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High Yield Soybean Management: Planting Practices, Nutrient Supply, and Growth Modification

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HIGH YIELD SOYBEAN MANAGEMENT:
PLANTING PRACTICES, NUTRIENT SUPPLY, AND GROWTH MODIFICATION

By

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HIGH YIELD SOYBEAN:
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Growers are constantly seeking ways to improve yield in soybean [*Glycine max* (L.) Merr.]. There has been much interest in the use of selected alternative practices to maximize soybean yield. These practices include planting soybean at higher than recommended seeding rates, planting soybean in narrow rows, breaking apical dominance to induce branching, application of strobilurin fungicides prophylactically to minimize disease and extend the seed filling period, the use of N fertilizer both in furrow and foliar applied, and the use of seed treatments to promote early stand establishment and health. Field studies were conducted at the University of Nebraska West Central Research and Extension Center in North Platte, Nebraska, and at the West Central Water Research Field Laboratory located near Brule, Nebraska and at Bancroft, Clay Center, Cortland, and Elba, Nebraska to determine how these practices affect soybean yield.

Increased seeding rate also increased soybean yield and 24.7, 43.2, and 61.8 planted seeds m^{-2} yielded 4.47, 4.79, and 4.79 Mg ha^{-1}, respectively. Soil fertility, application of strobilurin and seed treatments did not affect yield. Decreases in yield were observed by destroying the apical meristem by both clipping at V2 and application of lactofen.

These results suggest that soybean yield is optimized in west central Nebraska by planting soybean at between 24.7 and 43.2 seeds m^{-2} but not applying lactofen or pyraclostrobin. Growers should be very careful in selecting alternative practices due to the possible reduction in soybean yield.

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Literature Review

Soybean was domesticated in China, which has the first written records of soybean (Singh 2010), dating to about 3100 years ago (Hymowitz 2005). The earliest recorded introductions of soybean to the U.S. were by Samuel Bowen, a sailor, in 1765 from China (Hymowitz 2005), and by Benjamin Franklin in 1770 from France (Singh 2010). Originally introduced as a forage crop, soybean is now used for food, livestock feed, industrial processes, bio-fuel, and in pharmaceuticals (Singh 2010).

Soybean production in the U.S has increased from approximately 2,833 ha with 0.41 Mg ha^{-1} yield in 1934 to 31,324,336 ha with an average yield of 3.53 Mg ha^{-1} in 2010 (USDA NASS 2010). Nebraska ranked fourth in 2010 for soybean production with approximately 7.3 billion kg produced (USDA ERS 2011).

General Physiology

Soybean has advanced genetically for increased yield potential while maintaining 72% of the original sequence diversity present in Asian landraces in bred cultivars despite selective breeding, (Hyten et al. 2006). Specht et al. (1999) estimated the linear genetic increase in soybean yield to range from 10 to 30 kg ha^{-1} yr^{-1} due to changes in cultural practices, crop rotation, and genetics. Genetic advances include reduced yield loss to lodging (Luedders 1977), and improved N_2-fixation ability and better stress tolerance (Specht et al. 1999). Advances in agricultural technology and a rise in atmospheric CO_2 also have contributed to increased yield (Specht et al. 1999).

Improved plant nutrition, particularly nitrogen (N) uptake, has contributed to increased soybean yield. Adequate N supply throughout the growing season is important for high yield (Salvagiotti et al. 2009). Nitrogen uptake is highest during early seed fill (Gutierrez-Boem et al. 2004). Nitrogen that is supplied from fixation commonly is not sufficient to maximize yield (Ray et al. 2005). Uptake during the seed filling period may be reduced due to the decline of nitrogen fixing bacteria and insufficient soil N (Salvagiotti et al. 2009). To compensate, soybean remobilizes N from leaves causing senescence (Gutierrez-Boem et al. 2004), which is also seen in other crops (Kant et al. 2011). Ray et al. (2005) found that adding ammonium nitrate (NH_4NO_3) at emergence increased biomass, N accumulation, and seed yield in Mississippi and concluded that inadequate N supply may limit yield in soybean in both irrigated and non-irrigated environments. Haq and Mallarino (2000) state the response to fertilizer varies from site to site based on soil test levels and local weather conditions. Salvagiotti et al. (2009) maximized yield by applying 180 kg N ha^{-1} in a deep band at 20 cm below the soil surface before planting. Gutierrez-Boem et al. (2004) found that seed size was increased by 3.6% when 100 kg N ha^{-1} was applied at the R3 growth stage. A yield increase of 7.7% was observed by the addition of 290, 310 and 360 kg ha^{-1} N in 2002, 2003 and 2004, respectively, in Mississippi (Ray et al. 2005), but would not be an economical way to increase soybean yield. Adding 16 kg ha^{-1} N had a 6% yield increase over the non-treated check in South Dakota (Osborne and Riedell 2006) supporting the recommendation of starter N application for High Plains production (Ferguson et al 2006). Increases in yield have been noted from foliar fertilizing by increasing the number of harvestable seeds ha^{-1} while maintaining seed size (Garcia and Hanway 1976). Increases in seed yield were significant in three of 51 irrigated trials in Nebraska with application of N at R3 (Wortmann et al. 2012). Contradictory to what Ray et al. and Osborne and Riedell have found, but in general agreement with Wortmann et al. (2012), Barker and Sawyer (2005) observed no increase in soybean yields from applying 45 kg ha^{-1} N and 90 kg ha^{-1} at R3. There were no increases in yield observed in Virginia with using UAN applied at 0, 14, 28, 56, 84, 112, and 168 kg ha^{-1} N at either R3 and R5 (Freeborn et al. 2001).

In Eastern Nebraska, soybean maturity group 3.0 to 3.9 puts on a new node every 3.7 days or 0.27 nodes day^{-1} on its main stem (Bastidas et al. 2008), but it is not known if this rate translates to branches or to higher elevations in western Nebraska. Frederick et al. (2001) found that branch elongation was greatest between the R1 and R5 growth stages. As the number of branches increases, branch dry matter, branch nodes, branch reproductive nodes, and branch pods increased by 189% (Carpenter and Board 1997). Branch dry matter increased up to 41% with 50-cm row spacing compared to 100-cm row spacing (Board et al. 1990). Board et al. (1990) also found yield increases at an early planting date from 18-57% due to increased branch yield components and narrow row spacing. Branch seed yield is greatest under irrigated conditions (Frederick et al. 2001). Norsworthy and Shipe (2005) found that branch yield accounts for 14-57% of total seed yield in 19 cm rows, and 47-74% of total seed yield in 97 cm rows.

By planting soybean in rows narrower than 76 cm, yield may be maximized. Yield with 25-cm compared with 100-cm row spacing was 17% higher (Taylor 1980).

Cooper (1977) found a 10 to 20% yield advantage from planting soybeans in 17-cm row spacing compared with 50-cm and 75-cm row spacing at the 0.05 level. Seed yield was 10% higher in 25- and 51-cm rows than in 76-cm rows (Ethredge et al. 1989). Costa et al. (1980) concluded that seed yield in 27-cm rows vs. 76-cm rows had a 21% increase. Yield increases can be attributed to a greater leaf area index (LAI) in narrow compared to wide rows (Harder et al. 2007). Soybean grown in 23- compared with 46-cm rows had 15 and 30% more LAI and 100 and 290 kg ha^{-1} more yield in low and medium drought stress environments, respectively, in Virginia (Holshouser and Whittaker 2002). With a greater LAI, more radiation is intercepted resulting in more photosynthesis (Lambert and Lowenberg-De-Boer 2003). Increasing plant population in narrow row spacing resulted in fewer branches and increased lodging, seed weight, and LAI in 10 varieties (Costa et al. 1980). Benefits of narrow row spacing also included less weed emergence in narrow rows following glyphosate application (Harder et al. 2007).

Specific information on optimal seeding rates is needed in soybean to maximize yield. Edwards and Purcell (2005) showed that as soybean population increases, yield increases rapidly until it becomes asymptotic at 20 plants m^{-2}. Wright et al. (1984) found that seed yield approached 4.50 Mg ha^{-1} at 20 plants m^{-2}. In Iowa 19 plants m^{-2} were sufficient to attain 95% of maximum yield (De Bruin and Pedersen 2008). Extensive on-farm research was conducted from 2006 to 2008 in eastern Nebraska. In 2006, plant populations of 22, 26, 35, and 39 plants m^{-2} had yields of 4.40, 4.45, 4.50, and 4.53 Mg ha^{-1}, respectively (UNL Cropwatch 2008). Results from 2007 showed no differences in yield with plant populations of 21, 27, 34, and 40 plants m^{-2} (UNL Cropwatch 2008). In

2008 in eastern Nebraska, 21 plants m^{-2} yielded 4.58 Mg ha^{-1} and 39 plants m^{-2} yielded 4.70 Mg ha^{-1} (UNL Cropwatch 2008).

Seed treatments and inoculants have been reported to increase soybean yield as well (Johnson 1987, Schultz and Thelen 2008). Using inoculants increased yields across 14 studies by 85.6 kg ha^{-1} in Michigan with 12 of the studies having a recent history of soybean production (Schultz and Thelen 2008). When disease pressure is low, fungicide seed treatments are not needed to ensure adequate stands (300,000 to 370,000 seeds ha^{-1}) but under high disease pressure, fungicide seed treatments can aid in plant establishment (Johnson 1987). In Nebraska, inoculation did not increase yield from 2001 to 2004 in six studies (Abendroth 2006). Research conducted in Indiana, Iowa, Nebraska, Minnesota, and Wisconsin show that there is little probability for a yield response when inoculants are used in fields with a history of soybean (De Bruin et al. 2010).

Use of Strobilurins to Promote Plant Health

Applications of the strobilurin fungicide pyraclostrobin, increased yield in Indiana by 0.1 Mg ha^{-1} (Henry et al. 2011). Strobilurin fungicides have a preventative mode-of-action (Grossman et al. 1999). The mode of action of strobilurins is to inhibit mitochondrial respiration by binding at the Q_o site of cytochrome b (Bartlett et al. 2002) which disrupts the energy cycle of the targeted fungi. Strobilurin fungicides provide control against four major groups of plant pathogenic fungi: Ascomecetes, Basidiomycetes, Deuteromycetes, and Oomecetes (Bartlett et al. 2002).

Strobilurins also provide disease control over time because of slow degradation (Nason et al. 2007). This prolonged effectiveness is needed for control and prevention of outbreaks of pathogenic fungi. Applying strobilurin fungicides prior to infection is recommended for prevention by the Fungicide Resistance Action Committee (FRAC) (Bartlett et al. 2002) to limit outbreaks and minimize yield loss from fungal diseases throughout the growing season.

Strobilurin application can increase plant health and yield (Henry et al. 2011). This stems from the so-called strobilurin 'stay green effect' (Bartlett 2002). Grossman et al. (1999) suggests that this stems from the ability of strobilurins to delay leaf senescence and conserve water. This would extend the growth and seed filling period. There are mixed reports of how strobilurin fungicides affect yield in soybean. In northeast Missouri, strobilurin application at R4 increased soybean yield from 230-360 kg ha^{-1} (Nelson et al. 2010). Nelson and Meinhardt (2011) found that pyraclostrobin increased yield up to 36%. In Indiana there was no yield response to strobilurin application at R1, R3, R5, R3+R5, and R1+R3+R5 (Hanna et al. 2008). Swoboda and Pedersen (2009) found that in the absence of disease, strobilurin application did not increase yields in Iowa and concluded that environmental conditions and disease levels should guide fungicide application.

Protoporphorinogen Oxidase Inhibitors

Protoporphorinogen Oxidase (PPO) Inhibitors are classified as group 14 (E) herbicides which include lactofen, acifluorofen, oxyfluorofen, and fomesafen (Mallory-Smith and Retzinger 2003). These chemicals inhibit protoporphorinogen oxidase, an enzyme involved in the biosynthesis of heme and chlorophyll (Dann et al. 1999), and cause singlet oxygen generation which causes extensive damage to the cell (Landini et al.

2003). This damage occurs when protoporphorinogen is oxidized to protoporphorin and when activated by light, generates active oxygen species in the cell (Landini et al. 2003, Dann et al. 1999).

In soybean, lactofen contact causes bronzing of the leaves and causes cell death (Graham 2005). On expanded leaves, lactofen causes stomatal closure but has no effect on unexpanded leaves (Wichert and Talbert 1993). Because of its non-systemic properties, it is hypothesized that lactofen can break apical dominance in soybean. Wichert and Talbert (1993) reported that there was no yield reduction when lactofen was applied at the V2 to V3 growth stage. However, yields were reduced by 130 and 200 kg ha^{-1} in 1997 and 1998 by tank mixtures of bentazon, lactofen, and clethodim in Michigan (Nelson et al. 2007). Lactofen reduced yields at application timings of R1 and R5 by 170 and 330 kg ha^{-1}, respectively (Nelson et al. 2010) indicating that yield loss is more severe with later applications.

There has been much interest in these practices in Nebraska to increase soybean yield. More specific information is needed about how they affect yield is needed. This research project is designed to test combinations of these practices to make more accurate recommendations to Nebraskan farmers to increase yield in soybean.

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Chapter 2.
Row Spacing, Seeding Rate, and Pyraclostrobin Effects on Soybean

Introduction

Increasing soybean yield in western Nebraska may be possible by planting soybean [*Glycine max.* (L.) merr.] in rows narrower than 76-cm, at seeding rates above 43 plants m^{-2}, and with the prophylactic application of strobilurin fungicides. Current recommendations in Nebraska are to achieve a stand of 37 plants m^{-2} (Specht et al. 2006), and to apply fungicides when disease pressure is high (UNL Extension 2013). The research to make these recommendations has been conducted in eastern Nebraska and more specific information is needed for recommendations in western Nebraska.

Row spacing affects soybean yield. Seed yield was 17% higher with 25- compared to 100-cm row spacing (Taylor 1980). Cooper (1977) observed a 10-20% soybean seed yield increase with 17- compared to 50- and 75-cm row spacings. Seed yield was 10% higher with 25- compared with 76-cm row spacings in Georgia (Ethredge et al. 1989), and 21% higher with 27- compared to 76-cm row spacings in Wisconsin (Costa et al. 1980).

Row spacing affects yield components. Norsworthy and Shipe (2005) reported 1,402 and 669 harvested seeds m^{-2} in 19- and 97-cm rows, respectively. Yield contributed from branches in 19-cm rows was 14 to 74% of total seed yield, while yield contributed from branches in 97-cm rows was 47 to 74% of total seed yield (Norsworthy and Shipe 2005). Increases in harvested seed m^{-2} in narrow rows accounted for yield increases over wide row soybeans. Changes in harvested 100-seed wt., due to row spacing have little effect on total seed yield. Mean seed yields were 4.64 and 4.39 Mg ha^{-}

^{1} with 38- and 76-cm rows, respectively, at three sites in Iowa with one site reporting a 0.5 g 100 harvested seeds^{-1} reduction in seed mass in 38-cm rows (De Bruin and Pedersen 2008).

Yield increases in soybean can be attributed to a greater leaf area index (LAI) in narrower compared to wider than 76-cm row spacing (Harder et al. 2007). In rows less than 25-cm, 95% light interception was reported compared to 76% in 100-cm rows, resulting in more photosynthesis (Shibles and Weber 1966). Soybean grown in 23-cm rows had 15 and 30% more LAI and also increased seed yield compared to 46-cm rows by 100 and 290 kg ha^{-1}, respectively in low and medium drought stress environments in Virginia (Holshouser and Whittaker 2002).

Specific information on optimal seeding rates is needed in soybean to maximize yield. Edwards and Purcell (2005) showed that as soybean population increases, yield increases rapidly until it becomes asymptotic at 20 plants m^{-2}. Wright et al. (1984) found that seed yield approached 4.50 Mg ha^{-1} at 20 plants m^{-2}. In Iowa 19 plants m^{-2} were sufficient to attain 95% of maximum yield (De Bruin and Pedersen 2008). Extensive on-farm research was conducted from 2006 to 2008 in eastern Nebraska. In 2006, plant populations of 22, 26, 35, and 39 plants m^{-2} had yields of 4.40, 4.45, 4.50, and 4.53 Mg ha^{-1}, respectively (UNL Cropwatch 2008). Results from 2007 showed no differences in yield with plant populations of 21, 27, 34, and 40 plants m^{-2} (UNL Cropwatch 2008). In 2008 in eastern Nebraska, 21 plants m^{-2} yielded 4.58 Mg ha^{-1} and 39 plants m^{-2} yielded 4.70 Mg ha^{-1} (UNL Cropwatch 2008).

In field studies investigating population and row spacing effects, increasing plant population from 6 to 64 plants m^{-2} resulted in decreased number of branches plant^{-1} from 6 to 2 branches plant^{-1}, respectively, and decreased the number of pods plant^{-1} from 35 to 15, respectively (Boquet 1990). Increased main stem length from 600 to 800 mm also resulted from increasing plant population (Boquet 1990). Cox and Cherney (2011) found that 32 to 47 plants m^{-2}, pods plant^{-1} were 38 and 30 and harvested seeds plant^{-1} were 92 and 70, respectively.

Increasing plant population increases LAI until the later reproductive stages. LAI was between 4 and 5 m^{2} m^{-2} with populations of 41 and 51 plants m^{-2} in 23-cm rows compared with populations of 10, 20, and 30 plants m^{-2} which had LAI of 3 to 4 m^{2} m^{-2} at R2 (Holshouser and Whittaker 2002). At 10 weeks after planting, LAI was greater than 5.5 m^{2} m^{-2} with 95% of light interception with 19 cm rows and 45 plants m^{-2} compared with a LAI of 4.5 m^{2} m^{-2} with 77% light interception in 19 cm rows at 12 plants m^{-2} (Harder et al. 2007).

Prevention of fungal disease can mitigate yield loss and increase yield. One approach to prevent fungal diseases is with the prophylactic use of foliar fungicides (Swoboda and Pedersen 2009). The strobilurin fungicides have a preventative mode-of-action (Grossman et al. 1999). The mode-of-action of strobilurin fungicides is inhibition of mitochondrial respiration by binding at the Q_o site of cytochrome b, which is located in the inner mitochondrial membrane (Bartlett et al. 2002). This disrupts the energy cycle in the targeted fungi by stopping the production of ATP. Strobilurin fungicides control the four major groups of plant pathogenic fungi: Ascomecetes, Basidiomycetes, Deuteromycetes, and Oomecetes (Bartlett et al. 2002).

Strobilurins provide disease control over time because their degradation process is slow (Nason et al. 2007). With this slow degradation, fewer applications are needed to provide adequate control of existing and future outbreaks of pathogenic fungi. Applying strobilurin fungicides prior to infection is recommended by the Fungicide Resistance Action Committee (FRAC) as an effective control strategy (Bartlett et al. 2002). Prophylactic use of strobilurin fungicides would limit outbreaks and minimize yield loss from fungal diseases throughout the growing season.

Strobilurins can increase plant health and yield (Henry et al. 2011). This stems from the strobilurin ‘stay green’ effect (Bartlett 2002). Grossman et al. (1999) suggests that this effect comes from the ability of strobilurins to delay leaf senescence and conserve water which was seen in wheat (*Triticum aestivum*) with treated plants consuming 8% less water while increasing dry matter by 10%. This would extend the growth and pod filling period thus increasing yields through increased seeds per pod and seed mass. There are mixed reports of how strobilurin fungicides affect yield in soybean. In northeast Missouri, strobilurin application at R4 increased soybean yields from 0.23-0.36 Mg ha^{-1} (Nelson et al. 2010). Also in Missouri Nelson and Meinhardt (2011) found that pyraclostrobin increased seed yield up to 36%. In Indiana there was no yield response to strobilurin application at R1, R3, R5, R3+R5, and R1+R3+R5 (Hanna et al. 2008) but Henry et al. (2011) found a 0.10 Mg ha^{-1} increase in yield with applications at R3. Swoboda and Pedersen (2009) found that at low levels (0-15%) of disease, strobilurin application did not increase yields and did not have a ‘stay green’ effect in Iowa. Results from applications of pyraclostrobin in Nebraska have also been mixed. In 2005, two studies in eastern Nebraska showed no yield increase with applications of pyraclostrobin (UNL Cropwatch 2005a; UNL Cropwatch 2005b). In 2010, application of pyraclostrobin increased soybean yield by 0.61 Mg ha^{-2} in eastern Nebraska (UNL Cropwatch 2011).

There is ample evidence of yield advantage in planting soybean with less than 100 cm row spacing but less information on how very narrow row spacing affects yield. The effects on soybean yield of increasing seeding rate above 25 seeds m^{-2} and of prophylactic application of fungicides have been inconsistent. The objectives of this study were to determine if yield was higher in 19 or 38cm rows, how yield responded to planting population, and which application timing of fungicide had the greatest effect on soybean yield, if any. Our hypotheses are that soybean yield will be maximized when planted with seeding rates higher than 43.2 sown seeds m^{-1} to maximize light interception in a shorter growing season, and with prophylactic application of strobilurin fungicides at reproductive growth stages by increasing the seed fill period. The intended range of inference for this research is for High Plains irrigated soybean production above 800 m elevation.

Materials and Methods

An irrigated field study was conducted in 2011 and 2012 at the West Central Research and Extension Center (WCREC) near North Platte NE (41° 5'16"N 100°46'38"W in 2011 and 41° 5'18"N 100°46'24"W in 2012) on a Cozad silt loam soil (coarse-silty, mixed, mesic, Typic Haplustolls) in 2011 and 2012 and the West Central Water Resource Field Laboratory (WCWRFL) located near Brule, NE (41° 9'48.01"N 102° 1'56.21"W in 2011 and 41° 9'34.93"N 102° 1'4.82"W in 2012) on a Kuma loam soil (fine-silty, mixed, mesic, Pachic Argiustolls) in 2011 and 2012. The elevation was 853 m and 1113 m at the WCREC and WCWRFL, respectively. Both locations were in no-till soybean corn rotations for four to six years. A precipitation gradient existed between the WCREC and the WCWRFL. On average, the WCREC receives 550 mm precipitation each year and the WCWRFL receives 470 mm precipitation each year increasing the need for irrigation at the WCWRFL.

The study was a three way factorial (2 row spacings x 3 seeding rates x 8 fungicide application timings) in a split-plot randomized complete block design with four replications at each location. The main plot consisted of seeding rate x fungicide application and was 3 x 9m. The main plot was planted at 24.7, 43.2, and 61.8 seeds m^{-2} and pyraclostrobin (Headline, BASF Corporation Research Triangle Park, North Carolina) was applied at 877 g ai ha^{-1} using a backpack sprayer with a spray width of 3 m using Teejet TT11003 nozzles at 207 kPa. Pyraclostrobin was applied at beginning flower (R1), beginning pod (R3), full pod (R5), R1 plus R3, R1 plus R5, R3 plus R5, R1 plus R3 plus R5, with a non-treated control. The split-plot was 1.52 x 9 m and was planted in 19- or 38-cm row spacings, but was not a randomized factor.

The cultivars were Syngenta S25-R3, maturity 2.5 and AsGrow AG-2831 maturity 2.8 at Brule and North Platte, respectively, and were selected for adaptation to the environments. Seed was treated with a biological stimulant (BioForge, Stoller

USA,Houston, Texas) at 1.30 ml kg^{-1} of seed and BioForge was applied at 1.17 L ha^{-1} at the R3 growth stage using a backpack sprayer and a 3 m boom using Teejet TT11003 nozzles at 207 kPa. In 2011, planting took place on May 3 and May 4 at Brule and North Platte, respectively with a Kincaid plot drill that had Crustbuster All Plant Openers (CrustBuster/ Speed King, Inc., Dodge City, Kansas) installed. In 2012, planting occurred on April 30 and May 2 in North Platte and Brule, respectively. Seed was planted at a depth of 4.5 cm.

In order to control weeds, a post-emergence application of glyphosate (Roundup PowerMax, Monsanto Company, St. Louis, Missouri) and saflufenacil (Sharpen, BASF Corporation Research Triangle Park, North Carolina) was applied on June 1, 2011 at rates of 2.6 kg acid equivalent (ae) ha^{-1} and 0.075 kg ai ha^{-1}, respectively, in North Platte. Glyphosate and clethodim (Select Max, Valent U.S.A. Corporation, Walnut Creek, California) were applied on June 28, 2011 at rates of 2,600 g ae ha^{-1} and 153 g ai ha^{-1}, respectively, in North Platte. Glyphosate was applied at 2,602 g ae ha^{-1} on May 9, June, 27, and July 12, 2011 in Brule. Clethodim was applied at 153 g ai ha^{-1} on June 27, 2011 in Brule.

Stand counts were conducted at full maturity (R8) by counting 6 m of the two inside rows. Growth stage was recorded on a weekly basis at each location. Harvests at North Platte were October 4, 2011 and September 20, 2012, and at Brule October 6, 2011 and September 28, 2012. At plant harvest, one m of one row in each split-plot was sampled for harvested areas of 0.19 and 0.38 m^2 for the 19- and 38-cm row spacings, respectively, to determine yield components. From this sample, counts and measures were taken to determine 100-seed wt., seeds plant^{-1}, seeds m^{-2} and seed yield. Plots were also harvested using a Kincaid 8-XP (Kincaid Equipment Manufacturing, Haven, Kansas) plot combine and seed yield was adjusted to 13% water content by using the following equation:

$$Y = \left(\frac{\left(weight * \left(1 - \left(\frac{moisture}{100}\right)\right)\right)}{dry\ matter}\right) * \left(\frac{10{,}000m}{plot\ area}\right)$$

Data was analyzed using PROC GLIMMIX of SAS (SAS version 9.2, SAS Institute, Cary, NC). Prior to final analysis, tests for normality were conducted. Location and year were treated as random effects in the analysis and the fixed effects were row spacing, seeding rate, and pyraclostrobin application. Mean comparisons were made in the lsmeans statements in PROC GLIMMIX with an alpha level set at 0.05 for all significant interactions. The MSE for the main plot was 0.1826 with a standard error of 0.009753.

Results and Discussion

Weather conditions at the WCREC and the WCWRFL differed greatly between 2011 and 2012 (Table 2.1). Irrigation was 133 mm at the WCREC in 2011 and rainfall was 402 mm during the growing season with 81% of the precipitation during May to July. In 2012, irrigation was 441 mm. Irrigation did not take place at the WCREC in 2012 until late June due to the installation of a new irrigation system, explaining the lower yields at WCREC in 2012. In 2011, irrigation and rainfall at the WCWRFL were 294 and 321 mm, respectively. In 2012, rainfall was 128 mm and irrigation was 491 mm. In 2012, water was not a limiting factor at WCWRFL and yields were similar to those observed in 2011.

Mean temperatures in July at WCREC were 32 and 35 C in 2011 and 2012, respectively (Table 2.1). At WCWRFL average temperatures in July were 32 and 36 C in 2011 and 2012, respectively. With higher temperatures in 2012, the seed fill period was shortened. Previous research shows that cooler day/night temperatures (24/19 C) lengthen the seed filling period by approximately two weeks (Edwards and Purcell 2005).

Yield was higher in both 2011 and 2012 at the WCWRFL compared to the WCREC (Table 2.3). In 2012, the difference was caused by lower water availability at the WCREC. Final plant populations in 2012 were lower than in 2011 (Table 2.4). This was caused by poor germination from low water availability in 2012 and possibly heavy corn residue.

Seed Yield

Seed yield was significantly affected by the site x population interaction (Table 2.2). Seed yield was consistently less in 24.7 compared with 43.2, and 61.8 seeds m^{-2}, but the magnitude of the difference was greater at WCWRFL compared with WCREC (Table 2.5). The difference between locations is due to low precipitation and delayed irrigation at the WCREC in 2012. Others have observed effects of plateaued seed yield when conducting studies on planting population. In Louisiana, increasing plant population 43% between populations of 16.4 and 23.4 plants m^{-2} resulted in no seed yield change (Carpenter and Board 1997). Cox and Cherney (2011) found that seed yield increased 7% as seeding rate went from 32.1 to 42.0 seeds m^{-2} but declined 4% as seeding rate went from 42.0 to 46.9 seeds m^{-1}. A similar study conducted under non-irrigated conditions near Mead, Nebraska showed that yield plateaued at 12.9 plants m^{-1}

concluding that increasing seeding rates is not necessary to maximize seed yield (Ennin and Clegg 2001). In south central Nebraska, 29.5 planted seeds m^{-2} was optimal across 17 trials conducted on farmers' fields (UNL Cropwatch 2008).

100-seed wt.

100-seed wt. was less in in 2012 than in 2011 (Table 2.7). 100-seed wt. was affected by the year x population interaction (Table 2.2). In 2011, 100-seed wt. was 17.1 g 100 $seeds^{-1}$ at 24.7 seeds m^{-2} and a mean of 17.7 g 100 $seeds^{-1}$ at 43.2 and 61.8 seeds m^{-2} (Table 2.6) while seed rate did not affect 100-seed wt. in 2012 (Figure 2.3). Water availability in 2011 was much greater than in 2012 and is the primary reason for differences seen in 100-seed wt. The results in 2012 are consistent with findings in New York, which found that populations of 32.1 to 46.9 plants m-2 had no effect on 100-seed wt. (Cox and Cherney 2011). Results in 2011 can be explained by De Bruin and Pedersen (2008) which found that a seeding rate of 18.5 seeds m^{-2} had a 100-seed wt. of 14.2 g 100 $seeds^{-1}$ and seeding rates of 31.0 to 55.6 seeds m^{-2} had a 100-seed wt. of 14.4 g 100 $seeds^{-1}$, but these differences were most likely due to different location conditions.

Seeds $Plants^{-1}$

Seeds $plant^{-1}$ was affected by the year x site x population interaction (Table 2.2). Seeds $plant^{-1}$ always decreased with increased seed rate but the year x site x seed rate interaction was significant because of varying magnitude of seed rate effect. At WCWRFL in 2012, seeds $plant^{-1}$ were 56 and 164% more with 24.7 compared with 43.2 and 61.8 sown seeds m^{-2} (Table 2.4). For the other site-years, however, mean seeds $plant^{-1}$ were just 32 and 108% more with 24.7 compared with 43.2 and 61.8 sown seeds m^{-2}.

This effect helps to understand how soybean compensates yield at lower populations, by increasing the number of seeds plant^{-1}. Similar research indicates that the number of seeds plant^{-1} decrease as soybean population increases. Cox and Cherney (2011) report a strong relationship between seeding rate and seeds plant^{-1} with low seeding rates of 32.0 seeds m^{-2} having 92 seeds plant^{-1} and high seeding rates of 46.9 seeds m^{-2} having 70 seeds plant^{-1}.

Seeds m^{-2}

The number of seeds m^{-2} was affected by the site by population and year by population interactions but not the year by site by population interaction (Table 2.2). Seeds m^{-2} always decreased with increasing the seeding rate at WCWRFL but no effect was observed at WCREC (Table 2.5). At WCWRFL seeds m^{-2} were 13 and 18% more with 24.7 compared to 43.2 and 61.8 sown seeds m^{-2}, respectively (Table 2.5). In 2011, seeds m^{-2} was greatest at 61.8 sown seeds m^{-2} but greatest at 24.7 sown seeds m^{-2} in 2012 (Table 2.6). Other research has shown no effect on seeds m^{-2} by seeding rate (De Bruin and Pedersen 2008) which agrees with the WCREC result. Cox and Cherney (2011) also found that there was little change in seeds m^{-2} as seeding rate increased.

Pyraclostrobin Application

No differences in seed yield were observed from pyraclostrobin application at either site in 2011 or 2012. No disease pressure was observed throughout the growing seasons. In more favorable conditions for fungal disease to grow and develop, seed yield responses from prophylactic pyraclostrobin application might occur as seen in Indiana where a yield increase of 0.1 Mg ha^{-1} was seen with application of pyraclostrobin at R4

(Henry et al. 2011) . There was also no observed ‘stay green effect’ at any application rate. All combinations of row spacing, seeding rate, and pyraclostrobin days from planting to R7 were 133 and 124 WCREC in 2011 and 2012, respectively, and 136 and 127 at WCWFRL in 2011 and 2012.

Conclusions

Irrigated soybean yield in west central Nebraska above 800 m elevation is maximized with a seeding rate of between and 27.4 and 43.2 seeds m^{-2}, a rate that may be higher than generally found for Corn Belt production at lower elevation and with more growing degrees days per season. Further investigations into seeding rates between 24.7 and 43.2 seeds m^{-2} to determine where yield starts to plateau would lend more accurate recommendations for farmers in west central Nebraska. Application of strobilurin fungicides had no effect on yield and on yield components due to low disease pressure in both years at both locations; this research still needs to be pursued because yield increases have been noted by others. The majority of increases from pyraclostrobin have been noted in the eastern Corn Belt, while western Corn Belt results tend to show no benefit from prophylactic applications. No ‘stay green’ effect of strobilurin should be expected with High Plains soybean production.

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Table 2.1. Monthly irrigation, precipitation, and temperature recorded at the WCREC† and the WCWRFL†† in 2011 and 2012 during the growing season.

Location	Year	Month	Precipitation	Irrigation	Average temperature (C)	
			——mm——		High	Low
WCREC	2011	May	140	0	20	6
		June	85	0	27	13
		July	99	33	32	18
		August	54	83	31	16
		September	24	17	25	5
WCREC	2012	May	18	0	25	8
		June	33	7	33	15
		July	47	161	35	18
		August	11	114	32	14
		September	3	26	28	7
WCWRFL	2011	May	77	0	20	4
		June	43	39	28	12
		July	86	38	33	18
		August	53	168	32	16
		September	35	76	26	8
WCWRFL	2012	May	28	28	25	7
		June	17	76	34	15
		July	44	138	36	17
		August	13	208	34	14
		September	5	41	29	9

† The WCREC is located in North Platte, NE.

†† The WCWRFL is located near Brule, NE.

Table 2.2. Seed yield, seed mass, seeds plant^{-1}, and seeds m^{-2} analysis of variance for year, site, row spacing, planted population, and fungicide application at the WCREC‡ and WCWRFL§ in 2011 and 2012.

Effect	Df	Seed yield	Seed wt.	Seeds plant^{-1}	Seeds m^{-2}
Year (y)†	1	-	-	-	-
Site (s)	1	-	-	-	-
Population (p)	2	***	*	***	***
Fungicide (f)	7	NS	NS	NS	NS
y*s	1	-	-	-	-
y*p	2	NS	*	***	***
s*p	2	*	NS	***	**
y*s*p	2	NS	NS	***	NS

* Indicates significance at the $P \le 0.05$.

** Indicates significance at the $P \le 0.01$.

*** Indicates significance at the $P \le 0.001$.

NS Indicates non-significance at the $P \le 0.05$.

† Interactions not reported were not significant at the $P \le 0.05$, for complete results, see Appendix table 1.

‡The WCREC is located at North Platte, NE.

§The WCWRFL is located near Brule, NE.

Table 2.3. Soybean seed yield and yield components as affected by year and site in west central Nebraska in 2011 and 2012.

Main effect	Seed yield	Seed wt.	Seeds plant^{-1}	Seeds m^{-2}
	Mg ha^{-1}	g 100 seeds^{-1}		
Year x Site				
2011 WCREC‡	5.05	18.1	109.0	3,674
2011 WCWRFL§	5.75	16.2	97.3	3,490
2012 WCREC	2.81	15.0	75.5	4,098
2012 WCWRFL	5.11	12.9	168.1	7,666

‡ The WCREC is located at North Platte, NE

§The WCWRFL is located near Brule, NE

Table 2.4. Soybean seed yield and yield components as affected by year, site and seed rate in west central Nebraska in 2011 and 2012.

Year	Site	Seed rate	Population	Seed yield	Seed wt.	Seeds plant^{-1}	Seeds m^{-2}
		seeds m^{-2}	plants m^{-2}	Mg ha^{-1}	g 100 seeds^{-1}		
2011	WCREC‡	24.7	22.3	4.90	17.6	154 b	3,325
		43.2	37.1	5.11	18.5	95 e	3,523
		61.8	54.5	5.15	18.3	78 fg	4,172
	WCWRFL§	24.7	25.9	5.53	16.7	135 c	3,520
		43.2	38.1	5.81	17.1	90 ef	3,407
		61.8	53.0	5.90	16.7	66 g	3,544
2012	WCREC	24.7	22.0	2.71	14.9	111 d	4,749
		43.2	37.8	2.86	14.9	68 g	3,976
		61.8	48.9	2.85	15.2	48 h	3,568
	WCWRFL	24.7	20.3	4.72	12.8	256 a	8,941
		43.2	27.1	5.36	12.9	151 b	7,396
		61.8	36.2	5.25	13.0	97 de	6,660

† Values followed by the same letter are not significantly different at $P \leq 0.05$.

‡ The WCREC is located at North Platte, NE

§ The WCWRFL is located near Brule, NE

Table 2.5. Soybean seed yield and yield components as affected by site and seed rate in west central Nebraska in 2011 and 2012.

Site	Seed rate seeds m^{-2}	Population plants m^{-2}	Seed yield Mg ha^{-1}	Seed wt. g 100 $seeds^{-1}$	Seeds $plant^{-1}$	Seeds m^{-2}
WCREC‡	24.7	22.1	3.80 d	16.2	132 b	4,037 c
	43.2	37.4	3.99 c	16.7	82 d	3,750 c
	61.8	51.7	4.00 c	16.7	63 e	3,870 c
WCWRFL§	24.7	23.1	5.12 b	14.7	196 a	6,230 a
	43.2	32.6	5.58 a	15.0	121 c	5,401 b
	61.8	44.6	5.58 a	14.9	82 d	5,102 b

† Values followed by the same letter are not significantly different at $P \leq 0.05$.

‡ The WCREC is located at North Platte, NE

§ The WCWRFL is located near Brule, NE.

Table 2.6. Soybean seed yield and yield components as affected by year and seed rate in west central Nebraska in 2011 and 2012.

Year	Seed rate	Population	Seed yield	Seed wt.	Seeds plant^{-1}	Seeds m^{-2}
	seeds m^{-2}	plants m^{-2}	Mg ha^{-1}	g 100 seeds^{-1}		
2011	24.7	24.1	5.22	17.1 b	145 b	3,422 e
	43.2	37.6	5.46	17.8 a	93 d	3,465 e
	61.8	53.7	5.53	17.5 a	72 e	3,858 d
2012	24.7	21.2	3.71	13.8 c	183 a	6,845 a
	43.2	32.5	4.11	13.9 c	110 c	5,686 b
	61.8	42.6	4.05	14.1 c	72 e	5,114 c

† Values followed by the same letter are not significantly different at $P \leq 0.05$.

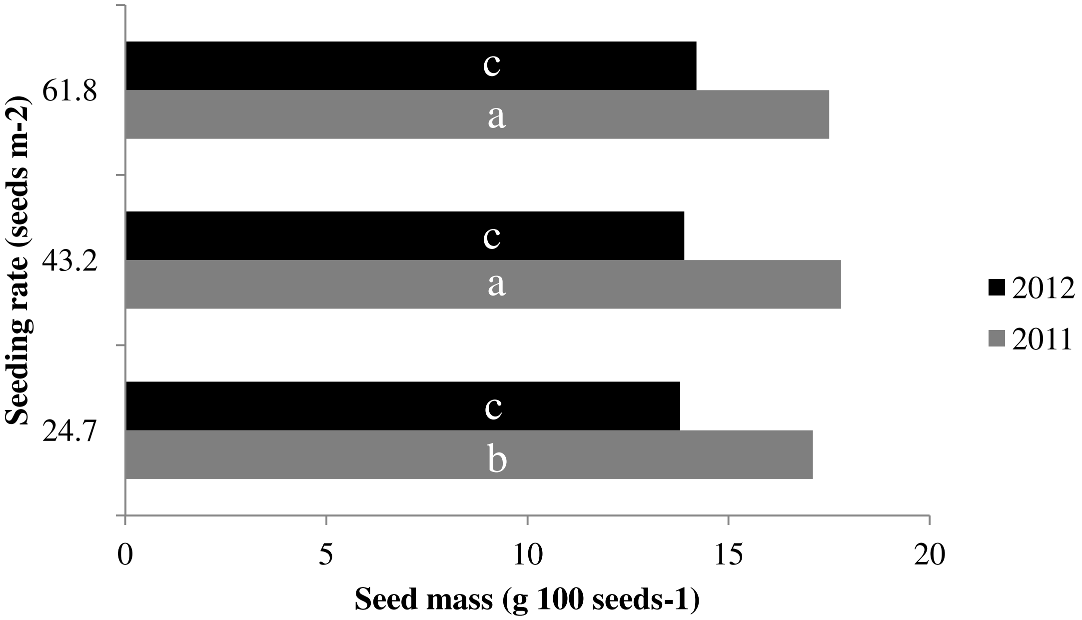

Figure 2.1. Soybean seed mass (g 100 seeds^{-1}) response to year and seeding rate in west central Nebraska in 2011 and 2012. Values followed by the same letter are not significantly different at $P \leq 0.05$.

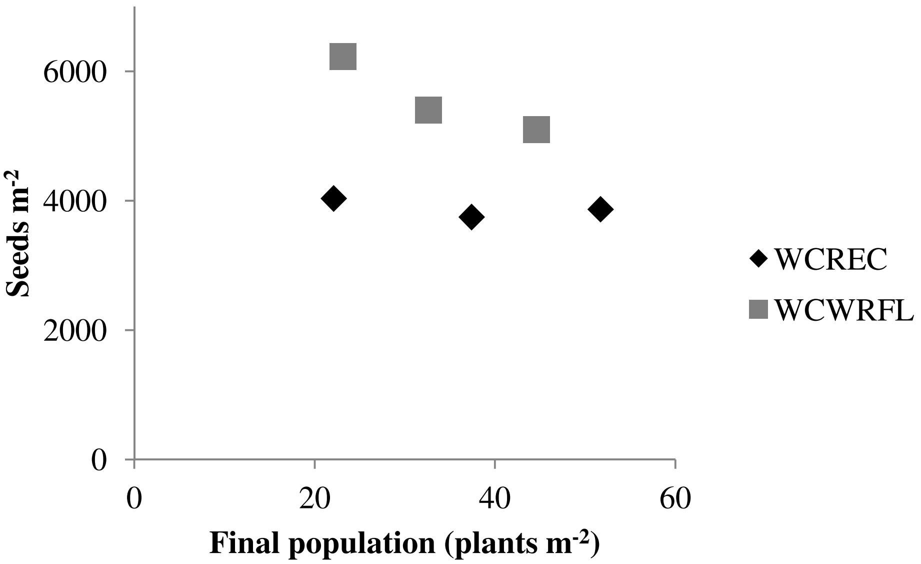

Figure 2.3. Soybean seeds m^{-2} as affected by site and population at the WCREC in North Platte, NE and the WCWRFL near Brule, NE.

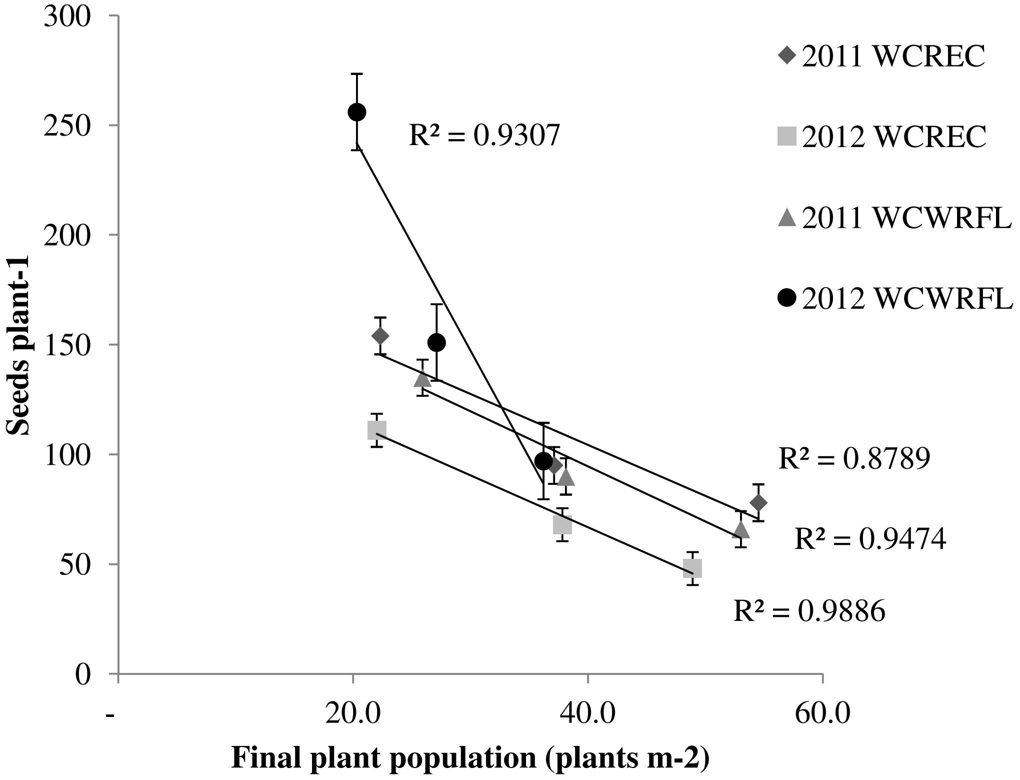

Figure 2.4. Soybean seeds plant^{-1} as affected by year, site, and seed rate at the WCREC in North Platte, NE and the WCWRFL near Brule, NE in 2011 and 2012.

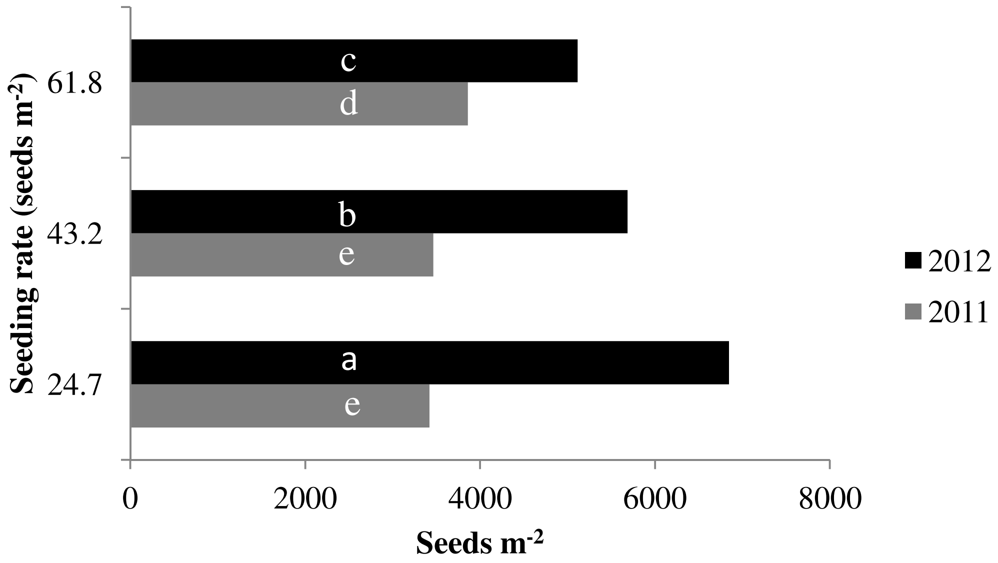

Figure 2.6. Soybean seeds m^{-2} as affected by year and population in west central Nebraska in 2011 and 2012. Values followed by the same letter are not significantly different at the $P \leq 0.05$.

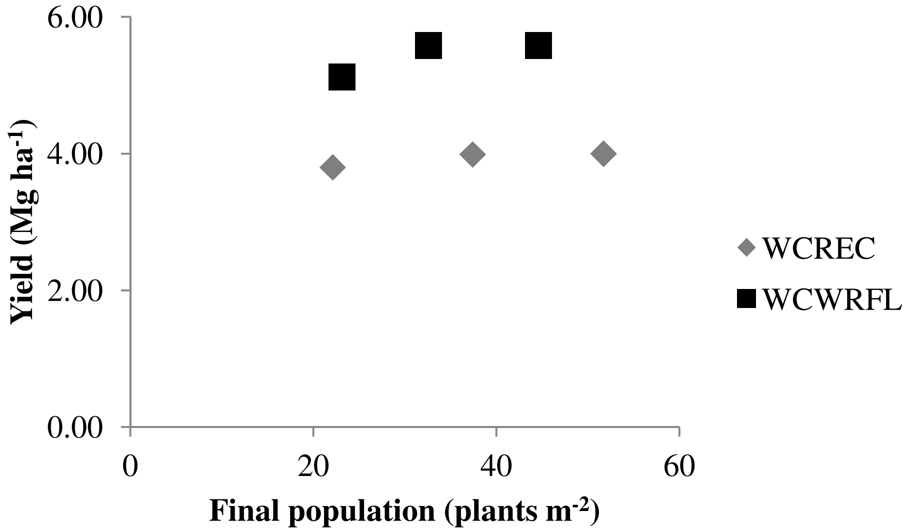

Figure 2.7. Soybean seed yield response in Mg ha^{-1} to site and population at the WCREC in North Platte, NE and the WCWRFL near Brule, NE.

Chapter 3.

Use of Fertilizer, Seed Treatments, and Apical Meristem Destruction to Optimize Soybean Yield

Introduction

Increasing yield in soybean [*Glycine max* (L.) merr.] to greater than 6.7 Mg ha^{-1} (100 bu ac^{-1}) is a goal in the soybean producing areas in Nebraska. Achieving this goal may be attainable through use of narrow row spacings, high plant populations, a combination of foliar and in-furrow fertilizers, practices to induce branching, seed treatments and inoculants to promote plant health and stand establishment, and foliar applied fungicides to delay leaf senescence and mitigate yield loss (Wichert and Talbert 1993; Ray et al. 2005; De Bruin and Pedersen 2008; Nelson et al. 2010; Cox and Cherney 2011).

Branching typically occurs at low plant populations in order to maximize yield (Carpenter and Board 1997). Branching is a natural response to both environmental conditions and population. A physical alteration of the plant, such as destruction of the apical meristem, may increase branching and subsequently increase yield (Jeuffroy and Ney 1997). Lactofen, a protoporphyrinogen oxidase inhibitor (PPO), is a post-emergence non-systemic herbicide labeled for broadleaf weed control in soybean that can break apical dominance in soybean. Witchert and Talbert (Wichert and Talbert 1993) showed that lactofen application at V2-V3 did not reduce yields. However, yields were reduced by 130 and 200 kg ha^{-1} in 1997 and 1998 by tank mixtures including bentazon, lactofen, and clethodim in Michigan at V5 (Nelson and Renner 2001). Lactofen reduced yields at application timings of R1 and R5 by 170 and 330 kg ha^{-1}, respectively (Nelson et al. 2010) indicating that yield loss can be severe with later applications.

Optimizing plant nutrition can increase yield. Adequate N supply throughout the growing season is important for high yield (Salvagiotti et al. 2009). A yield increase of 0.32 Mg ha^{-1} was observed by pre-plant application of 290, 310 and 360 kg ha^{-1} N in 2002, 2003 and 2004, respectively, in Mississippi (Ray et al. 2005). Adding 16 kg ha^{-1} N as banded starter fertilizer had a 6% yield increase over the non-treated check (Osborne and Riedell 2006). Ferguson et al (2006) recommend starter N application for soybean produced on the High Plains of Nebraska. Increases in yield have been noted from foliar fertilizing by increasing the number of harvestable seeds ha^{-1} while maintaining seed size (Garcia and Hanway 1976). Haq and Mallarino (2000) state the response to foliar N-P-K fertilizer application varies based on soil test levels and local weather conditions. Contradictory to what Ray et al. and Osborne and Riedell have found, Barker and Sawyer (2005) observed no increase in soybean yields from applying 45 kg ha^{-1} N and 90 kg ha^{-1} at R3. Yield of irrigated soybean in Nebraska was increased on just 3 of 53 fields with soil applied N at R3 (Wortmann et al. 2012). There were no yield increases in Virginia with UAN applied at 0, 14, 28, 56, 84, 112, and 168 kg ha^{-1} N at either R3 and R5 (Freeborn et al. 2001).

Seed treatments and inoculants have been reported to increase soybean yield as well (Johnson 1987, Schultz and Thelen 2008). Using inoculants increased yields across 14 studies by 85.6 kg ha^{-1} in Michigan with 12 of the studies having a recent history of soybean production (Schultz and Thelen 2008). In Nebraska, inoculation did not increase yield from 2001 to 2004 in six studies (Abendroth 2006). Research conducted in Indiana, Iowa, Nebraska, Minnesota, and Wisconsin show that there is little probability for a yield response when inoculants are used in fields with a history of soybean (De Bruin et al. 2010).

When disease pressure is low, fungicide seed treatments are not needed to ensure adequate stands (300,000 to 370,000 seeds ha^{-1}) but under high disease pressure, fungicide seed treatments can aid in plant establishment (Johnson 1987). In Nebraska, seed treated with fungicides plus inoculant and growth stimulant (lipo-chitooligosaccharide) yielded 0.20 Mg ha^{-1} higher than with non-treated seed (UNL Cropwatch 2008).

Practices that are of interest in this study include: inducing branching through destruction of the apical meristem by clipping or application of lactofen, the use of both foliar and in-furrow applied fertilizers, and the use of seed treatments and inoculants to promote plant health at emergence. Combining these practices may prove useful to maximize soybean yield. We hypothesize that irrigated soybean yield in the western Corn Belt will be maximized through the combination of fertilizers, seed treatments, and apical meristem destruction to reduce lodging. These methods will accomplish this through early plant establishment, and optimizing plant nutrition throughout the growing season. The objective of this study was to test if the combinations of fertilizer, seed treatments, and apical meristem destruction for breaking apical dominance to determine which, if any, would increase soybean yield.

Materials and Methods

Field studies were conducted near four locations in Nebraska in 2011: Bancroft (42° 1'2"N, 96°45'14"W) on a Belfore silty clay loam soil (fine, smectitic, mesic Udic Haplustolls), Clay Center (40°34'30"N, 98° 8'11"W) on a Crete silt loam soil (fine, smectitic, mesic, Pachic Uderic Argiustolls), Cortland (40°27'34"N, 96°39'56"W) on a Wymore silty clay loam soil (fine, smectitic, mesic, Aqueric Argiudolls), and Elba (41°17'48"N, 98°35'34"W) on a Hall silt loam soil (fine-silty, mixed, superactive, mesic, Pachis Argiustolls; Table 3.1). Soil chemical properties were favorable for high yield soybean except for low pH at Bancroft and low P and Zn availability at SCAL (Table 3.1). Elevation was 465, 555, 443, and 574 at Bancroft, Clay Center, Cortland, and Elba, respectively. Eight treatments with four replications at each site were planted at 55.6 seeds m^{-2} in 51 cm rows with plots being 3.7 x 15.2 m.

All locations were in a corn-soybean rotation and tilled prior to planting. Soil test levels at each of these sites were normal with very few nutrients below UNL optimum levels (Table 3.1). Pioneer (Pioneer Hi-Bred International, Inc., Johnston, Iowa) variety 93M11 was planted at Bancroft and Elba, the maturity group was 3.1 and Pioneer variety 93Y70 was planted at Clay Center and Cortland, the maturity was 3.7. Pyraclostrobin (Headline, BASF Corporation Research Triangle Park, North Carolina) was applied at 440 g ai ha^{-1} at both R1 and R3. Irrigation at each location began at R3. A soil application of ammonium nitrate at 28 kg ha^{-1} was applied to all plots at all locations at R1.

Treatments were arranged in a minus one design with all five, or all five except one, alternative treatments applied (Table 3.2). A check treatment with no alternative treatments was also included giving a total of eight treatments. The alternative treatments were: 1) 5.6 kg ha^{-1} starter N applied as urea ammonium nitrate in seed furrow; 2) 5.6 kg ha^{-1} N, 1.0 kg ha^{-1} P, 0.5 kg ha^{-1} K, 0.05 kg ha^{-1} Mn, 0.02 kg ha^{-1} Zn, 0.005 kg ha^{-1}Fe, and 0.007 kg ha^{-1} Mg foliar applied at R3; 3) BioForge seed treatment which consists of 2% urea, 3% potash, and 0.5% humic acid (BioForge ST, Stoller USA, Houston, Texas) at 1.3 mL kg^{-1} seed; 4) Optimize seed inoculant with growth promoter (Lipo-chitooligosaccharide) (Optimize 400, Novozymes BioAg, Inc., Milwaukee, Wisconsin) at 1.82 mL kg^{-1} seed; and 5) breaking of apical dominance at V2. Attempts to break apical dominance included clipping the meristem just below the V2 node by cutting or lactofen applied at 210 g ai ha^{-1} at V2.

Seed yield (kg ha^{-1}) was determined by harvesting the center three rows with a plot combine. Final plant population, branches plant^{-1}, pods plant^{-1}, seeds plant^{-1} and 100-seed wt. were determined from by collecting five consecutive plants in each plot and measuring the distance between them one day before plots were harvested with a plot combine. Samples were bagged and taken to the lab to collect the remaining data.

Data were analyzed using PROC GLIMMIX in SAS (SAS version 9.2, SAS Institute, Cary, NC). Prior to final analysis, tests for normality were conducted. Location was treated as a random effect in the analysis. Mean comparisons were made using the Dunnett's adjustment in the lsmeans statement in PROC GLIMMIX with an alpha level set at 0.05 for significant interactions. Initial analyses showed no differences in seed yield between some treatments and yield components were determined only for treatments one, two, seven, and eight.

Results and Discussion

Location mean yields ranged from 4.62 Mg ha^{-1} at Cortland to 3.81 Mg ha^{-1} at Bancroft. There were no treatment by location interaction effects on yield and mean yields combined across locations are presented (Figure 3.1). The starter N, R3 foliar nutrient, and R3 N applications did not affect yield or yield components. On average, 50-60% of soybean's demand for N is met by biological N_2 fixation (Salvagiotti et al. 2009), so additional N is needed to maximize yield but these sites had 2.5 to 5% soil organic matter with much organic N mineralization expected under irrigated conditions. These results are generally consistent with results from the western Corn Belt (Mallarino 2008).

Seed treatments did not increase yield. All of the locations had been in a corn-soybean rotation, and the use of inoculants in Nebraska is not recommended for fields with a history of soybean (Abendroth et al. 2006). Breaking apical dominance by clipping or using lactofen did not increase soybean branching (data not shown) but reduced yield by up to 12.9% (Figure 3.1). Yield components were not affected by treatments or treatment x site interactions (Table 3.3). Similar research conducted in South Dakota showed yield reductions of 14 to 93% in soybean with destruction of the apical meristem by plant growth regulator herbicides (Andersen et al. 2004). Destroying the apical meristem did not result in increased branching (data not shown). A reduced number of branches may also be attributed to higher plant population of soybean plants (Carpenter and Board 1997). Results from Carpenter and Board (1997) suggest that branching will optimize yield at suboptimal populations (populations less than 16.4 plants m^{-2}). Despite the reductions in yield from destruction of the apical meristem, further research is needed to determine why this happened and if different rates of lactofen or application timings would result in increased branching and yield.

Conclusions

Destruction of the apical meristem at V2 should not be done to increase soybean yield. Soybean yield did not respond to both in-furrow starter, foliar applied, and R1 soil applied fertilizer under these conditions where soil nutrient availability was generally high. These treatments might have shown response where soil nutrient availability is low. In a field with no recent history of soybean, inoculant would have a higher probability to increase yield. Future research needs to match hypotheses with field conditions to have a higher probability of treatment effects in order to make more specific and accurate recommendations to Nebraskan farmers.

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Table 3.1. Soil properties for field sites across Nebraska in 2011.

	Location			
Soil Parameter	Bancroft	Clay Center	Cortland	Elba
SOM, %	5.0	2.9	3.4	2.5
pH	5.7	6.7	6.4	6.2
NO3-N, ppm	8.4	5.3	10.6	7.8
M3 P, ppm	87	9	17	52
K, ppm	505	486	340	483
SO4-S, ppm	24	18	20	16
Zn, ppm	3.5	0.7	1.2	3.7

Table 3.2. Alternative practices used in combination to form each of eight treatments at field sites across eastern Nebraska in 2011.

Treatment	At plant N	BioForge foliar at R3	BioForge seed treatment	Optimize seed treatment	Clipping of apical meristem at V2
1. Full	X	X	X	X	X
2. Full with lactofen	X	X	X	X	lactofen at 210 g ai ha^{-1}
3. Minus starter N		X	X	X	X
4. Minus foliar	X		X	X	X
5. Minus BioForge ST	X	X		X	X
6. Minus Optimize	X	X	X		X
7. Minus clipping	X	X	X	X	
8. Minus all					

Table 3.3. Seed yield, seed mass, pods plant^{-1}, seeds plant^{-1}, seeds m^{-2}, and branches plant^{-1} analysis of variance for site and treatment across Nebraska in 2011.

Effect	df	Yield	Seed mass	Pods plant^{-1}	Seeds plant^{-1}	Seeds m^{-2}	Branches plant^{-1}
Treatment (t)	7	***	NS	NS	NS	NS	NS
s x t	21	NS	NS	NS	NS	NS	NS

*** Indicates significance using Dunnett's adjustment at $P \leq 0.05$.

NS Indicates non-significance at $P \leq 0.05$.

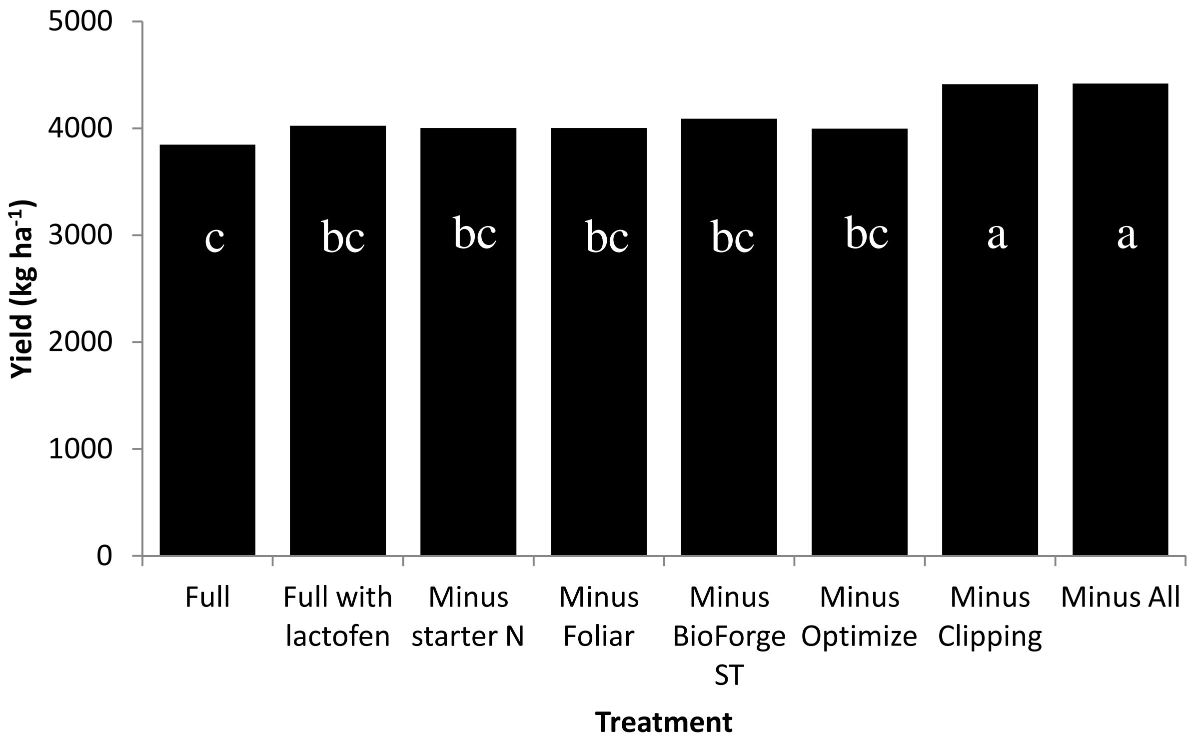

Figure 3.1. Yield response of soybean to treatment combination in 2011, with full treatment including at plant N, foliar NPK at R3, BioForge ST, Optimize 400, and clipping of the apical meristem at V2 averaged across four sites, Bancroft, Clay Center, Cortland, and Elba, NE. Treatments followed by the same letter are not significantly different using the Dunnett's adjustment at the P ≤ 0.05 level.

Chapter 4.

Effects of Row Spacing and Lactofen on Branching and Yield in Soybean

Introduction

Increasing yield in soybean [*Glycine max.* (L) merr.] may be possible by incorporating alternative methods into a management system. Specifically in Nebraska there has been much interest in inducing branching through the use of Protoporphyrinogen Oxidase (PPO) Inhibitors. PPO Inhibitors or diphenyl ethers are classified as group 14 (E) herbicides (Malory-Smith and Retzinger 2003). Common herbicides found in this group include lactofen, acifluorofen, oxyfluorofen, and fomesafen (Malory-Smith and Retzinger 2003). These chemicals inhibit protoporphyrinogen oxidase, an enzyme involved in the biosynthesis of heme and chlorophyll (Dann et al. 1999), and cause singlet oxygen generation which can cause extensive damage to the cell (Landini et al. 2003). This damage occurs when protoporphyrinogen is oxidized to protoporphorin which, when activated by light, generates active oxygen species in the cell (Dann et al. 1999; Landini et al. 2003).

In soybean, lactofen contact causes bronzing of the leaves and eventually leads to cell death (Graham 2005). On expanded leaves, lactofen causes stomatal closure but has no effect on unexpanded leaves (Wichert and Talbert 1993). There are mixed reports of lactofen's effects on seed yield. A 510 kg ha^{-1} yield increase was seen when lactofen was applied at the V5 growth stage in Michigan (Nelson et al. 2002). Wichert and Talbert (1993) reported that there was no yield reduction when lactofen was applied at the V2 to V3 growth stage. Yield reductions of 290 kg ha^{-1} and 330 kg ha^{-1} occurred with applications at the R1 and R5 growth stages, respectively (Nelson et al. 2007).

Soybean puts on a new main stem node every 3.7 days or 0.27 nodes day^{-1} (Bastidas et al. 2008), but it is not known if this rate translates to branches. Frederick et al. (2001) found that branch elongation was greatest between the R1 and R5 growth stages. As the number of branches increased, branch dry matter, branch nodes, branch reproductive nodes, and branch pods increased by 162%, 135%, 154%, 189%, respectively in 17 plants m^{-2} vs. 41 plants m^{-2} in Louisiana (Carpenter and Board 1997). Branch dry matter increased up to 41% with 50-cm row spacing compared to 100-cm row spacing (Board et al. 1990). Board et al. (1990) also found yield increases at an early planting date from 18-57% due to increased branch yield components and narrow row spacing. Branch seed yield was greatest under irrigated conditions (Frederick et al. 2001). Norsworthy and Shipe (2005) found that branch yield accounted for 14-57% of total seed yield in 19 cm rows, and 47-74% of total seed yield in 97 cm rows.

By planting soybean in rows narrower than 76 cm, yield may be maximized. Yield with 25-cm compared with 100-cm row spacing was 17% higher (Taylor 1980). Cooper (1977) found a 10 to 20% yield advantage from planting soybeans in 17-cm row spacing compared with 50-cm and 75-cm row spacing at the 0.05 level. Seed yield was 10% higher in 25- and 51-cm rows than in 76-cm rows (Ethredge et al. 1989). Costa et al. (1980) concluded that seed yield in 27-cm rows vs. 76-cm rows had a 21% increase. Yield increases can be attributed to a greater leaf area index (LAI) in narrow compared to wide rows (Harder et al. 2007). Soybean grown in 23- compared with 46-cm rows had 15 and 30% more LAI and 100 and 290 kg ha^{-1} more yield in low and medium drought stress environments, respectively, in Virginia (Holshouser and Whittaker 2002). With a greater LAI, more radiation is intercepted resulting in more photosynthesis (Lambert and Lowenberg-De-Boer 2003). Increasing plant population in narrow row spacing resulted in fewer branches and increased lodging, seed weight, and LAI in 10 varieties (Costa et al. 1980). Benefits of narrow row spacing also included less weed emergence in narrow rows following glyphosate application (Harder et al. 2007).

Utilizing lactofen to induce branching in a narrow row soybean may provide a framework to maximize yield. We hypothesize that lactofen application during the vegetative growth stages will induce branching and combined with planting in 19-cm rows, yield will be maximized. The objectives of this study were to quantify branching inducement through lactofen application and to determine the most effective rate and application timing.

Materials and Methods

A field study was conducted in 2011 at the West Central Research and Extension Center (WCREC) located in North Platte, Ne (41° 5'16"N 100°46'38"W) on a Cozad silt loam soil (coarse-silty, mixed, mesic, Typic Haplustolls) and the West Central Water Resource Field Laboratory (WCWRFL) located near Brule, Ne (41° 9'48"N 102° 1'56"W) on a Kuma loam soil (fine-silty, mixed, mesic, Pachic Argiustolls). The elevation was 853 m and 1113 m at the WCREC and WCWRFL, respectively. Both locations were in no till soybean corn rotation for four to six years.

The experiment was a split-plot randomized complete block design. The main plot was 3 x 9 m and planted at 37.1 seeds m^{-2}. The split-plot was 1.5 x 9 m and was planted in 19- and 38-cm rows with four replications at each location. The 19- and 38-cm row spacings were planted in strips and not randomized. The main plot was randomized. Lactofen (Cobra, Valent USA Corporation, Walnut Creek, California) was applied to the main plot at application timings of V1, V3, or V5 at rates of 35, 70, 140, and 210 g ai ha^{-1} with an added check, using a backpack sprayer with a spray width of 3 m using Teejet TT11003 nozzles at 207 kPa.

Syngenta S25-R3 a maturity group 2.5 cultivar was planted in Brule. AsGrow AG-2831 a maturity group 2.8 cultivar was planted in North Platte. Planting took place on May 3 and May 4, 2011 in Brule and North Platte, respectively with a Kincaid plot drill with Crustbuster All Plant Openers (CrustBuster/ Speed King, Inc., Dodge City, Kansas) installed. Seed was treated with BioForge ST (Stoller USA, Houston Texas) at 1.30 ml kg^{-1} of seed and planted to a depth of 4.5 cm. Visual estimations of crop injury compared to a non-treated check were recorded at 7, 14, and 21 days after application to determine crop injury and recovery and to determine if branching had been initiated.

In order to control weeds, a post-emergence application of glyphosate (Roundup PowerMax, Monsanto Company, St. Louis, Missouri) and saflufenacil (Sharpen, BASF Corporation Research Triangle Park, North Carolina) was applied on June 1, 2011 at rates of 2.6 kg acid equivalent (ae) ha^{-1} and 0.075 kg ai ha^{-1}, respectively, in North Platte. Glyphosate and clethodim (Select Max, Valent U.S.A. Corporation, Walnut Creek, California) were applied on June 28, 2011 at rates of 2,600 g ae ha^{-1} and 153 g ai ha^{-1}, respectively, in North Platte. Glyphosate was applied at 2,602 g ae ha^{-1} on May 9, June, 27, and July 12, 2011 in Brule. Clethodim was applied at 153 g ai ha^{-1} on June 27, 2011 in Brule.

One day prior to soybean harvest, five plants were taken from each plot and data was taken on branches plant^{-1}, pods plant^{-1}, seeds plant^{-1}, seed mass and seeds m^{-2}. Plots were harvested with a Kincaid 8XP (Kincaid Equipment Manufacturing, Haven, Kansas) plot combine. The harvest width was 1.52 m, or eight 19 cm rows and four 38 cm rows. Seed yield was adjusted to 13% seed water content with the following formula:

$$Y = \left(\frac{\left(weight * \left(1 - \left(\frac{moisture}{100}\right)\right)\right)}{dry\ matter}\right) * \left(\frac{10{,}000m}{plot\ area}\right).$$

Data was analyzed using PROC GLIMMIX is SAS (SAS version 9.2, SAS Institute, Cary, NC). Prior to final analysis, tests for normality were conducted. Location was treated as a random effect in the analysis. Mean comparisons were made using Dunnett's adjustment in the lsmeans statement in PROC GLIMMIX with an alpha level set at 0.05 for all comparisons.

Results and Discussion

Precipitation was with 479 and 294 mm during the growing season at the WCREC and WCWRFL, respectively. Irrigation was 321 and 133, respectively, at the WCWRFL and the WCREC with 52% and 62% applied during the reproductive stages. Monthly average high and low temperatures had little variation at both locations (Table 4.1).

Lactofen application timing and rate had no effects on seed despite causing injury to the plant canopy (Table 4.3). Highest injury was seen at V3 with a rate of 210 g ai ha^{-1}

at 7 days after application (DAA), also at V1 and V5 the highest percent injury to the plant canopy was seen with the 210 g ai ha^{-1} rate (Table 4.4). Lowest injury was seen at V5 with an application rate of 35 g ai ha^{-1}. Across all application timings and rates, the plant canopy showed no symptoms of injury based on visual estimation 21 DAA. Witchert and Talbert (1993) also saw that no yield increases were seen with applications of lactofen at V2-3. Yield was not increased or decreased with application of lactofen; further research in this area could focus on the effects of lactofen at higher use rates and/or at soybean reproductive growth stages.

Lactofen did affect 100-seed wt., but not on branching (Table 4.2). 100-seed wt. was 6% lower at an application of 210 g ai at V5 compared to 35 g ai at V1 (Table 4.3). This reduction in 100-seed wt. did not result in yield loss. Insufficient research has been done investigating the effects of lactofen on yield components. Future research in this area could focus on lactofen's effects on yield components. Soybean growth stages were not affected by lactofen application.

Conclusions

Lactofen application under these circumstances was not an effective way to initiate branching in soybean. Lactofen may still be useful as a branching agent because yield was not decreased with applications at V1, V3, and V5. Branching may be possible at higher application rates of lactofen or at different application timings, and future research should focus on this area.

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Table 4.1. Monthly irrigation, precipitation, and temperature recorded at the WCREC† and the WCWRFL‡ in 2011 during the growing season.

Location	Year	Month	Precipitation	Irrigation	Average temperature (C)	
			———mm———		High	Low
WCREC	2011	May	140	0	20	6
		June	85	0	27	13
		July	99	33	32	18
		August	54	83	31	16
		September	24	17	25	5
WCWRFL	2011	May	77	0	20	4
		June	43	39	28	12
		July	86	38	33	18
		August	53	168	32	16
		September	35	76	26	8

† The WCREC is located in North Platte, NE.

‡ The WCWRFL is located near Brule, NE.

Table 4.2. Seed yield, seed mass, pods plant^{-1}, seeds plant^{-1}, seeds m^{-2}, and branches plant^{-1} analysis of variance for lactofen application at the WCREC and WCWRFL in 2011.

Effect	df	Yield	Seed mass	Pods plant^{-1}	Seeds plant^{-1}	Seeds m^{-2}	Branches plant^{-1}
Lactofen (l)	12	NS	*	NS	NS	NS	NS

* Indicates significant using Dunnett's adjustment at $P \leq 0.05$.

NS Indicates non-significance at $P \leq 0.05$.

† The WCREC is located in North Platte, NE

‡ The WCWRFL is located near Brule, NE

Table 4.3. Main effects for seed yield and components in west central Nebraska 2011.

Main effects	Seed yield	Seed mass	Pods plant^{-1}	Seeds plant^{-1}	Seeds m^{-2}	Branches plants^{-1}
Location	kg ha^{-1}	g 100 seeds^{-1}				
WCREC‡	4,796	16.9	30.4	102	4,603	2.3
WCWRFL§	5,985	15.7	51.2	106	5,581	4.7
Treatment						
Check	5,483	16.3 abcd	39	98	4,694	3.8
V1, 35 g ai	5,373	16.7 a	47	112	5,166	3.8
V1, 70 g ai	5,342	16.5 abc	40	104	5,100	3.6
V1, 140 g ai	5,420	16.6 ab	41	109	5,189	3.8
V1, 210 g ai	5,484	16.6 ab	35	96	4,636	3.5
V3, 35 g ai	5,462	16.5 abcd	39	102	5,029	3.3
V3, 70 g ai	5,549	16.7 a	34	91	4,679	3.3
V3, 140 g ai	5,353	16.1 abcd	41	108	5,477	3.5
V3, 210 g ai	5,281	16.6 ab	49	120	5,547	3.9
V5, 35 g ai	5,247	15.9 cd	43	110	4,942	3.6
V5, 70 g ai	5,308	16.0 bdc	44	111	5,487	3.5
V5, 140 g ai	5,352	16.1 abcd	41	106	5,243	3.4
V5, 210 g ai	5,429	15.7 d	37	86	5,005	3.1

† Values followed by the same letter are not significantly different at $P \leq 0.05$.

‡ The WCREC is located in North Platte, NE.

§ The WCWRFL is located near Brule, NE.

Table 4.4. Percent of irrigated soybean plant canopy injured by lactofen application at 7, 14, and 21 days after application (DAA) at three growth stages and four rates in west central Nebraska in 2011 averaged across two locations.

Timing	Rate	7 DAA	14 DAA	21 DAA
	g ai ha^{-1}		% visual injury estimation	
Check	0	0	0	0
V1	35	25	11	0
	70	38	19	0
	140	37	20	0
	210	44	29	0
V3	35	16	7	0
	70	20	11	0
	140	28	15	0
	210	46	19	0
V5	35	13	8	0
	70	29	11	0
	140	33	15	0
	210	40	11	0

Appendix

Table A.1. Seed yield, seed mass, seeds plant^{-1}, and seeds m^{-2} analysis of variance for year, site, row spacing, planted population, and fungicide application at the WCREC and WCWRFL in 2011 and 2012.

Effect	df	Yield	Seed mass	Seeds plant^{-1}	Seeds m^{-2}
Year (y)	1	***	***	***	***
Site (s)	1	***	***	***	***
Population (p)	2	***	*	***	***
Fungicide (f)	7	NS	NS	NS	NS
y*s	1	***	***	***	***
y*p	2	NS	*	***	***
s*p	2	*	NS	***	**
y*s*p	2	NS	NS	***	NS
y*f	7	NS	NS	NS	NS
s*f	7	NS	NS	NS	NS
y*s*f	7	NS	NS	NS	NS
p*f	14	NS	NS	NS	NS
y*p*f	14	NS	NS	NS	NS
s*p*f	14	NS	NS	NS	NS
y*s*p*f	14	NS	NS	NS	NS

* Indicates significance at the $P \leq 0.05$.

** Indicates significance at the $P \leq 0.01$.

*** Indicates significance at the $P \leq 0.001$.

NS Indicates non-significance at the $P \leq 0.05$.

‡ The WCREC is located at North Platte, NE

§The WCWRFL is located near Brule, NE

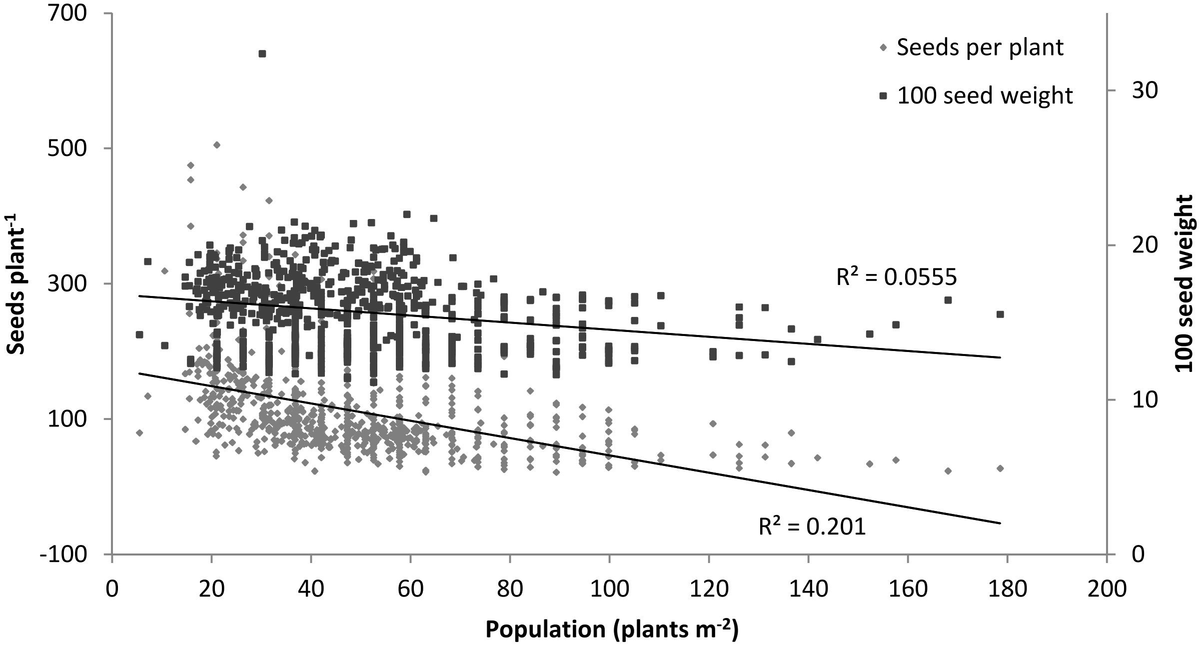

Figure A.1. Regression of seeds plant^{-1} ($y = -1.28x + 174.5$) and 100 seed weight ($y = -0.023x + 16.8$) against plant population from samples taken from the WCREC and the WCWRFL in 2011 and 2012.

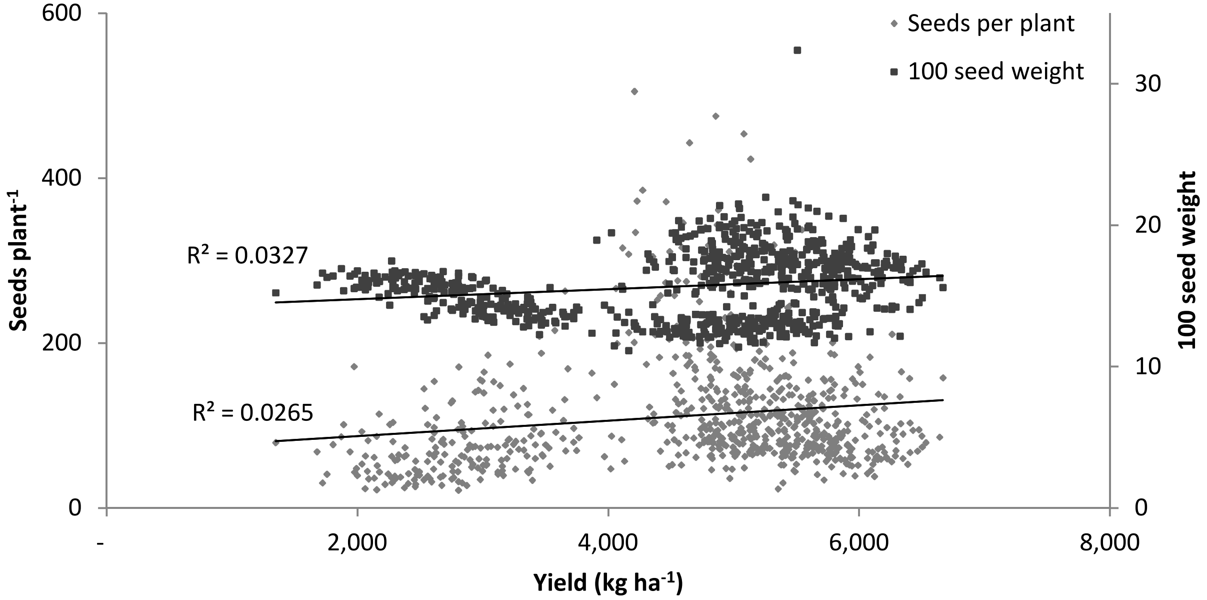

Figure A.2. Regression of seeds plant^{-1} ($y = 0.0093x + 68.6$) and 100 seed weight ($y = 0.0004x + 14.05$) against yield from samples taken from the WCREC and the WCWRFL in 2011 and 2012.

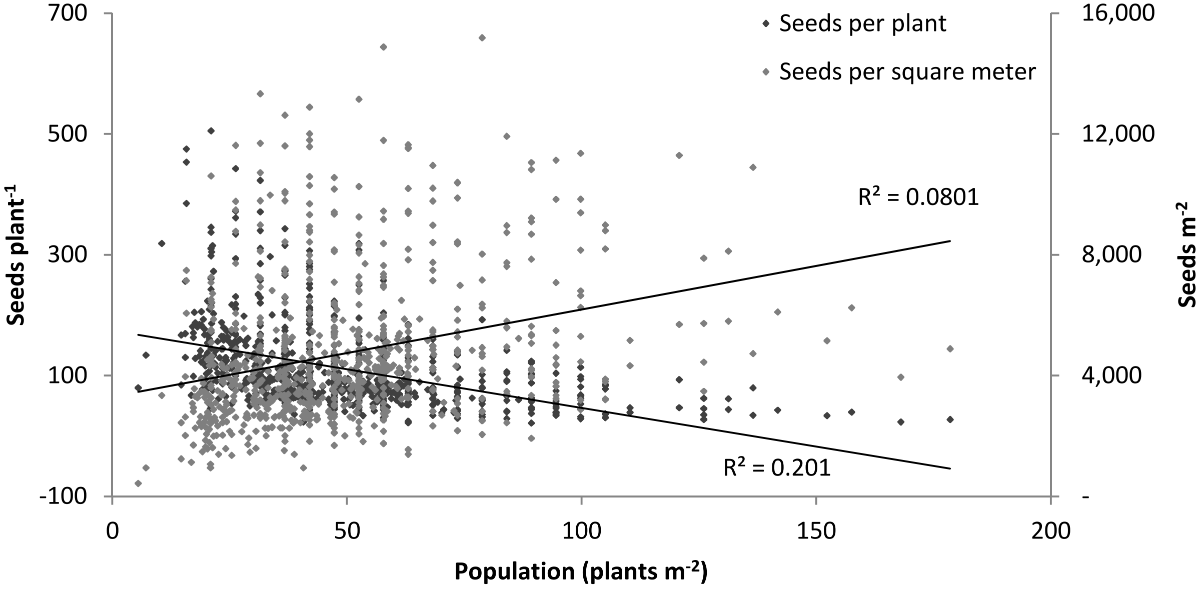

Figure A.3. Regression of seeds plant^{-1} ($y = -1.28x + 174.5$) and seeds m^{-2} ($y = 28.8x + 3308$) against plant population from samples taken at the WCREC and the WCWRFL in 2011 and 2012.

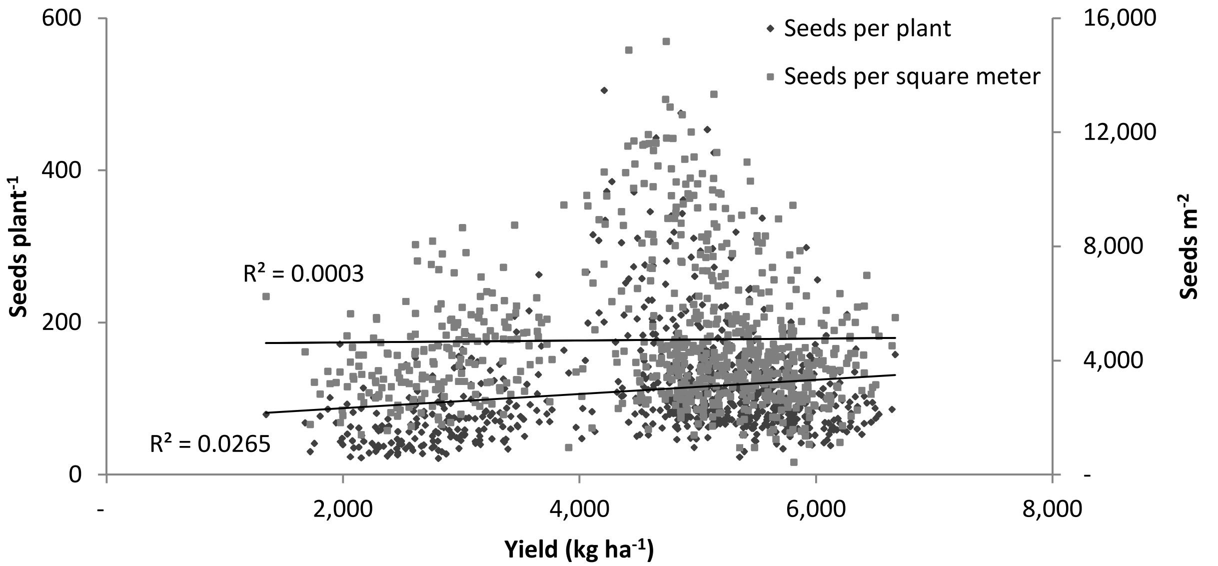

Figure A.4. Regression of seed yield components taken from samples collected at the WCREC and the WCWRFL in 2011 and 2012 to determine yield relationships between seeds plant^{-1} ($y = 0.0093x + 68.6$) and seeds m^{-2} ($y = 0.033x + 4563$) against seed yield.