

YIELD RESPONSE OF SOYBEAN TO PLANTING  
DATE AND ROW SPACING IN ILLINOIS

BY

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THESIS

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## Abstract

Soybean [*Glycine max* (L.) Merrill] is a primary Illinois field crop, and maximizing returns through use of efficient soybean planting practices is important to producers. Recent studies of planting date and row spacing have been limited in geographic scope, and few of these have included both factors together. Studies combining these factors, and seeding rate, were conducted during 2010 and 2011 at six Illinois locations. Four planting dates and two row spacings were evaluated. Planting date had a large effect on yield and the northern locations experienced progressive yield loss with delayed planting. At the northern locations from April 19<sup>th</sup> to May 24<sup>th</sup> yield loss per day more than doubled from 10.9 to 24.9 kg ha<sup>-1</sup> day<sup>-1</sup>. At southern sites with poorer soils and more stressful environmental conditions, yield loss was not always progressively greater with planting delay. Across planting date at the eight northern sites narrow rows out yielded wide rows by 122 kg ha<sup>-1</sup> (3.0%). A row spacing by environment interaction indicated that not all sites responded favorably to narrow rows. Another interaction between row spacing and planting showed that the narrow row yield advantage unexpectedly decreased with planting delay. Two the four southern sites also showed a yield increase from narrow rows. The data suggests that regardless of other factors, early planting and narrow rows increase yield. Planting date though clearly had the largest yield impact and planting earlier seems to present the greatest opportunity to maximize yield.

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## Introduction

World demand of soybean has increased dramatically with expanding uses in food and industrial products (Imhoff and Warshall, 1999; Trostle, 2010). In addition to expanding products, soybean as cattle feed has also been important to demand with per capita meat consumption rising (Trostle, 2010). Increased demand mirrors the increase of production. Soybean has become one of the two dominant crops in both Illinois and U.S. agriculture. In the last century, increases in soybean production can be attributed to both higher yields and more area of soybean being planted. From 1924 to 1979 area planted to soybean in Illinois increased from 127 000 ha to 3 800 000 ha, about 67 000 ha yr<sup>-1</sup>, and since then has remained relatively stable (USDA-National Agricultural Statistics Service, 2010). Illinois soybean yield has been increasing at a relatively steady rate of 26.2 kg ha<sup>-1</sup> since 1924 (USDA-National Agricultural Statistics Service, 2010). With soybean area stabilized in Illinois, greater production must come from higher yields. To continue to increase yield, improvement will depend on soybean development, management, and production practices.

In an attempt to increase producers' yields and efficiency, a couple planting practices were examined: planting date and row spacing. Recent studies have not sufficiently investigated the impacts of these practices combined in Illinois. Though in states bordering Illinois some of these practices have been tested. In recent years several trials in the Midwestern US have shown greater yield responses to earlier planted soybean (De Bruin and Pedersen, 2008b, Robinson *et al.*, 2009), but studies have not been conducted within Illinois to confirm and tweak response expectations to planting date. In earlier experiments, planting dates needed to produce highest yields typically extended into the third week of May before a significant decline was observed (Burlison *et al.*, 1940; Torrie and Briggs, 1955; Egli and Cornelius, 2009). Over the last twenty years planting progress has averaged 0.3, 11.5, 43.4, and

74.4% for the weeks of April 22<sup>th</sup>, May 6<sup>th</sup>, May 20<sup>th</sup>, and June 3<sup>rd</sup> respectively (USDA-National Agricultural Statistics Service, 2010). Directly investigating planting date response in Illinois will aid in quantifying yield potential lost with delayed planting.

Trials have also shown variable response to soybean row spacing, with some showing increases of 248 (De Bruin and Pedersen, 2008a) and 362 kg ha<sup>-1</sup> (Taylor *et al.*, 1982) while other experiments showing no differences (Hicks *et al.*, 1969; Pedersen and Lauer, 2003). Today, about 52% and 32.3% of Illinois soybean are planted in the row spacing ranges of 25.7 to 47 [narrow rows] and 72.6 to 87.6 cm [wide rows] respectively (USDA-Economic Research Service, 2012). By investigating row spacing at twelve site years in both of the previously mentioned ranges, row spacing and its interaction with planting date should be well evaluated for its impact in Illinois.

The objective of this research was to address differences in reported planting date yield responses, and to see if row spacing interacts with planting date. The ultimate goal is to optimize a planting system that maximizes return to planting management, whether planting is at the optimum time or is delayed due to weather.

## Literature Review

### Introduction and Expansion of Soybean in the United States

Soybean [*Glycine max* (L.) Merrill] is indigenous to Eastern China because numerous semi-wild and wild varieties are present in the region and the environment has wet low lying habitats required to grow varieties not yet bred for more arid regions (Ho, *The Loess and the origin of Chinese agriculture*, 1969). The earliest evidence of soybean domestication comes from China in the 11<sup>th</sup> century B.C. when soybean was mentioned in bronze inscriptions and *The Book of Odes* (Ho, *The Loess and the origin of Chinese agriculture*, 1969). Any inference that soybean is one of the world's oldest domesticated crop is incorrect (Hymowitz and Shurtleff, 2005).

Samuel Bowen first brought Chinese Vetches (soybean) to the United States in 1765 (Hymowitz and Harlan, 1983). Soybean was initially raised in the United States for human consumption as cooked vegetables, soy sauce, and vermicelli (soybean noodles) and for cattle consumption as a forage crop with multiple harvests similar to alfalfa, another legume (Hymowitz and Harlan, 1983; Hymowitz, 1990).

From the time Samuel Bowen first brought soybean to the United States until the last two decades of the 19<sup>th</sup> century, soybean was introduced to the country several more times. One such case was in 1851 when Dr. Benjamin Franklin Edwards brought soybean seed back to Alton, Illinois after an encounter with Japanese Fishermen. The seed was planted in the garden of an Alton horticulturist, Mr. John H. Lea (Hymowitz, 1990). Introductions of this manner allowed soybean to be multiplied, disseminated, and evaluated by farmers throughout the United States (Hymowitz, 1987).

It wasn't until the last two decades of the 19<sup>th</sup> century that soybean evaluation quickly expanded. In those twenty years soybean was grown and tested at nearly every agricultural

station in the country. The tests included pasture use as hay, silage and soiling, alone or in combination with other crops, as well as feeding experiments with horses, poultry, sheep, cattle, and milk cows (Probst and Judd, 1973; Hymowitz, 1990).

In the early 20<sup>th</sup> century the main uses of soybean were for forage, use of the grain as an oilseed came later. In 1915, oil from domestically grown soybean was first extracted by U.S. oil mills (Probst and Judd, 1973). From that point on, the demand of soybean grain quickly increased. The increase was driven by the boll weevil [*Anthonomus grandis* Boh.] hurting cottonseed [*Gossypium hirsutum* L.] oil production and a general shortage of fats and oils during World War I.

In 1941, area harvested for seed (2.4 million ha) first exceeded the acreage grown for all other purposes (2.2 million ha). From 1941 to 2010, soybean production increased 3000%, from 2.92 to 90.80 million metric tons, while area harvested only increased 1200%, from 2.3 to 31.0 million ha. During this time the average yield increased 139%, from 1224 to 2925 kg ha<sup>-1</sup> (USDA-National Agricultural Statistics Service, 2010).

The United States produced 35% of the world's soybean in 2010, with Brazil, Argentina, and China producing 27, 19, and 6% respectively (SoyStats, 2011). The United States' market share peaked in 1969 with 75% (Huyser and Smith, 1987).

As soybean demand increased, the number of uses followed suit. Research determined uses of soybean as a food and an industrial product. Some of the new and old soy foods include salad oils; cooking and frying oils; soy grits and flour; soy ice cream, cheese, and soymilk; and whole beans. In many instances soy oil is being substituted for petroleum-based oils in plastics, household and industrial cleaners, inks and paint, pharmaceuticals, and pesticides (Imhoff and Warshall, 1999).

## **Planting Date**

Planting date is possibly one of the most influential cultural practices of soybean production (Robinson *et al.*, 2009). Often though, producers plant soybean not on a certain date, but after corn [*Zea mays* L.] planting, resulting in later planted soybean. Producers justify this practice because delayed planting often reduces yield proportionally more for corn than soybean (Hoeft *et al.*; 2000). However, knowing how to maximize yield potential through various aspects of soybean production, including planting date, is important for producers' economic efficiency.

Soybean was introduced to the United States in South Carolina by Samuel Bowen as forage planted three to five times a year, depending on the killing frost, with six week growing periods (Hymowitz and Harlan, 1983). Otherwise, little soybean research was done until the last two decades of the 19<sup>th</sup> century, when soybean research increased dramatically due to interest at land grant institutions (Hymowitz, 1990). One early planting date study for soybean, as a grain and forage, was done in Knoxville, TN in 1907 and 1908, showed that planting around the first week of June returned the most favorable grain yields (Mooers, 1908).

Soybean production in the U.S. gradually transitioned from forage to grain production. In 1941, area for grain production exceeded that of forage production for the first time (Probst and Judd, 1973). This encouraged research on the grain production of soybean. During the 1940s and 1950s, planting date trials in the Midwest showed that yield decreased as soybean was planted after early to mid-May, and that later maturing cultivars were found to have an optimum planting date during the first three weeks of May (Feaster, 1949; Weiss *et al.*, 1950; Osler and Cartter, 1954; Torrie and Briggs, 1955). There are slightly conflicting results for planting dates of early-season cultivars: some studies showed that early cultivars planted in early May yielded the same as when planted in late May or early June (Weiss *et al.*, 1950; Torrie

and Briggs, 1955), while others showed that planting these in late May or early June produced more yield than planting in early May (Feaster, 1949; Osler and Cartter, 1954). Across six years of data and twelve varieties, Burlison *et al.* (1940) noticed that in general May plantings yielded 134 kg ha<sup>-1</sup> more than planting on June 1<sup>st</sup> or 10<sup>th</sup> and 403 kg ha<sup>-1</sup> than planting June 20<sup>th</sup>.

Throughout the second half of the 20<sup>th</sup> century research showed that early May plantings in the Midwest often yielded more than later plantings (Johnson, 1987; Lueschen *et al.*, 1992). The data again demonstrated that as planting was delayed beyond late May, yield loss accelerates (Oplinger and Philbrook, 1992; Johnson, 1987). Indeterminate and determinate cultivars were not affected by planting date in the same manner. The indeterminate cultivars yielded greatest when planted in early May, while the determinate cultivars had optimum planting dates during late May or early June (Beaver and Johnson, 1981; Wilcox and Frankenberger, 1987).

Recent studies have shown similar results, with late April planting dates in some cases yielding more than planting in early May (Robinson *et al.*, 2009), but not in other cases (Egli and Cornelius, 2009; De Bruin and Pedersen, 2008b). Still, planting in late April or early May typically produces higher yields than planting in late May. Looking at yield trends of soybean across planting dates show progressively greater yield decline will occur in soybean production with a delay in planting (De Bruin and Pedersen, 2008b; Egli and Cornelius, 2009). According to Egli and Cornelius (2009) the point of rapid decline in soybean yield begins May 30<sup>th</sup> in the Midwest.

Early plantings often yields more than later plantings and investigations into yield components have been conducted to determine how early planted soybean increase yield. Early planting has been observed to have more nodes (Wilcox and Frankenberger, 1987; Beaver and Johnson, 1981) as well as more pods and seeds for a given area (Pedersen and Lauer, 2004) which can in result in high yield (Robinson *et al.*, 2009). Soybean plants sometimes partially

compensate for delayed planting with increases in seed mass (Robinson *et al.*, 2009), but this doesn't always occur (Pedersen and Lauer, 2004; De Bruin and Pedersen, 2008b).

Across years, soybean yields have shown to improve with early May planting. The yield gain from planting date is dependent upon the cultivar chosen as well as the environmental effects of location and weather (Lueschen *et al.*, 1992; De Bruin and Pedersen, 2008b). There is greater yield gain when longer season varieties are used with early planting practices. Weather can have a significant impact upon yield regardless of planting date, but early planted soybean can be especially sensitive to the impact of weather on seedbed conditions. This impact is likely more important in April than May because cold spells and rain are more likely to create adverse operating conditions for machinery as well as inhibit the growth and emergence of soybean. Besides planting too early, it is also important for farmers to note that planting after mid-May in the Midwest can cause progressively lower yields (rapid decline) (De Bruin and Pedersen, 2008b; Egli and Cornelius, 2009).

### **Row Spacing**

Research on soybean row spacing has been conducted in numerous trials, and has led to the common understanding that narrow rows ( $\leq 50$  cm) generally provide a yield advantage over wide rows ( $> 50$  cm) under a wide range of production conditions. Some interest in wide rows has been due to more convenient production practices. Wide rows allow for post herbicide applications with less crop damage. Also, wide row planters also improve depth control compared to drills and are lighter than split row planter. In terms of yields, narrow rows yielded gains of 248 (De Bruin and Pedersen, 2008a) and 362 kg ha<sup>-1</sup> (Taylor *et al.*, 1982) over wide rows, while others had increases of 580 (Costa *et al.*, 1979), 100 kg ha<sup>-1</sup> (Heatherly, 1988), and 120 kg ha<sup>-1</sup> (Parker *et al.*, 1981). However, there are also trials that have shown no yield response to narrow rows (Hicks *et al.*, 1969; Pedersen and Lauer, 2003). Previously conducted

studies show how unique situations and environmental conditions can influence the yield responses of narrow rows in different ways. The varying impacts on narrow row response make it difficult to predict yield gain in a given year.

The most common row spacing dealt with in the literature includes 19, 25, 38, 50, 76, and 100 cm. Today, 52% and 32% of Illinois soybean are planted in the row spacing ranges of 25.7 to 47 and 72.6 to 87.6 cm respectively (USDA-Economic Research Service, 2012); given the equipment in use today, most of the soybeans in these two categories are in 38 (split-row based on 76-cm rows with the same planter) or 76 cm, respectively.

Growing seasons with lower than normal precipitation also tend to limit the response to narrow rows Taylor (1980). Similar results have been found in the drier states of North Dakota and Nebraska, but in cases of severe water stress, soybeans grown in narrow rows can actually yield less than wide rows (Alessi and Power, 1982; Elmore, 1998). This probably comes from rapid canopy development and increased water use in narrow rows early in the season, leaving less water available for critical pod-filling stages (Alessi and Power, 1982; Taylor, 1980).

Row spacing effects on soybean planted at a post-optimal date can be an important production consideration. Optimal planting dates in the Midwest typically fall around early May (Robinson *et al.*, 2009; Egli and Cornelius, 2009; De Bruin and Pedersen, 2008b), while in the Southern U.S. optimal planting date ranges from late May to early June (Cartter and Hartwig, 1963). Much of the research published on this matter has been conducted in the Southern United States. Though narrow rows cannot totally compensate for late planting, utilizing narrow rows can decrease the yield loss from late planting by as much as 16% (Boquet, 1990; Boquet *et al.*, 1982; Weaver *et al.*, 1991). Other studies have shown similar trends with narrow rows benefiting yield 244 (Beatty *et al.*, 1982) and 120 (Parker *et al.*, 1981), over wide rows regardless of planting dates. Another trial had wide rows out yielding narrow rows in no-tillage plots and

no yield difference in the conventional tillage plots for late (mid-June) planted soybean (Oplinger and Philbrook, 1992).

Yields of early maturing soybean cultivars have responded similarly to soybean planted at a post-optimal date. Early maturing cultivars have resulted with a yield increase over wide rows (Costa *et al.*, 1980). Both experience a shorter growing season and both can yield greater with narrow rows.

It is not completely clear why narrow rows result in higher soybean yields. According to Board and Harville (1992), increased light interception was considered responsible for a narrow row yield advantage. In addition, it has been concluded that if soybean achieve 95% light interception by pod-fill, the increased light interception prior to pod-fill by narrow rows will not directly impact yield (Board *et al.*, 1990). Taylor *et al.* (1982) argued that narrow row spacing slowed the onset of rapid pod-fill by two days and “the increased light interception ability of narrow-row soybean at the end of pod filling period, when the effective leaf area was small, was the key to the yield advantage.” This trial also showed that wide rows initially had more pods but only retained 61% compared to the narrow rows which retained 90% of its pods.

Exceedingly common is research theorizing the positive effects of equidistant [uniform] planting on yield. Some general studies have simply concluded that there is an advantage to uniform spacing (Wiggans, 1939), while others attribute the advantage to less plant competition (Ethredge *et al.*, 1989). More specific research has looked at how equidistant spacing promotes efficient use of photosynthate by soybean (Shibles and Weber, 1966) and enhances early growth resulting in larger (Duncan, 1986) and more fertile plants (Bullock *et al.*, 1998) to increase yield. Beyond equidistant planting, studies have differed in determining the specific source of increased grain yield from narrow rows. First off, Shibles and Webber (1966) showed that seed yield does not directly relate to dry matter produced, dry matter produced during seed

formation, or light intercepted. Though they did find that dry matter production directly relates to light intercepted. Shibles and Weber (1966) also concluded, by differences in the harvest index, that equidistant planting increased seed yield by partitioning photosynthate more efficiently to grain production and away from vegetative production. In another study looking at uniform planting, Duncan (1986) postulated that the increased yield is directly related to the larger plant weight, all other conditions remaining the same. Bullock *et al.* (1998) further presented that this larger plant size, due to enhanced early growth, created additional “fertile” nodes with more filled pods thus increasing yield.

Literature provides many different examples of research done on narrow and wide rows. Trends show that by planting narrow rows, producers are given the opportunity to increase soybean yield. Though the narrow rows do not increase yield every year (Hicks *et al.*, 1969; Pedersen and Lauer, 2003), they tend to increase yield in the majority of studies (Costa *et al.*, 1979; De Bruin and Pedersen, 2008a; Heatherly, 1988; Parker *et al.*, 1981; Taylor *et al.*, 1982).

### **Plant Density**

Seeding costs in soybean have increased very quickly in the last ten years. From 2010 to 2010 seed prices have risen by about 162% (USDA-Economic Research Service, 2012). The advent of genetically modified cultivars in the mid-1990s spurred the initial increases and since then seed costs have continued to rise quickly (Mascarenhas and Busch, 2006). With more expensive seed however, the price of increasing seeding rates for insurance of a good stand has also come at a greater cost to producers. A cost effective seeding rate has always been important for producers. There is no overhead cost in terms of equipment as there is with row width and there is no competition with corn as with planting date, so modifying seeding rate to extremely easy.

Some trials looking at final harvest populations found optimum density at around 388 000 in Wisconsin (Oplinger and Philbrook, 1992) and 259 000 seeds ha<sup>-1</sup> in Iowa (De Bruin and Pedersen, 2008a). In another study, (De Bruin and Pedersen (2008b) found that optimum seeding rate varied from 194 000 to 291 000 seeds ha<sup>-1</sup> in narrow rows but from 157 000 to 212 000 seeds ha<sup>-1</sup> in wide rows. In some trials, plant densities were thinned after planting a high seeding rate. A few of those trials in the Midwest have shown that optimum plant densities are about 258 000 in Iowa (Weber *et al.*, 1966), 250 000 in Minnesota (Lueschen and Hicks, 1977), and between 172 000 and 258 000 seeds ha<sup>-1</sup> in Indiana (Probst, 1945). Trials in other regions have offered slightly different results. In the Northeast, optimum plant density for one cultivar (Cayuga) was found to be 656 000 plants ha<sup>-1</sup> (Wiggans, 1939), and another cultivar (Evans) yielded the greatest with a harvest density of 680 000 plants ha<sup>-1</sup> (Herbert and Litchfield, 1984). In southern and mid-South regions, plant density suggestions have ranged from 61 000 to 287 000 seeds ha<sup>-1</sup> depending on cultivar, location, and year (Egli, 1988; Johnson and Harris, 1967). Within the Short-Season Production System, Ball *et al.* (2000) tested multiple varieties, plant densities, and row spacings. The data showed that in specific conditions densities beyond 540 000 plants ha<sup>-1</sup> would statistically increase yield, but Ball *et al.* (2000) concluded that further field testing was needed to determine optimum density. An Illinois trial produced an optimum seeding rate of 375 000 seeds ha<sup>-1</sup> (Cooper, 1977).

One of the reasons that optimum seeding rates have been found to cover such a wide range of densities is that the yield response to seeding rate is so flat; with minimal yield increases over a wide range of seeding rates, optima based on regression tend to have very wide confidence intervals. In some instances, seeding rates ranging some 7-fold, from 107 600 to 815 000 seeds ha<sup>-1</sup>, have shown little yield response (Doss and Thurlow, 1974; Elmore, 1991). Other studies have shown no significant yield response to more modest seeding rate ranges,

from 260 200 to 520 400 seeds ha<sup>-1</sup> (Ethredge *et al.*, 1989; Hicks *et al.*, 1969; Pedersen and Lauer, 2002).

The observation that soybean shows little or no yield response over a wide range of seeding rates reflects the ability of soybean plants to produce proportionally fewer or more seeds per plant when grown at lower or higher plant densities, respectively. Lueschen and Hicks (1977) found similar pod counts per unit ground area over a range of plant densities. The ability to compensate for reduced density is greatest when established early can be seen in a study by Oplinger and Philbrook (1992), when early planting had lower stands and higher yields than late plantings.

Higher yield from increased seeding rate has often been attributed to more seeds m<sup>-2</sup> (Herbert and Litchfield, 1984; Wright *et al.*, 1984). Increased seeding rate and yield have been correlated and literature has indicated the importance of insolation (solar radiation) interception and increased plant efficiency. Determinate soybean yield was maximized when 95% insolation interception was met prior to the beginning of seed fill (Egli, 1988). On the other hand, yields of indeterminate soybean were maximized at plant densities greater than required to achieve 95% insolation interception by the beginning of seed fill (Egli, 1988). Duncan (1986) postulated that yield gains after full light interception were a result of increased light efficiency and it was likely the plants more efficiently partitioned photosynthate to seed production. It is important to note that another trial found that the highest LAI was actually found at densities four times that of the highest yield (Weber *et al.*, 1966). From the data, they reasoned that photosynthate was inefficiently partitioned from the grain to the leaf vegetation. There is likely a seeding rate at which soybean increases yield beyond 95% insolation interception but does not to greatly over produce leaf vegetation.

Soybean plants lodge and as seeding rate increasing soybean lodging becomes more likely (Cooper, 1971b; Fontes and Ohlrogge, 1972). Lodging can decrease yield (Cooper, 1971a), with reported losses as high as 13% (Weber and Fehr, 1966). The yield decrease has been credited to disruption of the canopy architecture, shading of the more photosynthetically active leaves (Cooper, 1971a).

Additional factors may affect optimum seeding rate, including soybean genotype and region (Ball *et al.*, 2001; Weber *et al.*, 1966; Wiggans, 1939) and possible seeding rate interactions with row spacing (Boquet, 1990). Oplinger and Philbrook (1992) looked at differences in tillage in relation to density. They found that conventional tillage yielded 302.6 kg ha<sup>-1</sup> higher than reduced tillage (RT) and no tillage (NT). For the RT and NT to yield similarly, their seeding rates would have to be raised between 16 and 32% to counteract the effects of poor emergence and reduced early growth. In a trial by Elmore (1991), planting rate did not interact with tillage system, in this case triple disk versus no tillage (Elmore, 1991). The rotation sequence of soybean with corn was not found to significantly affect yields response of seeding rate either (Pedersen and Lauer, 2002).

In an Arkansas trial with early and late planting, data showed late planting could be partially compensated for by high plant densities (Ball *et al.*, 2001). Early planting produced adequate pods at low populations by a larger number of fertile nodes pre plant, whereas with late sowing less fertile nodes required more plants for the same pods (Ball *et al.*, 2001). Boquet (1990) similarly found that as planting date was postponed the yield benefited from increasing seeding rate. In contrast, De Bruin and Pedersen (2008b) found no planting date by seeding rate interaction, Their latest planting date was early June in Iowa, while Boquet planted into early July in Louisiana and Ball *et al.* (2001) planted around early July in Arkansas. Ball *et al.* (2001)

explained that when soybean is planted early the plant has more vegetative growth and thus more fertile nodes and pods to compensate for fewer plants.

Trials investigating interactions of seeding rate and row spacing have had contradicting results. One study found a significant interaction, with narrow rows requiring more seeds (Boquet, 1990). In contrast, Herbert and Litchfield (1984) showed that increasing seeding rate from 250 000 to 800 000 seed ha<sup>-1</sup> increased the yield 27% and using narrow rows (25 cm) yielded 16% greater than wide rows (75cm). Similarly, Cooper (1977) showed an advantage for narrow rows but no interaction with seeding rate, which reached an optimum at 375 000 seeds ha<sup>-1</sup>.

From the literature it is apparent that soybean plants compensate well over a wide range of densities and seeding rates. Though this may be true, there are population densities generally recommended for optimum or maximum yield. The highest yields are not always the most economical. By increasing the seeding rate to the point where the last increment of seed is just paid for by the last increment of yield, seeding rate can be economically optimized. This can be determined by knowing the mathematical relationship between higher densities and greater yield along with the ratio of soybean seed cost to price received for harvested grain. This mathematical process is similar to the one demonstrated by the National Academy of Sciences, which used it for fertilizer (Heady *et. al.*, 1961). This method was also used with nitrogen to price ratios for applying nitrogen in corn (Fernández *et al.*, 2009).

Much of the literature discussed showed that above an optimum seeding rate, yield response is relatively flat. Though considerations are often made for both planting additional seed for insurance against a low or reduced stand in less than ideal growing conditions (Lueschen and Hicks, 1977) and weather conditions that may provide higher than normal yield

responses to plant density. Regardless of considerations made, optimizing seed rate is a straight forward way to improve production and economic efficiency.

During the last USDA Economics Research Service (2012) survey in 2006, the average seeding rates were 70.6 and 68.8 kg ha<sup>-1</sup> in Illinois and the U.S. respectively. At a typical seed count of 6,174 seeds kg<sup>-1</sup> (2,800 lb<sup>-1</sup>) this would be about 435 900 and 424 800 seeds ha<sup>-1</sup>, respectively. Seeding rate has shown wide-ranging results, with highest yields requiring seeding rates ranging from 157 000 seeds ha<sup>-1</sup> (De Bruin and Pedersen, 2008b) to 388 000 seed ha<sup>-1</sup> (Oplinger and Philbrook, 1992) depending on environment, management system, and cultivar. Current recommendations in Illinois are to use enough seed to establish 247 000 plants ha<sup>-1</sup> (Nafziger, 2009).

## **Materials and Methods**

### **Environments and production practices**

Field experiments were conducted for two years, 2010-2011, at six University of Illinois Research and Education Centers. Locations included the Dixon Springs Agricultural Center (Dixon Springs), the Brownstown Agronomy Research Center (Brownstown), Orr Agricultural Research and Demonstration Center (Perry), Crop Sciences Research and Education Center near Urbana, Northwestern Illinois Agricultural Research and Demonstration center (Monmouth), and Northern Illinois Agronomy Research Center (DeKalb). Soil characteristics, soil test results, latitude and longitude, and productivity index are given in Table 1. Monthly precipitation, May through September, for all twelve environments was obtained as were the 30 year precipitation averages for each location (Table 2).

The previous crop in all cases was corn [*Zea mays* L.]. Fall tillage was utilized on corn residue with the exception of the two southern locations, Brownstown and Dixon Springs. All locations included spring tillage except at Dixon Springs Agricultural Center. There the soybean fields were no-tilled on soil that was moderately susceptible to water erosion with slopes greater than 2% (USDA-NRCS, 2012). The soybean varieties were chosen by location to be a locally adapted, mid-range maturity, and glyphosate-tolerant seed with fungicide and insecticide treatments (Table 1). Trial maintenance consisted of both pre-emergence and post-emergence herbicides and was designed to keep plots weed free. Hand weeding was supplemented where needed. After reaching physiological maturity, harvest densities were counted and plots were harvested for yield with a plot combine. Yields were adjusted to standard moisture (13.0%).

Table 1. Field location, variety, soil description, productivity index (PI) and soil nutrient concentrations for twelve Illinois trial sites.

Location	Year	Variety	Latitude, Longitude	Soil Series	Taxonomic classification	PI <sup>†</sup>	pH	P	K	OM
<u>DeKalb</u>	2010	AG2830	41.84173,-88.85027	Flanagan SIL	Fine, smectitic, mesic Aquic Argiudolls	144	6.4	68	255	4.1
	2011	AG2830	41.84026,-88.86057	Elpaso SICL	Fine-silty, mixed, superactive, mesic Typic Endoaquolls	144	6.3	70	292	4.2
<u>Monmouth</u>	2010	P93Y40	40.93648,-90.72158	Muscataune SIL	Fine-silty, mixed, superactive, mesic Aquic Argiudolls	147	6.4	158	502	4.4
	2011	P92Y80	40.93564,-90.72417	Muscataune SIL	Fine-silty, mixed, superactive, mesic Aquic Argiudolls	147	6.6	49	282	4.2
<u>Urbana</u>	2010	P93M61	40.07964,-88.22537	Drummer SICL	Fine-silty, mixed, superactive, mesic Typic Endoaquolls	144	5.8	127	257	4.5
	2011	P93M61	40.07750,-88.22450	Drummer SICL	Fine-silty, mixed, superactive, mesic Typic Endoaquolls	144	5.7	95	213	3.8
<u>Perry</u>	2010	P93Y70	39.79183,-90.82460	Downsouth SIL	Fine-silty, mixed, superactive, mesic Oxyaquic Hapludalfs	135	6	58	378	3
	2011	P93Y70	39.80369,-90.82166	Clarksdale SIL	Fine, smectitic, mesic Udollic Endoaqualfs	132	6.5	53	445	3
<u>Brownstown</u>	2010	AG3830	38.94977,-88.95695	Bluford SIL	Fine, smectitic, mesic Aeric Epiqualfs	101	6.4	103	292	1.6
	2011	AG3830	38.95050,-88.95895	Cisne SIL	Fine, smectitic, mesic Mollic Albaqualfs	109	5.9	54	168	1.8
<u>Dixon Springs</u>	2010	AG3830	37.45572,-88.72269	Grantsburg SIL	Fine-silty, mixed, active, mesic Oxyaquic Fragiudalfs	101	6	79	504	1.5
	2011	AG3830	37.45560,-88.72157	Grantsburg SIL	Fine-silty, mixed, active, mesic Oxyaquic Fragiudalfs	101	5.9	35	188	2

†Optimum Crop Productivity (Index) Ratings for Illinois (Olson, 2000).

Table 2. Monthly rainfall by environment.

	<u>Urbana</u>			<u>Perry</u>			<u>Monmouth</u>			<u>Dixon Springs</u>			<u>DeKalb</u>			<u>Brownstown</u>		
	2010†	2011	Avg‡	2010	2011	Avg	2010	2011	Avg	2010	2011	Avg	2010	2011	Avg	2010	2011	Avg
	-----mm-----																	
May	78	122	124	125	111	107	279	172	121	121	190	141	123	220	103	139	51	138
June	198	107	110	271	279	109	285	176	114	100	196	103	175	107	114	229	302	105
July	90	40	119	291	3	110	81	53	104	54	116	98	99	101	105	138	97	101
August	40	45	100	95	8	98	46	11	120	68	102	84	119	108	114	40	12	76
September	76	71	80	122	27	92	137	72	95	63	168	90	50	97	85	74	86	81
Total	483	385	533	905	428	516	828	484	555	406	772	516	567	632	520	621	547	502

†Monthly data (Illinois State Water Survey, <http://www.isws.illinois.edu/>)

‡30 year average (1981-2010) (Illinois State Water Survey, <http://www.isws.illinois.edu/>)

### **Experimental design**

The experimental design was a randomized complete block design (RCBD) with the three factors of planting date (4 levels), row spacing (2 levels), and seeding rate (3 levels) arranged into 24 factorial combinations. There were four replications.

The four planting dates were set as weeklong target windows of 15 to 22 April, 3 to 10 May, 20 to 27 May, and 7 to 14 June. Actually planting dates are recorded in Table 3. Planned seeding rates for the four northern locations (Monmouth, Perry, DeKalb, and Urbana) were 173 000, 297 000, and 420 000 seeds ha<sup>-1</sup>; while the two southern locations (Brownstown and Dixon Springs), due to planter setting restrictions, were planned at 198 000, 321 000, and 445 000 seeds ha<sup>-1</sup>. Harvest density was utilized instead of seeding rate to account for different populations, due to planting errors. The two row spacings compared were 38 and 76 cm. The plots were 3.05 meters wide which consisted of four rows for the 76 cm row spacing and seven rows for 38 cm row spacing. The plots were a minimum of 9.1 meters long.

### **Statistical Analysis**

The data was analyzed with Statistical Analysis Software 9.2 (SAS) (SAS Institute Inc., 2008) using the MIXED procedure. Within MIXED procedure the restricted maximum likelihood (REML) method was utilized to strengthen the model for locations with unequal replication due to missing plots. The models were simplified and mean comparisons were made with an alpha of 0.05. Within the statistical model, the fixed effects were split into class variables (row spacing) and continuous predictor variable (covariate) (planting date and harvest density). Using the class variables, levels within each independent variable can be compare. Linear and quadratic components and interactions of harvest density were utilized as covariates to account for differences from incorrect seeding rates. The covariate allows treatments of planting date and row spacing to be compared equally by adjusting for potential differences in plant density.

Table 3. Planting dates by environment for two years of six Illinois locations.

Location	Year	Planting Date (Days after April 1st)			
		1 <sup>st</sup>	2nd	3rd	4th
<u>Brownstown</u>	2010	7-Jun (67)	2-Jul (92)	16-Jul (106)	- (-)†
	2011	18-May (47)	31-May (60)	6-Jul (96)	- (-)
<u>DeKalb</u>	2010	20-Apr (19)	10-May (39)	29-May (58)	10-Jun (70)
	2011	5-May (34)	20-May (49)	3-Jun (63)	17-Jun (77)
<u>Dixon Springs</u>	2010	7-May (36)	24-May (53)	7-Jun (67)	21-Jun (81)
	2011	11-May (40)	20-May (49)	1-Jun (61)	17-Jun (77)
<u>Monmouth</u>	2010	15-Apr (14)	6-May (35)	21-May (50)	12-Jun (72)
	2011	13-Apr (12)	4-May (33)	18-May (47)	8-Jun (68)
<u>Perry</u>	2010	15-Apr (14)	4-May (33)	26-May (55)	11-Jun (71)
	2011	14-Apr (13)	7-May (36)	31-May (60)	22-Jun (82)
<u>Urbana</u>	2010	21-Apr (20)	6-May (35)	25-May (54)	7-Jun (67)
	2011	14-Apr (13)	5-May (34)	21-May (50)	8-Jun (68)

†Planting not made.

On the other hand, both linear and quadratic components of planting date (measured as days after April 1<sup>st</sup>) were used as continuous predictor variables to estimate a regression line adjusted for differences in actual planting date.

Considerations were made to analyze the data as a single set for all twelve site years, but there were considerable differences between the northern and southern sites. The yield differences were great as well as some of the independent variables. The differences in planting dates were great for the southern locations compared to each other and the northern locations. In addition, the southern locations were planted at higher seeding rates than the northern locations. Testing revealed that the southern sites had extremely high leverage (Cook's D values), indicating that in a combined model the southern locations affected the model much more than the northern locations. For consistency, data from the eight northern environments were analyzed as a set and the four southern environments were separated into location and year location. Since harvest density only influenced yield in a linear matter and did not interact with any other factors in the model, yields were adjusted to the harvest density of 250 000 plants ha<sup>-1</sup>.

Following determination of the models, normality and homogeneity of variance were investigated through examination of the QQ plot and residuals. The data appear to have relatively homogeneous variances; however, the northern sites and Brownstown showed some non-normality mainly due to high kurtosis. Mean separations for class variables were conducted by comparing treatments through LSMEANS, ESTIMATE, and CONTRAST statements in MIXED procedure within SAS. Estimates were also calculated. To evaluate the continuous predictor variable, the SOLUTION option within MIXED procedure was used to provide coefficient values for the regression parameters to estimate curves and their relationship with yields.

## Results and Discussion

### Environments

Yields varied by environment (Figure 1), with variation between locations greater than between years. Yields were calculated across planting date, rows spacing, at a harvest density of 250 000 plants ha<sup>-1</sup>. Much of the yearly yield variation was generated at Perry, where large differences in rainfall patterns (Table 2) resulted in the 2011 yield being 1,790 kg ha<sup>-1</sup> less than the 2010 yield.

Typically sites with more productive soils yielded better (Table 1). The yield response from year to year was interesting at Perry. In 2010, with favorable conditions, the trial at Perry yielded near locations with more productive soils and in 2011 with unfavorable weather conditions, the trial at Perry yielded near those with less productive soils. Across all other factors, the highest yielding site in this study was Monmouth in 2011 which yielded 5,010 kg ha<sup>-1</sup> and the lowest yielding site was Dixon Springs in 2011 at 2,125 kg ha<sup>-1</sup> (Figure 1).

### Northern Locations

At the northern location, yield was influenced by row spacing and planting date, as well as harvest density and interactions between row spacing and planting date and row spacing and environment. Planting date had a large effect on yield and the relationship with the continuous predictor variables proved to be curvilinear ( $y = -.200x^2 - 3.7x + 4821$ ) (Figure 2). Yields were predicted for the middle of each planting window, across row spacing and environment. For planting on April 19<sup>th</sup>, May 7<sup>th</sup>, May 24<sup>th</sup>, and June 11<sup>th</sup> predicted soybean yields were 4,683, 4,422, 4,057, and 3,545 kg ha<sup>-1</sup>, respectively. The slopes of the curve at the same respective planting dates were -10.9, -18.1, -24.9, and -32.1 kg ha<sup>-1</sup> day<sup>-1</sup>. From April 19<sup>th</sup> to June 11<sup>th</sup>, the daily yield loss from planting delay almost tripled. In this study the late April planting yielded

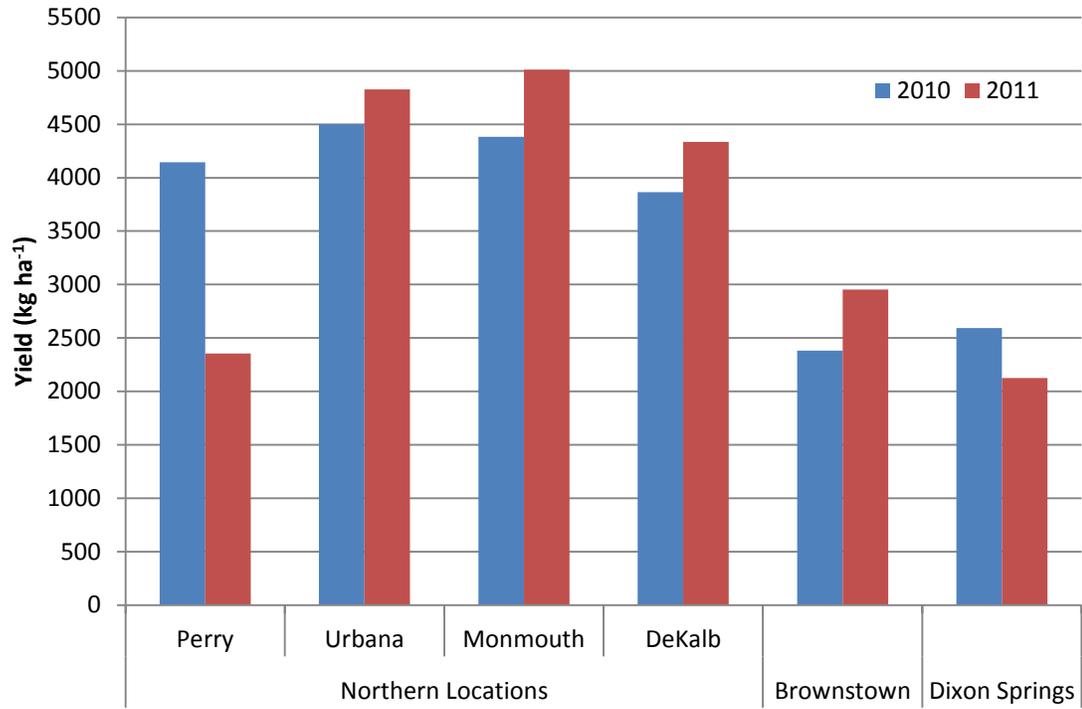


Figure 1. Yields of twelve environments calculated across row spacing and planting date.

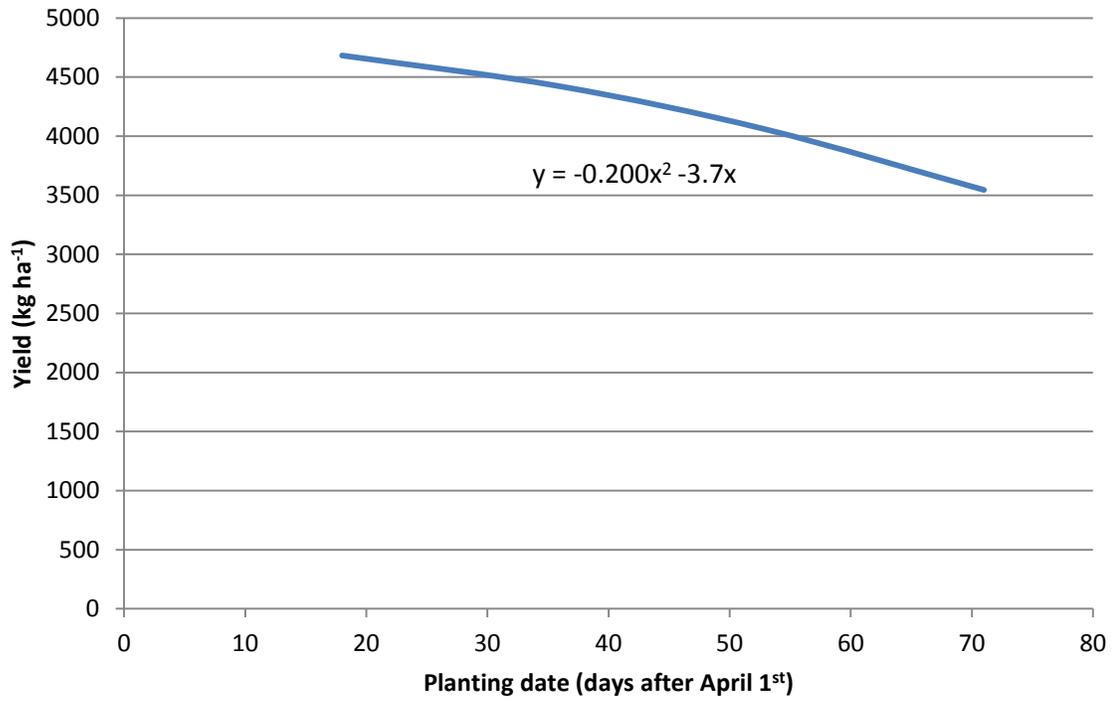


Figure 2. Yield response to planting date for the northern locations the across row spacing.

the highest, agreeing with studies by De Bruin and Pedersen (2008b) and Robinson *et al.* (2009). With delayed planting, our yields were progressively lower. This was similar to De Bruin and Pedersen's (2008b) and Robinson *et al.*'s (2009) studies, which showed that with delayed planting, especially to late May and early June, yield decreases became larger.

Across planting date and environments, the northern locations showed yield increase of  $122 \text{ kg ha}^{-1}$  (2.9%) for narrow rows over wide rows. Our results were in agreement with studies by De Bruin and Pedersen (2008a), Taylor *et al.* (1982), and Costa *et al.* (1979), which showed narrow rows increased yield by 248, 362, and  $580 \text{ kg ha}^{-1}$  over wide rows respectively. The benefit of narrow rows was smaller in our study, similar to two studies with 100 (Heatherly, 1988) and  $120 \text{ kg ha}^{-1}$  (Parker *et al.*, 1981) yield advantages. Bullock *et al.* (1998) found an advantage of  $247 \text{ kg ha}^{-1}$  for narrow rows and concluded that narrow row yield increase benefits from increased growth prior to main grain-fill. The narrow rows advantage in our study was also contrary to the finding of studies by Hicks *et al.* (1969) and Pedersen and Lauer (2003), which had no yield advantage from narrow rows.

Harvest density was primarily used as a covariate to adjust for different densities when comparing planting date and row spacing. However, harvest density offers some insight into its relationship with yield as well. The quadratic component and interactions with harvest density were not significant, yield only responded to the linear component of harvest density linearly. For these eight sites, the slope (Figure 4) shows that  $.615 \text{ kg ha}^{-1}$  is received for every additional 1000 seeds planted.

Both significant interactions found at the northern sites involved row spacing, once with planting date and once with environments. Initially (April 19<sup>th</sup>) narrow rows yielded  $205 \text{ kg ha}^{-1}$  (4.5%) greater than wide rows and yields of both decreased with a curvilinear response to

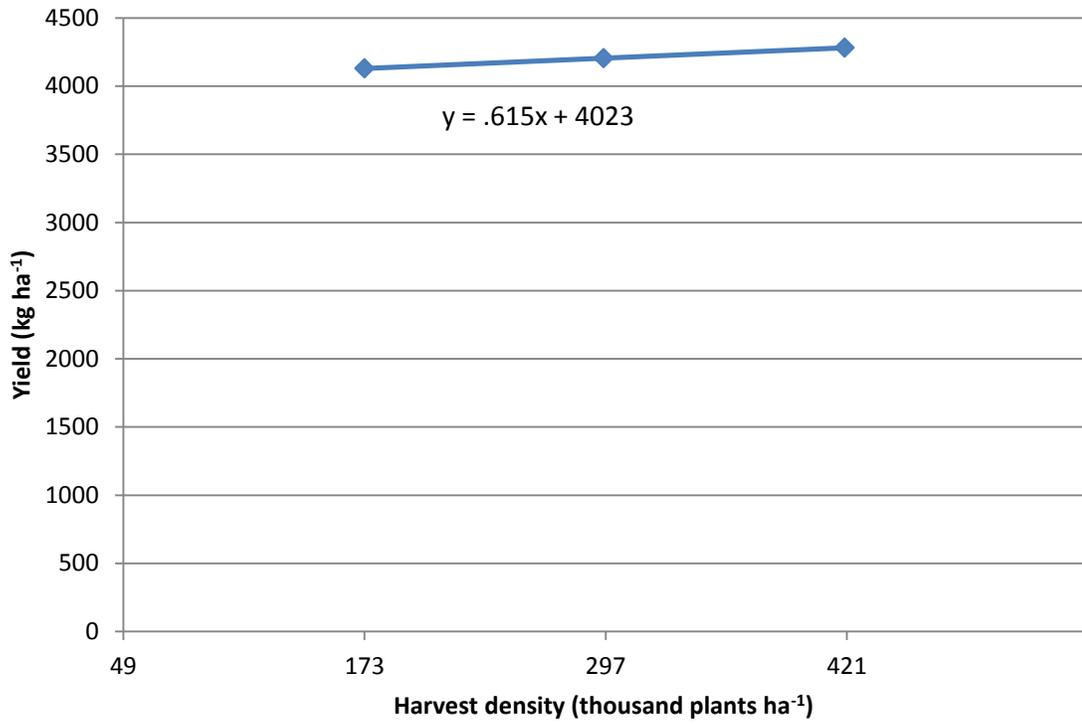


Figure 3. Yield response to harvest density for the northern locations across planting date and row spacing.

planting delay (Figure 4). Unexpectedly, narrow row yields decreased quicker with planting delay and so yields of narrow and wide rows appear to be converging. With planting on May 7<sup>th</sup>, May 24<sup>th</sup>, and June 11<sup>th</sup>, the predicted benefit of narrow rows over wide rows decreased to 148 (3.4), 95 (2.4), and 39 (1.1%) kg ha<sup>-1</sup>, respectively. Averaged across the northern environments, narrow rows yielded significantly more than wide rows only prior to May 21<sup>st</sup>, but the same afterwards. The trend is contrary to southern USA studies that found narrow rows increase yield consistently across planting dates (Beatty *et al.*, 1982; Parker *et al.*, 1981), which can lead to proportionally larger yields increases (Boquet, 1990; Boquet *et al.*, 1982).

Across planting dates, three of the eight sites responded with a significant yield increase to narrow rows. At Urbana in 2010 and 2011 and Monmouth in 2011, narrow rows out yielded wide rows by 186 (4.2), 144 (3.0), and 276 (5.7%) kg ha<sup>-1</sup> respectively. The other five sites averaged a non-significant advantage of 74 (2.1%) kg ha<sup>-1</sup> for narrow rows. The row spacing and environment interaction was also affected by the row spacing and planting date interaction. At the first predicted planting date (April 19<sup>th</sup>), narrow rows increased yield over wide rows at six locations, all except Monmouth and Perry in 2010. At the last predicted planting date (June 11<sup>th</sup>), only Monmouth in 2011 continued to exhibit a significant advantage from narrow rows.

### **Brownstown**

At Brownstown in 2010, yield was affected by planting date and row spacing. In 2011, yield was only influenced by planting date. Both years returned a curvilinear response to planting date with yield becoming progressively lower as planting was delayed (Figure 5). Planting date response in 2010 showed a very quick decline with delays. Planting timings were on June 7<sup>th</sup>, July 2<sup>nd</sup>, and July 16<sup>th</sup> with yield declining 8.5, 69.9, and 104 kg ha<sup>-1</sup> day<sup>-1</sup>. In 2011, planting timings were earlier and the progressive yield loss was much less. Soybean planted on May 19<sup>th</sup>, May 31<sup>st</sup>, and July 6<sup>th</sup> only showed yield loss of 5.3, 6.8, and 10.9 kg ha<sup>-1</sup> day<sup>-1</sup>,

respectively. The yield followed a progressive pattern as the northern sites, but the curve and yield levels were different.

Yield response to row spacing varied by year (Figure 6). In 2010, narrow rows out yielded wide rows by 371 kg ha<sup>-1</sup> (16.9%) across all other factors and in 2011, narrow and wide rows were not significantly different. Harvest density did not influence yield in either year at Brownstown and there were no interactions.

### **Dixon Springs**

Planting date response was significant in both years at Dixon Springs, but the responses differed from other sites as well as year to year (Figure 5). In 2010, yield decreased linearly in response to delayed planting. For each day of delay, yield decreased by 16.6 kg ha<sup>-1</sup>. Across row spacing, the soybean planting on May 7<sup>th</sup> yielded 2980 kg ha<sup>-1</sup>, while the yield on June 21<sup>st</sup> was 2,233 kg ha<sup>-1</sup>. In 2011, yield initially started at a higher level and decreased quickly with delayed planting. As the delay continued yield decreased more slowly until yield began increasing (Figure 5). Across row spacing, yields estimated at May 11<sup>th</sup>, May 20<sup>th</sup>, June 1<sup>st</sup>, and June 17<sup>th</sup> were 2,276, 2,013, 1,926, and 2,282 kg ha<sup>-1</sup>, respectively. Changes in yield per day (slopes) at the respective plantings dates were -38.7, -19.8, 5.4, and 39.0 kg ha<sup>-1</sup> day<sup>-1</sup>. In this case the severity of yield decline with late planting is minimized and eventually reversed.

During 2011, the early planting dates were likely under more drought stress during reproductive development, which could impact yield. In 2011, the trials experienced a rather dry period from late July through early September, with some relief during mid-September. This precipitation pattern was similar to Brownstown, though Brownstown had even less rain and

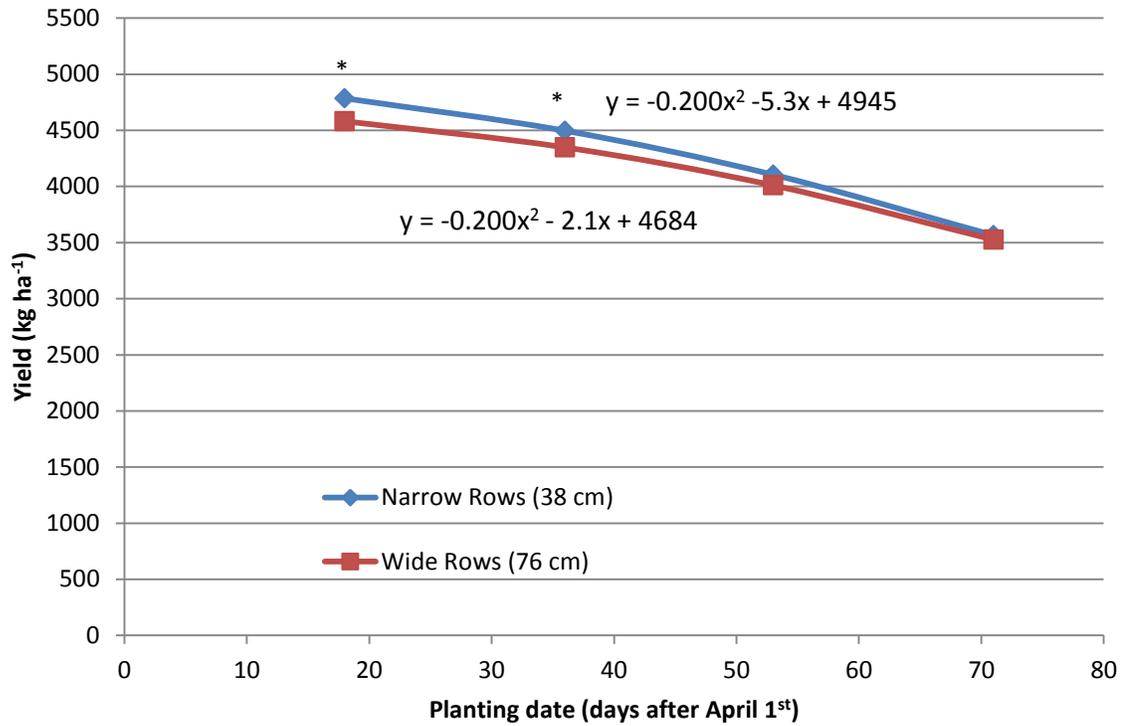


Figure 4. Yield response to planting date for narrow and wide row spacing and across the four northern locations. Significantly different row spacings are marked (\*) for an alpha of 0.05.

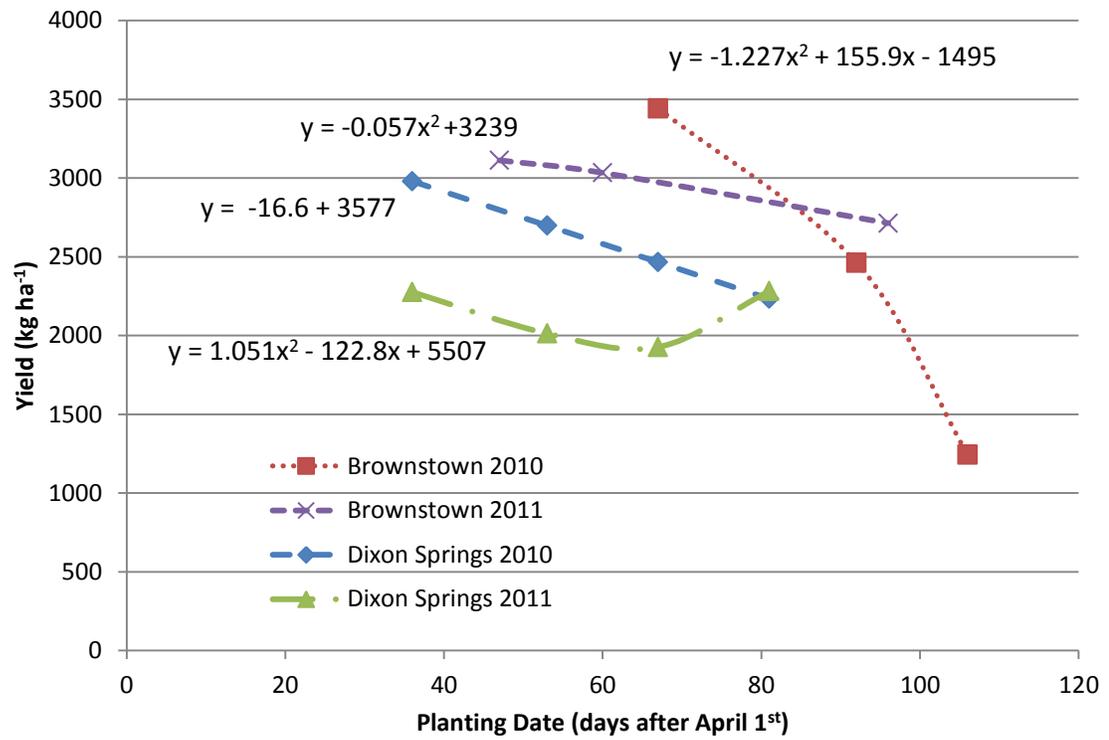


Figure 5. Yield response to planting date for Brownstown and Dixon Springs across planting date and row spacing.

was planted later. Judging by the timing, the pattern appears to favor late planting dates because the late plants would be the furthest from maturity and utilize the greatest amount of September precipitation.

Row spacing effected yield differently by year. In 2010, narrow and wide rows were not significantly different in 2010. In 2011 however, narrow rows out yielding wide rows by 129 kg ha<sup>-1</sup> (6.3%) across planting date.

Harvest density had a curvilinear effect on yield in both years at Dixon Springs, but did interact with any other effects. The curvilinear relationship indicated that yields increased with increasing harvest densities to a point and then began to decrease. The maximum yield was reached with 246 000 and 306 000 plants ha<sup>-1</sup> at harvest for 2010 and 2011, respectively.

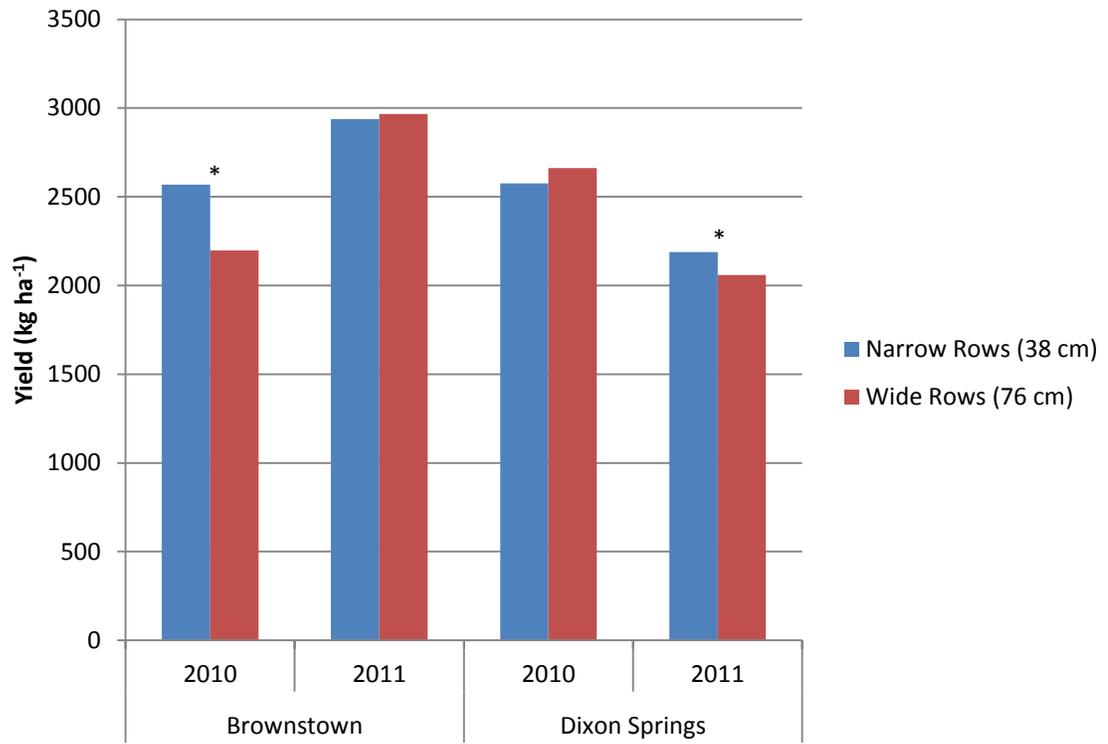


Figure 6. Yield response to row spacing at Brownstown and Dixon Springs across planting date. Significant differences (\*) are at an alpha of 0.05.

## Summary and Conclusions

The contrasting environments in this study aid in developing a full understanding of planting date response. Small yield penalties in late April from delayed planting give way to more dramatic decreases in late May and early June. As planting was delayed beyond late April, soybean yields were usually progressively lower. The early planting dates often allowed the soybean plants to reach a greater proportion of their potential. However, the data indicates that water stress at our southern locations can impact the effectiveness of planting date and change the relationship between yield and planting date.

Across all factors, narrow row spacing provided a yield advantage. Interaction of row spacing with planting date and environment individually, show how effectiveness can vary depending on environment and planting date. Yield potential did not seem to impact the effectiveness of row spacing, with both high (northern sites) and low (select southern sites) yield environments benefiting from narrow rows. We unexpectedly found that narrow rows in our northern locations were more beneficial at early planting date. The effect of planting date showed that early planting resulted in more favorable responses to narrow rows, but with delay past mid-May, yields of both narrow and wide rows were similar.

The impact of harvest density proved to be linear at the northern sites and curvilinear at the Dixon Springs. Harvest density did not influence yield at Brownstown either year. At the northern sites, yield increased .615 kg ha<sup>-1</sup> for every additional thousand seeds planted. Yields at Dixon Springs were maximized with harvest densities of 246 000 and 306 000 in 2010 and 2011 respectively.

Row spacing results were different over environment and date, but on average narrow rows provided a yield advantage. Unexpectedly at the northern sites, narrow rows proved more effective at earlier planting dates and should be explored further. Of fixed effects within this

trial, planting date clearly had the largest impact on yield. Considering that over the last 20 years only 43.4% of soybean area has been planted by May 20<sup>th</sup> on average (USDA-National Agricultural Statistics Service, 2010), earlier planting would presents an opportunity to increase yield potential.

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