [ethyl 2-[[[[(4-chloro-6-methoxyppyrimidin-2-yl)amino] carbonyl] amin]sulfonyl] benzoate]. In 2003 and 2004, cloransulam-methyl [N-(2-carbomethoxy-6 chlorophenyl)-5-ethoxy-7-fluoro(1,2,4)triaxolo-[1,5-c]pyrimidine-2-sulfonamide], and sulfentrazone [N-[2,4-dichloro-5-[4-(difuoromethyl)-4,5-dihydro-3-methyl-5-oxo-1H-1,2,4-triazol-1-y1]phenyl]methanesulfonamide] were added and chloriumuron ethyl and metribuzin were removed from the preemergence mix. Postemergence applications of glyphosate were used as necessary for additional weed control.

Irrigation was performed as needed. During the growing season, 63.5 mm were applied in 2002, 44.5 mm were applied in 2003, and no irrigation was used in 2004. Fertilizer was applied in the fall before each study year at a rate of 22.7 kg P/ha as super triple phosphate and 55.8 kg K/ha as potassium chloride. Prior to harvest, plots were end trimmed to 6.1 meters. A Massey Ferguson small plot combine was used for harvest. Harvested width for each plot was 1.52 meters. Yield was corrected to 13% moisture.

To determine planting date and seeding rate effects on stand density and yield, data from the “Let Be”, “Replant V1” and “Replant V3” treatments were analyzed separately. Whole plots were the three planting dates and split plots were the six seeding rates. Data analyses for yield combined over years revealed significant date X year and date X rate X year interactions, so data are presented for each year. A Fisher protected LSD was used for mean comparisons. Stand densities were regressed on yield using a quadratic-plateau model (Proc nlim; SAS Institute, Cary, NC) to calculate “break points” for each planting date within each year. These break points are the junctions between the quadratic and the plateau regions of the model.

Yield responses from replanting at V1 were calculated by subtracting yields obtained from each seeding rate within the “Let be” treatment from averaged yields obtained from 296 400, 370 500, and 444 600 seeds/ha seeding rates of the “Replant V1” treatment. These seeding rates produced stands above the break points. The mean of three seeding rates were used to reduce variation. In other words, the response from replanting was calculated using data in which an acceptable stand was obtained. Data were expressed as the percent response with the “Let Be” yield used as the denominator. Yield responses from replanting at V3 were calculated in a similar manner, but used yield obtained from the three greatest seeding rates of the “Replant V3” treatment.

Yield responses from interplanting at V1 were calculated by subtracting yields obtained from each seeding rate within the “Let be” treatment from yields obtained from interplanting the same seeding rate at V1. Responses were expressed as percentage of the “Let Be” yields. Yield responses from interplanting at V3 were calculated in a similar manner, but used plots assigned to the “Interplant V3” treatment.

Yield responses from all four actions: replanting at V1, replanting at V3, interplanting at V1, and interplanting at V3, were subjected to analysis of variance. The design was a randomized complete block and seeding rate was the single treatment. A Fisher protected LSD was used for mean comparisons.

To determine which of the four actions was most beneficial for yield response, the yield responses of the four actions from the 74 100 seeding rate were subjected to additional analysis of variance. This seeding rate was chosen because the yield response was positive for nearly every action in each year. The design was a randomized complete block with the four actions as the treatment. A Fisher protected LSD was used for mean comparisons.

RESULTS AND DISCUSSION

Year x planting date and year x planting date x seeding rate interactions were significant for both stand density and yield, so data for each year are presented separately. Soybean yields were adversely affected by a delay in planting date in all three years of the study (Table 1). Mean yield of all six seeding rates of the first planting date was significantly greater than mean yield of the second planting date, and the mean yield of the second planting date was significantly greater than the mean yield of the third planting date in each of the three years. The numbers of days between the first and second planting dates were 18, 25, and 18 for 2002, 2003, and 2004. The decrease in yield from the first planting to the second planting was 17%, 19% and 27% for 2002, 2003, and 2004, respectively. The planting delays from second to third planting dates were only 9, 8 and 6 days, but the decrease in yield was 26%, 45%, and 20% for 2002, 2003, and 2004, respectively. So, yield loss from delayed planting increased from about 1% per day to over 3% per day during the planting dates used in this research.

Soybean yield loss from delayed planting has been well documented (Boquet, 1990; Elmore, 1990; Heatherly, 1988; Oplinger and Philbrook, 1992; Walker, 1983; Weaver et al., 1991). For example, Weaver et al. (1991) found a June planting date yielded 27% more than a July planting date. In a study conducted by Elmore (1990), comparisons were made between planting dates at the end of May and in the middle of June along with comparison of conventional tillage and no-tillage systems. Tillage system effects were not significant, but planting date had a significant effect on soybean yield. The mean yield for all cultivars and all tillage systems used in the study showed that the June planted soybean yield was 17% less than the May planted soybean yield.

Although the data from each year are presented separately, a comparison of yield potential among years is warranted. The overall soybean yields in 2003 were somewhat reduced in comparison to the 2002 and 2004 yields. One of the limiting factors in 2003 was the lack of rainfall (Figure 1). During the critical growth period from 1 July through 25 August, rainfall accumulation in 2003 totaled 45 mm. In contrast, rainfall accumulation during the same time period was 280 mm in 2002 and 251 mm in 2004. This lack of rain accounted for the 2003 yields being approximately 85%, 82%, and 59% of the average yield of 2002 and 2004 for the first, second, and third planting dates, respectively. An additional 45 mm of irrigation water was applied, but it was not enough to correct for lack of rainfall.

Six seeding densities were used to establish a range of stand densities. Although ranges differed among years and planting dates, average stand densities ranged from 58 000 to 370 000 plants/ha (Tables 2, 3. 4). In almost every instance, an increase in seeding rate resulted in a significant increase in stand density.

For each planting date of each year, the smallest planting rate produced the least yield. Yield increased with increased seeding rate until either 222 300 or 296 400 seeds/ha. Yields did not increase as seeding rates were increased above these seeding rates to 444 600 seeds/ha, my maximum seeding rate. Although my data conflict with results reported by Ball et al. (2000), most researchers have reported similar results. Norsworthy and Fredrick (2002) found that seeding densities of 248 0000 and 620 000 seeds/ha were not significantly different for yield. Holshouser and Whitaker (2002) determined that 208 880 plants/ha was the optimum seeding densitity when little drought stress occurred. Katochvil et al. (2004) comparing the standard seeding rate of 432 250 seeds/ha to seeding rates that were 20% and 40% less than the standard rate and 20% greater than the standard rate. They found no significant difference in yields among the standard rate, 20% reduced rate, and 20% increase in rate. There was a significant yield reduction for the 40% less than standard seeding rate.

I used regression analyses to determine the number of plants required to maximize yield. The breakpoint between the quadratic and the plateau phases of the model differed dramatically among planting dates in 2002 and 2003 (Table 5). The planting date x seeding rate interaction was not significant in 2004. In 2002 and 2003 breakpoints for the first planting date were 114 235 and 170 796 plants/ha. Breakpoints increased to 287 693 and 310 896 plants/ha for the second planting date and increased again to 299 890 and 365 763 plants/ha for the third planting date. My data suggest that greater plant stands are required to achieve maximum yield if soybean planting is delayed from late May to mid-June. Boquet (1990) planted soybean in June and July at various seeding densities to determine rates needed to maximize yield. They found that the optimum seeding rate required for the July planting date was 27% higher in 0.5-meter rows and 50% higher in 1-meter rows compared with the June planting date.

In most instances yield responses from replanting were negative, especially if replanting was delayed until plants of the original stand had reached V3 stage of development (Table 6). Only at the smallest plant densities were there positive yield responses from the "Replant V1” treatment. The “Interplant V1” and the “Interplant V3” treatments exhibited more instances of positive yield responses than either replant treatment (Table 6). However, except for the lowest stand densities, responses were small and not significantly different than the negative yield responses found for greater stand densities. To allow for a comparison among the four treatments I subjected yield responses for the lowest seeding rate (74 100 seeds/ha) to a separate analysis. In 2002 and 2004 at the V1 stage, the interplant treatment yielded significantly better than the replant treatment. At the V3 stage, the interplant treatment was significantly better than the replant treatment for all years.

Few other studies have been designed to make comparisons between replanting and interplanting. Vasilas et al. (1990) planted soybean in 76-cm rows at a seeding rate of 292 800 seeds/ha. Treatments consisted of a control in which the initial seeding was left until harvest, uniform reductions in stand by 33% and 66%, nonuniform or "gap" treatments reducing plant densities by 33 and 66%, replanting of the original stand, and the use of an offset row that was planted into the existing stand 20 cm from the row of the original uniform and non uniform stand reduction treatments. The replant and offset rows were planted 24 days after the initial plantings. They concluded that the uniform stand reduction of 33 and 66% as well as the 33% gap reduction were not significantly different from the control, but the 66 % gap reduction treatment significantly reduced yield by 672 kg/ha. The yield loss associated with replant was greater then any yield loss effected by poor stands. The addition of an offset row increased grain yield only when 66% of stand had been lost by gaps and the addition of the offset row reduced yield loss by only 50%.

Conclusions

Planting date effects were significant with decreasing yield occurring with later planting dates. Increasing plant density increased soybean yield to a breakpoint in two of the three years.   Plant densities required to maximize yield increased with later planting dates. At the smallest seeding density, the interplant treatments were a viable option compared with the replanting at the V1 stage in 2 of the 3 years and in all years at the V3 stage.

Management of a deficient soybean stand can be a difficult challenge for a producer. It can be seen in this study what options are viable solutions. Leaving an existing stand to maturity is the best option unless the stands are extremely low. In the case of very small plant densities, the interplanting of seeds into the existing stand is an economical and agronomically sound practice.

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Table 1. Effects of planting date on soybean stand density and yield in 2002, 2003, and 2004. Means are averages of six seeding rates.

Planting date†	2002 Stand density	2002 Yield	2003 Stand density	2003 Yield	2004 Stand density	2004 Yield
	no./ha	kg/ha	no./ha	kg/ha	no./ha	kg/ha
First	233 269a‡	4264c	167 068a	3581c	196 656ab	4459c
Second	209 957a	3554b	231 027c	2889b	227 440b	3227b
Third	226 694a	2626a	210 106b	1579a	193 070a	2692a

† First, second, and third planting dates were 31 May, 18 June, and 27 June in 2002; 23 May, 17 June, and 25 June in 2003; 4 June, 22 June, and 28 June in 2004.

‡numbers within a column followed by the same letter are not different ($\mathrm{FLSD}_{0.05}$).

Table 2. Effects of planting date and seeding rate on soybean stand density and yield, 2002.

Seeding rate	31 May		18 June		27 June	
	Stand density	Yield	Stand density	Yield	Stand density	Yield
no./ha	no./ha	kg/ha	no./ha	kg/ha	no./ha	kg/ha
74 100	58 280a†‡	3304a§	60 073a	2489a	66 349a	1396a
148 200	124 629b	4251bc	127 319b	3192b	138 975b	2441b
222 300	190 081c	4576cd	194 564c	3774c	179 322b	2588b
296 400	287 812d	4208b	240 291d	3835c	245 671c	3013c
370 500	335 332e	4577cd	294 985e	3944c	310 227d	3072c
444 600	403 475f	4668d	342 505f	4090c	419 613e	3249c

†numbers within a column followed by the same letter are not different ($FLSD_{0.05}$).

‡$LSD_{0.05}$ to compare any two numbers representing stand density is 45 900.

§ $LSD_{0.05}$ to compare any two numbers representing yield is 348.

Table 3. Effects of planting date and seeding rate on soybean stand density and yield, 2003.

	23 May		17 June		25 June	
Seeding rate	Stand density	Yield	Stand density	Yield	Stand density	Yield
no./ha	no./ha	kg/ha	no./ha	kg/ha	no./ha	kg/ha
74 100	47 520a†‡	3234a§	62 763a	1848a	52 003a	543a
148 200	85 178b	3534b	132 698b	2573b	118 353b	1198b
222 300	144 354c	3756bc	201 737c	3025c	182 012c	1646c
296 400	205 324d	3433b	258 224d	3400c	251 947d	1888cd
370 500	243 878e	3988c	313 814e	3316c	294 985e	1972cd
444 600	276 156f	3944c	416 924f	3171c	361 334f	2227d

†numbers within a column followed by the same letter are not different (FLSD$_{0.05}$).

‡LSD$_{0.05}$ to compare any two numbers representing stand density is 19 348.

§ LSD$_{0.05}$ to compare any two numbers representing yield is 372.

Table 4. Effects of planting date and seeding rate on soybean stand density and yield, 2004.

Seeding rate	4 June Stand density	4 June Yield	22 June Stand density	22 June Yield	28 June Stand density	28 June Yield
no./ha	no./ha	kg/ha	no./ha	kg/ha	no./ha	kg/ha
74 100	60 969a†‡	3578a§	69 936a	1875a	46 624a	1592a
148 200	83 385a	4110bc	120 146ab	2990b	96 834ab	2541b
222 300	156 907b	4485cd	199 047b	3548cd	177 529cd	3017bc
296 400	225 049c	3973b	263 603c	3482c	209 807d	3007bc
370 500	292 295d	4818cd	320 986d	3549cd	272 569e	3071c
444 600	361 334e	5120d	390 922e	3949d	355 058f	2924bc

†numbers within a column followed by the same letter are not different ($FLSD_{0.05}$).

‡$LSD_{0.05}$ to compare any two numbers representing stand density is 55 056.

§ $LSD_{0.05}$ to compare any two numbers representing yield is 436.

Table 5. Stand density breakpoints calculated using quadratic plateau models of stand density regressed on to soybean yield.

Year	Planting date	Breakpoint	R^2	$P > F$
		no./ha		
2002	31 May	114 235	0.59	<0.0001
2002	18 June	310 896	0 83	<0.0001
2002	27 June	299 890	0.90	<0.0001
2003	23 May	170 796	0.44	0.0021
2003	17 June	287 693	0.76	<0.0001
2003	25 June	365 763	0.31	<0.0001
2004	4 June	196 708	0.57	0.0004
2004	22 June	198 072	0.75	<0.0001
2004	28 June	155 694	0.91	<0.0001

Table 6. Yield response from performing replanting or interplanting at V1 and V3 stage of development.

		Action			
Year	Stand density	Replant V1	Replant V3	Interplant V1	Interplant V3
	no./ha	-----------------------------%		-----------------------------	
2002	58 280	21.9a†	-3.5a	30.1a	19.9a
2002	124 629	-6.1b	-26.2b	-1.4b	-2.5b
2002	190 081	-13.0b	-31.5b	-1.4b	-0.9b
2002	287 812	-5.3b	-25.4b	5.6b	4.2b
2002	335 332	-13.5b	31.9b	-3.0b	1.6b
2002	403 475	-14.6b	-32.9b	0.9b	7.3b
2003	47 520	17.7a	-27a	25.7a	20.6a
2003	85 178	-5.4bc	-41.2b	4.5b	-0.9b
2003	144 354	-12.2bc	-46.2b	-3.3b	-4.4b
2003	205 324	-3.9b	-40.8b	9.8b	8.3ab
2003	243 878	-16.7c	-48.4b	-0.5b	-0.2b
2003	276 156	-15.9bc	-47.9b	-3.3b	-3.2b
2004	60 969	2.7a	-14.7a	27.8a	13.9a
2004	83 385	-9.8ab	-25.1ab	12.2ab	3.0ab
2004	156 907	-18.1bc	-32.0bc	3.0bc	-3.1ab
2004	225 049	-21.3bc	-35.3bc	-4.5c	-0.8ab
2004	292 295	-24.3c	-37.3c	-7.2c	-2.5ab
2004	361 334	-28.7c	-41.3c	-9.4c	-7.6b

†Numbers within a column and within a year followed by the same letter are not significantly different (FLSD $_{0.05}$).

Table 7. Yield response from performing replanting or interplanting at V1 and V3 stage of development for stands obtained from the 74 100 seeds/ha seeding rate.

		Action			
Year	Stand density	Replant V1	Replant V3	Interplant V1	Interplant V3
	no./ha	------------------------------%	------------------------------		
2002	58 280	21.9b†	-3.5c	30.1a	19.9b
2003	47 520	17.7a	-27b	25.7a	20.6a
2004	60 969	2.7c	-14.7d	27.8a	13.9b

†Numbers within a row followed by the same letter are not significantly different (FLSD $_{0.05}$).

Figure 1. Precipitation totals for 2002, 2003, and 2004 at Bradford Research and Extension Center near Columbia, MO.