SEEDING DATE, MATURITY RATING, AND LOCATION INFLUENCE ON SOYBEAN (*GLYCINE MAX L. (MERR.))* PERFORMANCE AND PHENOLOGY IN EASTERN NORTH DAKOTA

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MASTER OF SCIENCE

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ABSTRACT

In North Dakota, soybean is typically planted in mid to late May; however, a late spring frost or flooding event may cause a grower to plant late, or replant their crop. The objective of this research was to determine the influence of seeding date, cultivar maturity rating (CMR), and environment on the growth and development of soybean. Six seeding dates were established from 23 May to 9 July using soybean CMR of 00.9, 0.7, and 1.4 at Carrington, Prosper, and Lisbon, ND. The experimental design was a randomized complete block with a 6x3 factorial. The interaction of date by CMR indicated that yield decreased as seeding was delayed further into the growing season with yields becoming less than economical in soybean seeded after 22 June. Soybean with CMR of 00.9 and 0.7 are best suited for delayed seeding in North Dakota, while CMR 1.4 rapidly loses yield with delayed seeding.

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INTRODUCTION AND JUSTIFICATION

In North Dakota, soybean is typically planted after the threat of spring frost has passed in mid to late May and is harvested in either October, or November. Production in North Dakota continues to increase every year with the total area planted in 2015 equaling 2.3 million hectares (NASS 2015). This growth in production increases the amount of information that growers require to help them obtain maximum yields and higher profits.

Soybean is very dependent on photoperiod length throughout the growing season when it comes to the overall development of the plant, especially when it comes time to initiate reproduction. Soybean is also very susceptible to extreme temperatures, both hot and cold, and the different temperature regimes that exist all across North Dakota put forth the question of what maturity ratings can perform better at different locations. These vulnerabilities pose a threat to the overall yield of soybean if it were planted too early or late, or when reseeding in the event of late spring frost or early season flooding. Determining how the soybean growth, development, and yield are affected by different temperature and moisture profiles, in both terms of precipitation and soil water holding capacity, and at different seeding dates could provide growers in North Dakota with helpful information to make the decision of when to plant or replant their soybean crop.

LITERATURE REVIEW

Soybean

Soybean (*Glycine max L.* Merr.) is a dicotyledonous annual legume that is grown in many crop growing areas of the world and is used in a wide variety of products ranging from food and oils, both edible and industrial, to plastics and biodiesel. Domestication of the soybean plant originated in southeastern China where it has been cultivated for millennia and is an important staple in their everyday diet. Soybean acreage started to increase in the United States (US) around 1880 as a minor forage crop in the Corn Belt region of Indiana, Illinois, Iowa, Minnesota, Ohio, and along the Mississippi River Delta. By 1920, soybean in the US was approaching 4 million hectares, but only 20% was actually harvested for grain (Rather 1942). The total amount of US soybean acreage has grown from 4.5 million hectares in 1940 to 34.4 million hectares in 2015 (NASS 2015).

Soybean has two types of growth habits; determinate and indeterminate. Determinate cultivars stop vegetative growth once flowering begins on the main stem, whereas indeterminate cultivars continue vegetative growth until the plant gets close to physiological maturity and begins to dry down. Determinate cultivars are typically grown in Japan, Korea, and the southern United States, while indeterminate cultivars are primarily grown in northeast China and northern areas of the US (Beaver and Johnson 1981).

Maturity ratings

All soybean cultivars are placed into one of 12 different maturity ratings based on the number of days it takes the plant to reach physiological maturity. These range anywhere from Group 000, which is grown in southern Canada, to Group 9 that is grown in Florida and parts of southern Texas (Clemson 1993). These groups are further divided by decimal places to indicate the maturity ratings within a group. For example, a 1.4 maturity rating is an early group 1 cultivar, whereas a 1.9 is a later group 1 cultivar and will take more calendar days to reach physiological maturity. The decision about which maturity rating to plant is based heavily on growing season length, temperature regimes, and moisture availability in a grower's specific region. In North Dakota, most growers will choose a cultivar in group 000, group 00, group 0, or group 1 due to the ability of these maturity groups to perform well given in the short growing season seen in North Dakota (Kandel 2013).

Boerma (1979) performed an experiment regarding the growth and development of soybean in Athens, GA, from selected cultivars in maturity ratings 6, 7, and 8 to see if any difference was noticed in yield, pods m^{-1}, seeds pod^{-1}, nodes $plant^{-1}$, seedless pods m^{-1}, and plant height. Three rows of each cultivar were in plots that measured 5.8 m in length with rows spaced 0.96 m apart. The seeding rate was 26 viable seeds m^{-1} and all assessments were taken from a 1-meter section in the middle row of the plot. Results indicated that the later maturing soybean cultivars had more nodes $plant^{-1}$, pods m^{-1}, and were taller than their earlier maturity rating cultivars. However, the total yield and amount of seedless pods m^{-1} were similar among maturity ratings. Boerma stated that genetic improvements in the seed yield had been accomplished through hybridization and selection of cultivars in the 30 years prior to the study, but no statistical difference in yield was observed between the different maturity ratings.

The idea amongst growers is that later maturing cultivars can produce higher yield due to the longer amount of time it takes for the plants to mature. Boerma's research indicates that this idea may not always be true given the environment in which a grower is planting soybean. Maturity ratings that are close enough to be grown in the same area do not necessarily outperform each other when it comes to the total yield obtained.

Seeding Dates

Early seeding dates are recommended for growers across all regions where soybean is grown. In North Dakota, the recommended seeding date for soybean is in the middle of May in order to optimize yield (Kandel 2013).

Feaster (1949) conducted research to study the effect of seeding dates on yield, seed quality, and chemical composition, of the seed, in southeastern Missouri. It was reported that the interaction of date by cultivar was highly significant for three of the four years the study was conducted. The one year, 1945, in which the interaction was not significant was attributed to the lack of a hot, dry period that caused an increase in the total yield observed across all dates and cultivars with early maturing cultivars having twice the yield compared to the 1942-1944 averages. The three-way interaction of cultivar by date by year was not significant.

The cultivars used in the study were Ralsoy, S-100, Boone, Chief, and Dunfield and had rated maturities in calendar days if planted at Sikeston, MO, on 1 June of 137, 124, 117, 109, and 100, respectively. Seeding dates for this study were 20 April, 10 May, 1 June, 20 June, and 10 July. Feaster's (1949) findings indicated that the optimum time for seeding at this location was during a period between 10 May and 20 June to achieve the highest yield, because soybean bloom and seed development for these two seeding dates occurs after the hot and dry period typically experienced in the month of July. Conversely, early planted soybean cultivars that began blooming during the period of hot and dry weather in July. Soybean planted on 10 July had the lowest yield due to the short amount of time it took to for the plant reach maturity, as well as the warmer temperatures it experienced early on in its growth. Soybean planted on 10 July had fewer days from planting to flowering than earlier planting dates. The decreased vegetative period, due to the 10 July planting date, resulted in the lowest yield of all planting dates. Feaster also noted that the days to plant maturity decreased with delayed seeding across all cultivars, but more so in the early maturing cultivars. Plant maturity for this particular study was noted as the time when most of the leaves had dropped, most of the pods were ripe, and the stems were fairly dry. This would be comparable to stage R7 in our modern staging system. Feaster attributed the decrease in time to maturity to the decrease in overall day length during the late summer and fall.

Osler and Carter (1954) conducted a study that utilized a mixture of short season cultivars and long season cultivars: Blackhawk, Hawkeye, Adams, Lincoln, Clark, Wabash, Perry, and an experimental line (L6-5679). They reported long season cultivars typically achieved the highest yield when they were planted early in the growing season around 1 May while short season cultivars had better yield when planted later around 15 May. These results were similar to those of Feaster (1949). Osler and Carter stated that short season cultivars possessed the ability to be less affected, in terms of yield loss, by delayed seeding than long season cultivars. On average, the short season cultivars had higher yields, seed weight, protein, and oil content as well as less lodging, and had a less dramatic decrease in plant height compared to the long season cultivars. With each successive seeding date, there was a drop in yield, greater degree of lodging, lower plant heights, and a decrease in seed oil content. The study found that the interaction of cultivar by date was significant and possibly caused from different temperatures occurring during critical periods of plant development.

In Kentucky, Hatfield and Egli (1974) conducted a study to investigate the effect of temperature on hypocotyl emergence of soybean. These were then placed into various chambers of 10°, 15°, 20°, 25°, 30°, 35°, 37°, and 40°C. Cultivars included Cutler and Lee 68 and all seeds were hand selected to be as uniform in size as possible with no visible damage. Measurements of the hypocotyl were taken every 12 hours until a length of 6 cm maximum which is greater than the recommended seeding depth of 3.8 cm for soybean. Results showed that the optimum temperature for rapid hypocotyl emergence of soybean was between 25° and 35°C. Time to 50% emergence at 30°C was around 100 hours. Soybean seed kept at 10°C were extremely slow to emerge and seeds at 40°C died from excessive heat, illustrating the effect of temperature extremes on soybean. This study provided some insight into the effect of soil temperature and how it affects soybean emergence at different seeding dates. Emergence can be effected by cooler soil temperatures typically seen at the early seeding dates and hotter temperatures at later dates, which would be detrimental to stand establishment. If the seeds were left in the soil too long during cooler temperatures they would rot before they emerge due to the lack of heat units, but if the soil temperature is too hot then the embryo could become permanently damaged and not germinate.

Beaver and Johnson (1981) examined the effects of seeding date on both determinate, and indeterminate growth types of soybean. Research was conducted at Urbana, Illinois with cultivars Gnome (maturity rating II determinate), Elf (maturity rating III determinate), Beeson (maturity rating II indeterminate), and Williams (maturity rating III indeterminate). Average seeding dates across all three years were 13 May, 23 May, 4 June, 18 June, and 6 July. Both determinate and indeterminate cultivars yielded similarly across all seeding dates with the authors noting a 33% decrease in yield as the seeding dates progressed from early May to early July. Regression analysis indicated the determinate cultivars did not show a yield loss until seeding was delayed past the early June seeding dates and decreased in a quadratic fashion. This is compared to the yield for indeterminate cultivars in which yield decreased linearly after each successive seeding date.

Parker et. al (1981) conducted trials in Georgia to determine the effect of seeding date on yield and seed weight using four different cultivars and seven different seeding dates. Seeding dates were 7 April, 22 April, 7 May, 25 May, 7 June, 23 June, and 8 July and the cultivars were Essex (maturity rating 5), Davis (maturity rating 6), Bragg (maturity rating 7), and Hutton (maturity rating 8). The researchers found that the interaction of seeding date by cultivar was significant for yield in all three years of the study. Soybean yield was consistently highest in the seeding dates from late April to early June, with early July having the lowest average yield across the three years. Soybean yield increased from early April to late April, which was attributed to cooler air and soil temperatures that are typically seen at that time of the year. The heaviest seed was obtained from the late May and early June seeding dates with the cultivar Hutton (maturity rating 8) being less affected by the change in seeding dates than the other three cultivars.

Lussenden (1987) conducted research trials in Fargo and Casselton, ND, during the 1985 and 1986 growing seasons. The cultivars used in the study were Maple Amber (maturity rating 00), McCall (maturity rating 00), and Ozzie (maturity rating 0). The soybean cultivars were planted on 21 May, 28 May, 3 June, 10 June, and 17 June in both years. Results indicated that seeding date had a significant effect on the accumulated heat units necessary to reach 50% emergence, the days to reach maturity, and yield. All three soybean cultivars took fewer heat units to reach 50% emergence at the later seeding dates than the earlier dates. The author stated that this could be attributed to warmer soil temperatures at the time of seeding which can help speed up the process of germination allowing for quicker soybean emergence. This is congruent with the findings made by Hatfield and Egli (1974). Maturity was defined as the days after seeding date required to reach 95% maturity which would be growth stage R8 in the modern soybean staging system. Ozzie was the latest maturing and Maple Amber was the earliest maturing, with the range among cultivars being 20 days and 13 days for the 21 May and 17 June seeding dates, respectively.

Lussenden (1987) also noted that delayed seeding date reduced the overall seed yield of soybean across all cultivars especially when seeding was delayed until after 3 June. The mean yield averaged across all cultivars for the first seeding date was 2% higher than the second date, 3% higher than the third date, 13% higher than the fourth date, and 26% higher than the fifth date. This shows soybean at the first, second, and third seeding dates produced similar yields that were greater than later seeding dates where yield was lower at date five than date four. The fourth date was significantly lower than the first three dates and the fifth date was significantly lower than the fourth date. Ozzie produced the highest yields, especially in the early seeding dates while Maple Amber produced the lowest yield. This was evident at all but the final seeding date where Ozzie produced the lowest yield at 2271 kg ha^{-1} compared to McCall which had the highest yield of 2406 kg ha^{-1} at the final seeding date.

Similar to the study conducted by Lussenden, Halvorson (1994) conducted trials in 1991 and 1992 to evaluate the effects of different seeding dates and fall freeze date on soybean yield and reproductive stages. The study was conducted at Casselton and Lisbon, ND, in 1991, and Casselton, Lisbon, and Great Bend in 1992. The four cultivars chosen were Dawson (maturity rating 0), Glenwood (maturity rating 0), Kasota (maturity rating 1), and Sturdy (maturity rating 2) with Dawson and Glenwood being adapted for growth in North Dakota while Kasota and Sturdy are typically grown in warmer climates with longer growing seasons. Seeding dates were set 10 to 14 days apart with mean seeding dates for all locations across both years being 8 May, 21 May, and 2 June. Two simulated freeze dates and one natural freeze date were also applied at one-week intervals with the mean freezing dates being 6 Sept., 14 Sept., and 21 Sept when averaged across years. Fall freeze was simulated using an application of gramoxone (Paraquat®[1]) at a rate of 0.56 kg ai ha^{-1}.

Halvorson (1994) averaged yield across all cultivars at each location and there was no difference seen in the yield obtained from any of the seeding dates, cultivars, and freeze dates at both locations in the 1991 growing season. Yields at Casselton, for example, were 1790 kg ha^{-1} on the 6 Sept. freeze date and 1760 kg ha^{-1} on 21 Sept. However, in 1992 there was a yield difference reported with the 6 Sept. freeze date at Casselton having a yield of 1010 kg ha^{-1}, whereas the 21 Sept. freeze date at Casselton had a yield of 2040 kg ha^{-1}. The author noted that 1992 had lower than normal temperatures during the summer, which ultimately led to fewer growing degree days. This caused the soybean to be in less mature reproductive stages at the time of freezing especially with later maturity rating cultivars, Kasota and Sturdy. Results of this study were consistent with results of Lussenden (1987), show yield losses are expected with later seeding dates especially in the later maturing soybean groups because the accumulated growing degree days between seeding and the end of the season are not adequate before a killing freeze.

Kahn (2007) conducted research on the effects of soybean seeding dates at the Agricultural University Peshawar, Pakistan, during the 2000 and 2001 growing seasons. This study involved four different seeding dates, which were 1 May, 1 June, 1 July, and 1 August, to determine the effect on seed yield and plant development. Soybean cultivars chosen for this study were Epps (maturity rating 5, determinate) and Williams 82 (maturity rating 3, indeterminate). The results of the study showed that the change in seeding dates created significant differences in the amount of dry seed weight of 50 randomly selected pods in each treatment. The pods were then kept in a paper bag and dried down to 12-15% moisture after

[1] Syngenta Crop Protection, Inc. PO Box 18300 Greensboro, NC, 27419-8300

which they were weighed. The earliest date had the greatest amount of dry seed weight and then declined with each successive seeding. Decreases in the amount of dry seed weight stem from two different temperature sources. The first was the high temperatures observed during the development of the plant. These temperatures typically lead to drought stress, which lead to a decrease in the overall leaf area and a decrease in respiration rates. The second was the low temperatures and shorter photoperiod for photosynthesis during the reproductive stages, particularly when the pods were filling, which is a crucial time for the plants in producing good yields.

Bajaj et al. (2008) looked into the effects of different seeding dates on soybean cultivars from maturity ratings 00, 1, 3, and 4 grown in Arkansas. Their study was planted in April, to represent an early season seeding, May, to represent typical full-season production, and June, to represent a double-cropping system. Their research found that seeding date had a significant effect on seed yield with May seeding having the highest yield at 2972 kg ha^{-1}, April having a 12% drop to 2646 kg ha^{-1}, and June having a 49% drop from the May seeding date to 1998 kg ha^{-1}.

Researchers at the Sakha Research Station in Kafr El-Sheikh, Egypt (Kandil 2013) found that significant differences appeared in seed, seed oil content, and protein yields ha^{-1} with soybean that was planted on different dates. Cultivars chosen for this study were Giza 21 (maturity rating 4), Giza 22 (maturity rating 4), Giza 111 (maturity rating 4), H_2L_{12} (maturity rating 4), H_{30} (maturity rating 3), and H_{32} (maturity rating 4). The seeding dates for soybean were 20 April, 5 May, 20 May, and 5 June. Unlike a majority of the other studies, the earliest seeding date in this study did not produce the highest amount of yield. Soybean harvested from the 5 May seeding date had the highest amounts of seed, oil, and protein yield ha^{-1}. This decrease in the total seed yield ha^{-1} for the later seeding dates was attributed to the increase in temperatures around the time of reproductive growth stages in the soybean, which lead to increased stress at a time when the plant needs to accumulate nutrients in order to adequately fill the seed pods. Warmer temperatures in the R5 and R6 growth stages also enhanced the oil content in the soybean, but led to a decrease in the overall protein content.

The main result amongst all these articles was that delayed seeding often results in a decrease in yield. This decrease in yield could come from a variety of different components that all come together to form yield. A grower could expect to have a decrease in the total plants $hectare^{-1}$, pods $plant^{-1}$, seeds pod^{-1}, or seed weight, which could be due to a lack of growing degree days that help a soybean plant reach physiological maturity, an early frost that kills a plant during the seed filling stages, or higher than normal temperatures during reproductive development. Establishing an optimal seeding date for our area will provide evidence that will help to inform growers when it is too late to plant soybean and could prove to be very beneficial in helping them obtain higher yields and profits.

OBJECTIVES

I. Determine the influence of cultivar maturity rating on soybean yield.

II. Determine the influence of seeding date on soybean yield.

III. Determine the influence of location on soybean yield, growth and development.

IV. Determine the influence of calendar days and growing degree days on cultivar phenology.

MATERIALS AND METHODS

Field experiments to evaluate soybean performance were conducted in 2014 and 2015 near Prosper (46 58’ N, 97 4’ W, elevation 220 m), Lisbon (46 26’ N, 97 50’ W, elevation 407 m), and Carrington, ND (47 30 N, 99 08’ W, elevation 489 m). Soils at Prosper are a complex of Beardon (fine-silty, mixed, superactive, frigid Aeric Calciaquolls) and Perella (fine-silty, mixed, superactive, frigid Typic Endoaquolls). Soils at Lisbon are a complex of Barnes (fine-loamy, mixed, Pachic Udic Haploborolls) and Svea (fine-loamy, mixed, superactive, Pachic Udic Haploborolls). Soils at Carrington are a complex of Heimdahl (coarse-loamy, mixed Udic Haploborolls) and Emrick (coarse-loamy, mixed Pachic Udic Haploborolls) (Web Soil Survey 2016). The previous crop at the Carrington and Prosper locations was hard red spring wheat (*Triticum aestivum* L.) (HRSW) in both 2014 and 2015, while the previous crop at Lisbon was corn (*Zea mays* L.) in 2014 and 2015.

Each experiment was arranged in a randomized complete block design (RCBD), with four replicates. The factorial arrangement of treatments included six seeding dates and three cultivars. The three cultivars that were chosen have different maturity cultivar ratings (CMR), which included: AG00932 (Asgrow, 00.9 CMR), 90Y70 (Pioneer, 0.7 CMR), and 91Y41 (Pioneer, 1.4 CMR). In 2015 the three cultivars were AG00932 (Asgrow, 00.9 CMR), 90Y70 (Pioneer, 0.7 CMR), and 14T52R2 (Pioneer, 1.4 CMR). All three cultivars are glyphosate resistant. The change in cultivar from 91Y41 to 14T52R2 was due to the phasing out of 91Y41 by Pioneer in 2015 and because of this we were unable to obtain that same cultivar. The cultivars, 91Y41 and 14T52R2, share the same maturity rating, which is one of the key treatment factors. Because of the similarity between the different cultivars in regards to their maturity rating, the soybean cultivars were selected to be an accurate representation of soybean production in eastern North Dakota. Each experimental unit (plot) measured 1.8 meters wide and 7.6 meters in length with each plot consisting of six rows spaced 30.5 cm apart and a targeted established plant population of 494,000 plants ha^{-1}.

The six different seeding dates were at 10-12 day intervals from May 10 to July 10 (Table 1). Growth stages were determined based on Endres and Kandel (2015), and determined when seeding the next date. For example, the growth stage for the first seeding date was taken when the second date was seeded, then the first and second seeding date growth stages were taken when the third date was seeded, and so on. After the final seeding date (date 6), each location was visited on a weekly basis at which time the growth stage of each plot was determined. Growth stages were recorded starting at emergence (VE) and end at full maturity (R8), or the current growth stage of the soybean in the event of a terminating frost. Growth stages were recorded for each plot by selecting a uniform stand area in the middle four rows of the plot and determining whether or not 50% of the soybean plants were at a specific growth stage. There were some instances in which the soybean did not have a stage V5 or did not reach stage R7. In those cases, the data was analyzed as an unbalanced data set and there are multiple LSDs to compare the means between seeding dates.

Environment is defined as a single location in a single year, which results in six total environments, three in 2014 and three in 2015. The Carrington 2015 environment was removed from the combined analysis due to the poor data acquired from this environment caused by whitetail deer (*Odocoileus virginianus* Z.) predation and an outbreak of stem canker (*Diaporthe phaseolorum* Sacc.), which is why there are only two environments in 2015 instead of three as planned. Grain yield, growth stage, 1000 seed weight, seed oil content, plant height, and plant lodging data were obtained from soybean plants in the central four rows of each plot. Seeding and harvest dates are shown in Table 1. Lodging was rated using a scale of 0 to 9 where 0 indicates no lodging, and 9 indicates that all plants were flat on the ground.

Table 1. Seeding and harvest dates for five environments at Carrington, Lisbon, and Prosper, ND, during 2014 and 2015.

Environment	Seeding dates						Harvest dates
	Date 1	Date 2	Date 3	Date 4	Date 5	Date 6	
Carrington 2014	23 May	4 June	13 June	23 June	3 July	10 July	21 Oct
Lisbon 2014	22 May	3 June	10 June	23 June	2 July	9 July	22 Oct
Lisbon 2015	23 May	1 June	10 June	23 June	30 June	9 July	29 Oct
Prosper 2014	28 May	4 June	13 June	23 June	2 July	9 July	20 Oct†, 24 Oct
Prosper 2015	22 May	1 June	10 June	19 June	30 June	10 July	2 Nov
Average	23 May	2 June	11 June	22 June	1 July	9 July	24 Oct

†Soybean seeded at date 1 were harvested on 20 Oct; other seeding dates were harvested 24 Oct
‡Killing frost is the date at which the temperature reached 30 degrees for 3 hours

If a plant terminating frost occurred before harvest of the plots, five single, consecutive, above ground portions of the soybean plants were harvested from one of the four middle rows in each plot to calculate total biomass, seeds plant^{-1}, seed yield plant^{-1}, harvest index, nodes plant^{-1}, total pods plant^{-1}, filled pods plant^{-1}, unfilled pods plant^{-1}, seeds pod^{-1}, and 1000 seed weight to determine the yield components of the soybean. Total pods plant^{-1} is the number of pods on the main stem and were counted in the field directly after the plants were taken from the plot. The amount of filled pods plant^{-1} were determined to be pods that contained at least two mature seeds and were subtracted from the total pods plant^{-1} to get the number of unfilled pods plant^{-1}. Seeds pod^{-1} is the ratio of average number of seeds per the total amount of pods on an individual soybean plant. Harvest index was calculated by taking the seed weight divided by the plant biomass from the individual plants. Samples taken were uniform to the size of plants in the stand and representative of the entire plot. This single plant sampling was conducted at the Prosper, ND location in 2014 and 2015, which provides us with two environments that were combined and analyzed.

An average plant height of each plot was recorded in centimeters by placing a measuring stick in the middle of each plot and determining a consistent height across all plants in the center four rows from soil surface to the top node of the plant just prior to direct harvesting with a Hege 125B plot combine. Harvested plot grain yield samples were transferred from the Hege 125B seed drawer into plastic mesh bags and taken to the Waldron Hall drying rooms where they were dried at a temperature of 60° C for one week.

After drying, the seed was processed for yield, seed weight, and seed oil content with various instruments. Yield samples were placed in the Waldron hall drying rooms and left until they dired to a uniform moisture content of 3%, at which point they were cleaned on a seed cleaner, transferred to brown paper bags and weighed. Samples were mathematically adjusted to 13% moisture after the data was collected. Subsamples were taken from each yield sample to calculate the 1000 seed weight by counting out and weighing 200 seeds and then multiplying that by a factor of 5. Seed oil content was determined from a 40 ml seed sample from the plot yield sample and processed with a Bruker Minispec mq10 nuclear magnetic resonance (NMR) analyzer to determine the seed oil content as a percent of the seed mass.

Determination for the amount of growing degree days was taken from data obtained from NDAWN stations near where the soybeans were being grown (North Dakota Agricultural Weather Network 2016). Growing degree days were based on the growing degree day calculation for corn. Growing degree days are calculated by subtracting the lower temperature threshold of 10°C from the average daily air temperature at each environment. The maximum temperature for growing degree days in corn is 30°C; therefore, if the air temperature was above this threshold then the temperature would be set at a high of 30°C. The number of accumulated growing degree days was entered as the day the soybean was seeded until it reached stage R1 and R7. In the event that the soybean did not reach growth stage R7, the amount of growing degree days ended at the harvest date.

General observations were made for pest issues throughout the growing season when visiting the locations for seeding and when determining growth stages. Based on these observations, appropriate management measures were applied by utilizing North Dakota State University (NDSU) weed control guides (Zollinger et al 2014). To control weeds that emerged during the growing season an application of glyphosate (Roundup Powermax®[2]) at 1.06 kg ai ha^{-1} was made. In the event that soybean aphids (*Aphis glycines* Matsumura) passed the economic threshold and become a hindrance to the overall plant growth, an application of bifenthrin (Capture®[3]) was applied at 0.067 kg ai ha^{-1} as a control method. Pesticides were applied using a CO_2-pressurized backpack sprayer and boom system with TurboTee11001 nozzle tips at a pressure setting of 276 kPa to deliver 80 L ha^{-1} with the applicator walking at approximately 5 km h^{-1}. Individual weeds that were observed between applications of herbicide were removed from the plots by hand in an effort to keep the soybean as weed free as possible and reduce interspecies competition.

Treatment trait means separation was performed using an *F*-protected LSD at 5% level of probability (Steele and Torrie, 1980). One location in one year was termed an environment and considered a random effect in the statistical analysis. Seeding date and cultivar were considered fixed effects. Homogeneity of trait variances was tested by Bartlett's X^2 ($P \leq 0.05$) and environments combined where appropriate. Sources of variation, degrees of freedom, and

[2] Monsanto Company, 800 N Lindbergh Blvd. St. Louis, MO, 63167
[3] FMC Corporation 1735 Market St. Agricultural Chemical Group, Philadelphia, PA, 19103

expected mean squares for a single environment and combined environments appear in Tables 2 and 3, respectively (SAS Institute 2016).

Table 2. Sources of variation (SOV), degrees of freedom (df), and expected mean squares (EMS) for a single environment for the seeding date and cultivar maturity rating (CMR) study conducted in 2014 and 2015 in North Dakota.

SOV	df	EMS
Rep	3	—
Seeding Date (D)	5	$\sigma^2_\varepsilon + rc\sigma^2_D$
CMR	2	$\sigma^2_\varepsilon + rd\sigma^2_C$
D × CMR	10	$\sigma^2_\varepsilon + r\sigma^2_{DC}$
Error	51	σ^2_ε

Table 3. Sources of variation (SOV), degrees of freedom (df), and expected mean squares (EMS) for analyses combined across five environments for the seeding date and cultivar maturity rating (CMR) study conducted in 2014 and 2015 in North Dakota.

SOV	df	EMS
Environment (ENV)	4	—
Rep (ENV)	15	—
Seeding Date (D)	5	$\sigma^2_\varepsilon + rc\sigma^2_{ED} + rec\sigma^2_D$
CMR	2	$\sigma^2_\varepsilon + rd\sigma^2_{EC} + red\sigma^2_c$
ENV × D	20	$\sigma^2_\varepsilon + rc\sigma^2_{ED}$
ENV × CMR	8	$\sigma^2_\varepsilon + rd\sigma^2_{EC}$
D × CMR	10	$\sigma^2_\varepsilon + r\sigma^2_{EDC} + re\sigma^2_{DC}$
ENV × D × CMR	40	$\sigma^2_\varepsilon + r\sigma^2_{EDC}$
Error	255	σ^2_ε

RESULTS AND DISCUSSION

The Carrington 2014 environment was very dry throughout the entire growing season with the amount of total precipitation being 123.6 mm less than the 45- year average precipitation for May to October (Table 4). May and October were the two driest months at 29.9 and 38.9 mm below average monthly precipitation, respectively. This season long moisture deficiency hindered adequate growth and development of the plants at this environment.

Precipitation at Lisbon 2014 alternated between below average and above average monthly precipitation for the entire growing season (Table 4). In the early season, (May to June) May had a precipitation amount that was 25.1 mm below the average monthly precipitation followed by an amount of precipitation above the monthly average in June at 31.8 mm. The same pattern was observed in the mid-season (July to August) where July was 62.5 mm below the average monthly precipitation and August was 73.9 mm above the average monthly precipitation. This above average amount of precipitation in August was very important because this is when the pods are filling (stages R5 and R6), and a lack of drought stress on the plant is crucial to producing acceptable yield. With above average precipitation during these stages, soybean pods were able to fill more efficiently and create higher yields. Late season (September to October) was drier than the average with September having 50.3 mm below the average monthly precipitation and October having 47.5 mm below average monthly precipitation.

Table 4. Precipitation and mean monthly temperatures for five environments at Carrington, Lisbon, and Prosper, North Dakota, in 2014 and 2015‡.

		Precipitation		Temperature			
Environment	Month	Total	±Normal†	Max.	Min.	Avg.	±Normal†
		—mm—		—°C—			
Carrington 2014	May	40.2	-29.9	19	6	12	-1
	June	84.4	-11.3	22	12	17	-1
	July	65.4	-20.7	25	12	19	-2
	Aug	45.3	-13.4	24	12	18	-2
	Sept	39.1	-9.4	21	7	14	0
	Oct	6.1	-38.9	14	1	8	+1
Lisbon 2014	May	49.8	-25.1	20	7	13	-1
	June	112.0	+31.8	24	13	19	0
	July	17.3	-62.5	26	13	20	-2
	Aug	127.5	+73.9	26	14	20	-1
	Sept	14.5	-50.3	22	9	15	0
	Oct	6.4	-47.5	16	2	9	+1
Lisbon 2015	May	154.0	+79.1	19	6	13	-1
	June	90.7	+10.5	26	14	20	+1
	July	35.1	-44.7	29	16	22	0
	Aug	43.5	-10.1	28	14	21	0
	Sept	6.6	-58.2	26	11	18	+3
	Oct	27.5	-26.5	17	3	10	+2
Prosper 2014	May	52.1	-25.4	20	7	14	0
	June	107.2	+6.9	25	14	20	+1
	July	33.3	-54.6	27	14	20	-1
	Aug	60.5	-6.1	27	14	21	0
	Sept	46.7	-18.8	23	8	15	0
	Oct	9.1	-52.6	15	1	8	+1
Prosper 2015	May	148.7	+71.2	19	6	12	-1
	June	109.8	+9.4	26	13	19	+1
	July	88.4	+0.5	28	15	21	0
	Aug	36.3	-30.2	26	12	19	-1
	Sept	21.8	-43.7	25	10	17	+3
	Oct	30.8	-31.0	16	2	9	+2

†Based on 1971-2015 average.
‡Weather data obtained from: https://ndawn.ndsu.nodak.edu/weather-data-monthly.html

Precipitation in Prosper 2014 was 25.1 mm below the average monthly precipitation for the month of May, but rebounded in June with a precipitation amount that was 6.9 mm above the monthly average amount of precipitation. This early season rain came at a time when soybean planted at the earlier dates 1 and 2 would have begun progressing through the early growth stages, or when soybean at dates 3 and 4 were just planted and germinating. This gives the soybean an appropriate amount of water to properly develop in the early growth stages, which is crucial to the overall growth and development of the plant. After this month of above average monthly precipitation there was a shift in the middle and late-season where all months had below the average monthly amount of precipitation. The month with the lowest amount of precipitation was July, which was 54.6 mm below the average monthly precipitation. This midseason lack of rainfall would have inhibited the early development of the late seeding dates when these soybean are beginning to germinate and progress through the early growth stages, possibly causing lower yields.

Lisbon 2015 started out with an extremely high amount of precipitation in the early season where the month of May had precipitation that was 79.1 mm above the average monthly precipitation and June was also 10.5 mm above the average monthly precipitation. This early addition of water into the soil profile made seeding a struggle at times, but also ensured that developing plants would have plenty of water in the early stages of their development. Mid-season saw a change to drier conditions than what was seen in the early season with July having 44.7 mm less than the average monthly precipitation and August having 10.1 mm below average monthly precipitation. These dry conditions continued into the late-season where, on top of the lack of precipitation, temperatures were above the monthly average with September and October average monthly temperatures being 3° and 2°C above normal, respectively.

Similar to the Lisbon 2015 environment, Prosper 2015 also began the growing season with a very high amount of precipitation. The month of May was 71.2 mm above the average monthly precipitation and June was 9.4 mm above the average monthly precipitation. A period of dry, midseason weather arrived when July measured 0.5 mm below the average monthly amount of precipitation and August had 30.2 mm below the average monthly precipitation. Late season precipitation was hard to come by at this environment where September and October both registered amounts that were considerably less than the average monthly precipitation at 43.7 and 31.0 mm, respectively. Temperatures in the late season were also above the monthly average for this environment and echo what was seen at the Lisbon 2015 environment with September being 3°C, and October being 2°C above the monthly average temperature.

Grain yield

The combined analysis of variance across five environments indicated that there was a significant effect for the interaction of seeding date by cultivar maturity rating (CMR) and the three-way interaction of date by CMR by environment for grain yield (Table 5). The analysis indicated that the main effect of seeding date was significant (Table 5). As seeding was delayed, yield decreased when averaged across maturity ratings and environments (Table 6). The main effect of CMR was not significant (Table 5).

Table 5. Sources of variation (SOV), degrees of freedom (df), and trait mean squares for the seeding date and soybean cultivar maturity rating study combined across five North Dakota environments during 2014 and 2015.

SOV	df	Grain yield	Plant height	Plant lodging	1000 Seed weight	Seed oil content
Environment (ENV)	4	15 242 931**	505.1**	73.4**	6 967.5**	58.1**
Rep (ENV)	15	114 460*	46.3**	2.64**	146.0**	1.21**
Seeding date (D)	5	41 271 149**	169.3*	1.50*	16 772**	82.6**
Cultivar maturity rating (CMR)	2	725 127	926.2*	1.55	12 577*	25.2*
Env × D	20	2 869 473**	42.7**	0.37	1 461.2**	3.02**
Env × CMR	8	1 202 355**	30.1**	1.01*	570.7**	1.43**
D × CMR	10	823 067*	19.5	0.10	663.0	0.52*
Env × D × CMR	40	172 541**	11.4*	0.26	325.2**	0.23**
Error	255	38 367	5.52	0.28	27.7	0.10
Total	359					
CV%		9.2	7.7	72.8	3.7	1.6

*, ** significant at 0.05 and 0.01 level, respectively

The cultivars with a CMR of 1.4 yielded more than the cultivars with a CMR of 0.7 and 00.9 for seeding date 1 (Table 6). There is a common thought among growers that the later maturity rating soybean cultivars produce higher yields because the soybean plants take more time to develop and produce more pods that will create higher yields, regardless of the environment in which they are being seeded. Since soybean with a CMR of 1.4 take the longest time to mature it would have the highest yield when it has the time and resources to properly develop, however; this was only true for seeding date 1 when averaged across all five environments. The soybean with a CMR of 00.9 was able to better maintain its yield as seeding was delayed later into the growing season with a significant decrease in yield occurring at seeding date 3, which yielded 2470 kg ha^{-1}. Each seeding date after date 3 was significantly lower than the previous date for the cultivar with a CMR of 00.9. This was different from the findings reported by Osler and Carter (1954) in which they stated that short season cultivars had higher compared to their long season counterparts.

Table 6. Mean grain yield of three cultivar maturity ratings at each of six seeding dates averaged across five North Dakota environments in 2014 and 2015.

	Cultivar maturity rating (CMR)			
Seeding date	00.9	0.7	1.4	Mean
		—kg ha^{-1}—		
Date 1 (23 May)	2790	3013	3273	3025
Date 2 (2 June)	2682	2787	2830	2766
Date 3 (11 June)	2470	2563	2653	2562
Date 4 (22 June)	2156	2320	1916	2130
Date 5 (1 July)	1429	1510	1124	1354
Date 6 (9 July)	1103	1094	588	928
Mean	2105	2214	2064	
LSD (0.05)†		296		
LSD (0.05)‡				721

† LSD to compare the interaction of planting date by CMR at the 0.05 level of significance
‡ LSD to compare the main effect of planting date at the 0.05 level of significance

The decrease in yield, for the 00.9 CMR, was similar to the decrease that was seen for the cultivar with a 0.7 maturity, which also did not have a significant decrease in yield until seeding date 3 (Table 6). From seeding date 1 to seeding date 6, the 00.9 CMR had the lowest percentage of total yield loss of 60%, which is compared to 64% loss with the 0.7 CMR. The largest loss of yield was seen with the 1.4 CMR of 83%, indicating that this maturity group has the greatest yield loss if seeding is delayed further into the growing season. Lussenden (1987) also reported in his study that there was a drop in yield as seeding date was delayed, especially if seeding was after 3 June in North Dakota.

The mean grain yield was significant for the interaction of environment by date by CMR (Table 5). The mnimum yield required for a grower to profit from a soybean crop was 2016 kg ha^{-1} (Swenson and Haugen 2014). When comparing this target yield to the grain yield obtained at the Carrington 2014 environment, seeding date 4 was the latest that soybean could be seeded for a cultivar with a CMR of 00.9 and 0.7 with 2018 kg ha^{-1} and 2014 kg ha^{-1}, respectively. Seeding date 3 was the latest date at which an economical yield was reached at 2045 kg ha^{-1} (Table 7).

Soybean seeded at the Lisbon 2014 environment reached economical yields much later into the growing season than what was observed at the Carrington 2014 environment. At Lisbon 2014, the yields obtained from seeding date 5 were both above the estimated economical yield of 2016 kg ha^{-1} with soybean CMR 00.9 having a yield of 2100 kg ha^{-1} at seeding date 5 while soybean CMR 0.7 had a yield of 2135 kg ha^{-1} (Table 7). Soybean with a CMR of 1.4 also achieved economical yields at a later date for this environment compared to Carrington 2014 with seeding date 4 having a yield of 2385 kg ha^{-1}.

Table 7. Mean grain yield of three cultivar maturity ratings at each of six seeding dates across five North Dakota environments, in 2014 and 2015.

		Environment								
		Carrington			Lisbon			Prosper		
		— Cultivar maturity rating (CMR) —								
		00.9	0.7	1.4	00.9	0.7	1.4	00.9	0.7	1.4
		— kg ha^{-1} —								
2014	Date 1	2431	3001	2796	2777	2968	3455	4287	4503	4726
	Date 2	2517	2442	2390	2736	2847	3212	3916	4182	3643
	Date 3	2407	2154	2045	2851	3247	3090	3418	3607	3536
	Date 4	2018	2014	1144	2666	2885	2385	2658	3042	1777
	Date 5	724	673	78	2100	2135	1476	1420	1725	500
	Date 6	635	336	5	1716	1844	593	826	833	89
2015	Date 1				2062	1907	2593	2397	2685	2795
	Date 2				2035	1882	2212	2205	2580	2693
	Date 3				1640	1689	2100	2036	2118	2492
	Date 4				1576	1665	2017	1860	1995	2260
	Date 5				1445	1388	1703	1459	1630	1862
	Date 6				1140	1067	1347	1198	1388	903
	LSD (0.05)					272				

Soybean seeded at the Prosper 2014 environment behaved similarly to what was observed at the Carrington 2014 environment with economical yields being achieved up to seeding date 4 for CMRs 00.9 and 0.7 at 2658 kg ha^{-1} and 3042 kg ha^{-1}, respectively (Table 7). Soybean with a CMR of 1.4 achieved economical yields up to seeding date 3 with a yield of 3536 kg ha^{-1}. Yield sharply declined after these respective seeding dates at this environment where CMRs 00.9 and 0.7 fell to 1420 kg ha^{-1} and 1725 kg ha^{-1} at seeding date 5, respectively. Soybean with a CMR of 1.4 declined to 1777 kg ha^{-1} at seeding date 4.

For soybean with a CMR of 00.9 at the Lisbon 2015 environment, seeding date 2 was the last seeding date with an economical yield at 2035 kg ha^{-1}. Soybean with a CMR of 1.4 achieved economical yields farther into the growing season with seeding date 4 being the latest an economical yield was achieved at 2017 kg ha^{-1}. Soybean with a CMR of 0.7 did not have any seeding dates achieve an economical yield for this environment, but seeding dates 1, 2, 3, and 4 were all similar in the yield that was achieved.

Soybean seeded at the Prosper 2015 environment achieved economical yields later in the growing season compared to what was seed at Lisbon 2015. CMRs 00.9 and 0.7 had economical yields up to seeding date 3 where the yields were 2036 kg ha^{-1} and 2118 kg ha^{-1}, respectively (Table 7). Soybean with a CMR of 1.4 had a yield of 2260 kg ha^{-1} at seeding date 4, which was the last time that it would have an economical yield at this environment.

Cultivars with a CMR of 1.4 should only be seeded in central and southeast North Dakota in the month of May. If seeding date is delayed past the month of May, growers should plant a cultivar with a CMR of 00.9 or 0.7. The cultivar with a CMR of 1.4 did not yield more than the cultivars with a CMR of 0.7 or 00.9 when seeding date was delayed until June or July.

1000 seed weight

Mean 1000 seed weight was significant for the interaction of environment by date and the main effect of seeding date (Table 5). 1000 seed weight, when averaged across CMRs, decreased as seeding date progressed further into the growing season at all five environments (Table 8). The interaction was primarily associated with seeding date ranking differences for mean 1000 seed weight among environments. The decrease in the weight of 1000 seeds as seeding was delayed further into the growing season was expected since growth resources, particularly water, calendar days, and heat units became less as seeding was delayed, which resulted in inadequately filled pods that are unable to produce economical yields. The 2014 environments illustrate this decrease very well due to drier conditions and cooler temperatures, especially later in the growing season (Table 4 and 8).

Table 8. Mean 1000 seed weight for six seeding dates averaged across the three cultivar maturity ratings at five North Dakota environments in 2014 and 2015.

	Environment				
	Carrington 2014	Lisbon 2014	Prosper 2014	Lisbon 2015	Prosper 2015
Seeding date			— g —		
Date 1	156.9	183.5	169.1	149.0	146.1
Date 2	144.5	172.8	165.3	146.3	143.3
Date 3	130.4	160.8	159.6	144.0	144.0
Date 4	118.7	138.6	147.5	141.2	150.0
Date 5	108.3	121.8	137.5	133.9	139.0
Date 6	90.9	110.3	119.6	126.6	134.7
LSD (0.05)			14.9		

Seeding dates are as follows: Date 1 (23 May), Date 2 (2 June), Date 3 (11 June), Date 4 (22 June), Date 5 (1 July), Date 6 (9 July)

Carrington 2014 produced the lowest seed weight among 2014 environments at all seeding dates (Table 8). Seeding dates 1 and 2 had the heaviest seed weights for this environment, which were 156.9 g for seeding date 1 and 144.5 g for seeding date 2. Seeding date 3 was different from seeding date 1 at 130.4 g, but was similar to seeding date 2, and was also similar to seeding date 4 at 118.7 g. 1000 seed weight for seeding date 6 was significantly different from all other seeding dates at this environment at 90.9 g and had the lowest 1000 seed weight of any environment in either 2014 or 2015 when averaged across all cultivars.

Seeding dates 1 and 2 produced the heaviest 1000 seed weight at the Lisbon 2014 environment with a 1000 seed weight of 183.5 g at seeding date 1 (Table 8), and 172.8 g at seeding date 2. The seed weight of seeding date 3 was less than seeding dates 1 and 2. After seeding date 3, seed weights rapidly declined. Seeding date 4 had a 1000 seed weight of 138.6 g, and was significantly different from seeding dates 5 and 6, which were 121.8 and 110.3 g, respectively.

At Prosper in 2014, 1000 seed weights were more uniform across the seeding dates (Table 8). Seeding dates 1 through 4 had the heaviest seed weights with seeding date 1 being the heaviest at 169.1 g. No statistical differences were observed until seeding date 4, with a 1000 seed weight of 147.5 g (Table 10). Seeding dates 6 had the lightest 1000 seed weight at this environment with a 1000 seed weight of 119.6 g.

At the Lisbon 2015 environment, seeding dates 1, 2, 3, and 4 had similar seed weights (Table 9). The seed weight of seeding date 5 was similar to seeding dates 2, 3, and 4. Seeding dates 4, 5, and 6 had similar seed weights. At the Prosper 2015 environment, seeding dates 1, 2, 3, 4, and 5 had similar seed weights. Seeding dates 5 and 6 had the lowest 1000 seed weight for this environment with a 1000 seed weight of 139.0g and 134.7 g, respectively.

Seed oil content

The interaction of date by CMR was significant for seed oil content for statistical analysis across five environments (Table 5). The main effect of seeding dates showed a step-wise decrease in seed oil content as seeding date was delayed as seeding date 1 had the highest seed oil content when averaged across cultivars, and seeding date 6 had the lowest seed oil content

(Table 9). The seeding date by CMR interaction indicated the highest seed oil content was observed with CMR 0.7, which had 21.5% oil content at seeding date 1. The lowest seed oil content was at seeding date 6 in both the 00.9 and 1.4 maturity rated soybean cultivars where the oil content was 17.4%. Cultivar seed oil contents averaged across seeding dates and environments were 19.2, 19.9, and 19.1% for cultivars with maturity ratings of 00.9, 0.7, and 1.4, respectively. The cultivar with a maturity of 0.7 had greater seed oil content than the other two CMRs.

Table 9. Mean seed oil content for three cultivar maturity ratings at six seeding dates averaged across five North Dakota environments in 2014 and 2015.

	Cultivar maturity rating (CMR)			
Seeding date	00.9	0.7	1.4	Mean
		— % —		
Date 1	20.7	21.5	20.3	20.8
Date 2	20.1	20.7	19.8	20.2
Date 3	19.6	20.1	19.5	19.7
Date 4	18.7	19.3	18.8	18.9
Date 5	18.0	19.0	17.9	18.3
Date 6	17.4	18.3	17.4	17.7
Mean	19.1	19.8	19.0	
LSD (0.05)†		0.3		
LSD (0.05)‡		0.2		
LSD (0.05)§		0.3		

† LSD to compare the main effect of seeding date at the 0.05 level of significance
‡ LSD to compare the main effect of CMR at the 0.05 level of significance
§ LSD to compare the interaction of seeding date by CMR at the 0.05 level of significance

The main effect of seeding date was significant for plant height and plant lodging in the statistical analysis across five environments (Table 5). Plant height was similar at seeding dates 1, 2, 3, and 4. Plant height for seeding dates 5 and 6 was shorter than the previous four seeding dates at dates 5 and 6 were similar in plant height (Table 10). Mean plant height was 30.3, 26.5, and 31.5 cm for CMRs 00.9, 0.7, and 1.4, respectively, when averaged across environments and seeding dates (data not shown). Cultivars with maturity ratings of 00.9 and 1.4 were similar for plant height and taller than soybean with a CMR of 0.7. Plant lodging fluctuated across the six seeding dates with date 1 having the most lodging followed by a decrease at date 2, but an increase at date 3 before decreasing steadily at the later dates (Table 12). Date 6 had the lowest lodging, most likely due to shorter plant height.

Table 10. Mean plant height, plant lodging, and seed oil content for six seeding dates averaged across three cultivar maturity ratings and five North Dakota environments in 2014 and 2015.

	Plant height	Plant lodging
Seeding date	cm	
Date 1 (23 May)	30.7	0.78
Date 2 (2 June)	30.4	0.69
Date 3 (11 June)	30.9	0.75
Date 4 (22 June)	30.7	0.63
Date 5 (1 July)	27.8	0.54
Date 6 (9 July)	26.2	0.38
LSD (0.05)	2.4	0.10

Yield components for individual plant sampling analysis

1000 seed weight

The analysis of individual plants at Prosper, ND, in 2014 and 2015 was significant for the interaction of environment by date for seed yield plant^{-1}, 1000 seed weight, and unfilled pods plant^{-1} (Table 11). The 1000 seed weights at Prosper 2014 decreased as seeding progressed further into the season with seeding dates 1, 2, and 3 having the highest 1000 seed weights of 174.2, 161.4, and 165.5 g, respectively (Table 12). Seeding dates 2 and 3 were also similar to seeding date 4 at 147.2 g. Seeding dates 5 and 6 had the lowest 1000 seed weights. Seeding dates 1, 2, 3, 4, and 5 were all similar for 1000 seed weight at Prosper 2015. Seeding dates 5 and 6 had the lowest 1000 seed weight for this environment with a 1000 seed weight of 141.4 g for seeding date 5 and 125.7 g for seeding date 6 (Table 11).

Table 11. Sources of variation (SOV), degrees of freedom (df), and trait mean squares for the seeding date and soybean cultivar maturity rating study combined across two environments at Prosper, North Dakota, during 2014 and 2015.

SOV	df	Nodes plant^{-1}	Total pods plant^{-1}	Filled pods plant^{-1}	Unfilled pods plant $^{-1}$	Plant biomass	Seed yield plant^{-1}	Harvest Index	Seeds plant^{-1}	1000 seed weight	Seeds pod^{-1}
Environment (ENV)	1	45.9	1506.5	389.2	294.3*	58687*	162.5	9.27*	3572.4	5.89	3.68*
Rep (ENV)	6	15.7*	615.0**	639.9**	4.72	8931.0**	109.3**	0.75**	3821.1**	3600.1**	0.36*
Date (D)	5	131.8*	1297.7	2188.9	226.3	2451.0	600.6	0.12	10758.1*	48812.1	1.32
Cultivar maturity rating (CMR)	2	118.8*	390.8	874.4	205.7	5.45	205.6	0.20	4468.9	18431.3*	2.43
Env × D	5	10.1	267.9	693.2	161.4**	661.5	148.8*	0.08	2071.1	20125.9**	0.39
Env × CMR	2	6.3	686.6	1617.6*	230.9**	69.9	151.9	0.37*	9013.8*	601.0	2.65**
D × CMR	10	14.5	230.6	260.2	59.2	229.1	50.8	0.08*	1557.6	4144.9	0.52
Env × D × CMR	10	6.9	298.7	189.5	58.7**	285.6	33.1	0.01	1639.2	2941.4*	0.68*
Error	572	3.9	70.1	68.7	2.94	41.6	9.9	0.01	410.0	618.0	0.10
Total	714										
CV%		15.5	36.4	37.9	151.9	27.6	40.5	22.0	38.0	17.5	14.1

*, ** significant at 0.05 and 0.01 level, respectively

Table 12. Mean 1000 seed weight at six seeding dates averaged across three cultivar maturity ratings for two environments at Prosper, ND, in 2014 and 2015.

	2014		2015
Seeding date		— g —	
Date 1 (23 May)	174.2		150.0
Date 2 (2 June)	161.4		144.7
Date 3 (11 June)	165.5		143.0
Date 4 (22 June)	147.2		146.1
Date 5 (1 July)	112.9		141.4
Date 6 (9 July)	91.5		125.7
LSD (0.05)		22.1	

Seeds plant^{-1}

The amount of seeds plant^{-1} obtained from individual plants was significant for the interaction of environment by cultivar (Table 11). The number of seeds plant^{-1} at the Prosper 2014 environment was highest for the cultivars with a maturity rating of 0.7 and 00.9 that had 64.8 and 57.4 seeds plant^{-1}, respectively (Table 13). Soybean with a cultivar maturity rating of 1.4 had the lowest seeds plant^{-1} with 44.4. The Prosper 2015 environment contained no statistical differences between any of the CMRs for number of seeds plant^{-1}. This can most likely be attributed to the total amount of precipitation that was accumulated throughout the growing season at each environment. Prosper 2014 had a season that was marked by dryness that started in July where the amount of precipitation was 54.6 mm below the average monthly precipitation.

Table 13. Mean number of seeds plant^{-1} for three cultivar maturity ratings taken as individual plants averaged across six seeding dates at two environments at Prosper, ND, in 2014 and 2015.

Cultivar maturity rating	2014		2015
00.9	57.4		49.1
0.7	64.8		50.4
1.4	44.4		53.6
LSD (0.05)		11.7	

Since soybeans with a cultivar maturity rating of 1.4 develop at a slower pace compared to the other two cultivar maturity ratings, the lack of water during the shift from the vegetative to reproductive growth stages more than likely stressed the plant and hindered the ability of the plant to produce higher yields. Conversely, at the Prosper 2015 environment, the amount of precipitation was above the average monthly precipitation until the month of August, which was 30.2 mm below the average monthly precipitation (Table 4).

Filled pods plant^{-1}

The interaction of environment by CMR was significant for the number of filled pods plant^{-1} taken from individual plants (Table 11). The data indicated ranking differences among cultivar maturity ratings for filled pods plant^{-1} between the Prosper 2014 and Prosper 2015 environments (Table 14). At the Prosper 2014 environment, cultivars with a CMR of 0.7 and 00.9 were similar and had the most filled pods plant^{-1} at 26.6 and 23.5, respectively. Cultivars with a CMR of 1.4 produced a lower number of filled pods plant^{-1} than the other two cultivar maturity ratings at 17.8 pods plant^{-1}. There were no statistical differences between the CMRs at Prosper 2015 where the amount of filled pods plant^{-1} ranged from 20.4 filled pods plant^{-1} for cultivars with a CMR of 00.9, to 22.1 filled pods plant^{-1} for soybean with a CMR of 1.4. Differences in the amount of similarities and difference observed at the two environments can, once again, be attributed to the differences in the amount of precipitation accumulated throughout the growing season between the two environments.

Unfilled pods plant^{-1}

The number of unfilled pods plant^{-1} taken from individual plants at Prosper, ND in 2014 and 2015 was significant for the interaction of environment by date (Table 11). The cause of the environment by date interaction is primarily ranking differences among seeding dates for unfilled pods plant^{-1} between environments (Table 15). Seeding date 6 in 2014 had an average of 6.23 unfilled pods plant^{-1} which was different from seeding dates 1, 2, 3, and 4, but similar to seeding date 5 at 3.33 unfilled pods plant^{-1} (Table 15). This sharp increase in the amount of unfilled pods plant^{-1} at seeding dates 5 and 6 helps to explain the decrease in yield that was observed as seeding date was delayed further into the growing season, especially in 2014. Seeding date did not influence unfilled pods plant^{-1} at the Prosper 2015 environment.

Table 14. Mean trait yield component values for three cultivar maturity ratings from five individual plants averaged across six seeding dates at two environments at Prosper, ND, in 2014 and 2015.

Cultivar maturity rating (CMR)	Filled pods plant^{-1}		Seeds pod^{-1}		Seed yield plant^{-1}		Unfilled pods plant^{-1}	
	2014	2015	2014	2015	2014	2015	2014	2015
00.9	23.5	20.4	2.38	2.37	8.93	7.35	0.57	0.28
0.7	26.6	20.9	2.31	2.36	9.53	7.39	0.81	0.76
1.4	17.8	22.1	1.99	2.38	6.29	7.14	3.94	0.39
LSD†	4.0		0.24		1.82		3.60	

†LSD to compare maturity ratings to the 0.05 level of significance

Table 15. Mean number of unfilled pods plant^{-1} for six seeding dates taken as individual plants averaged across three cultivar maturity ratings and two environments at Prosper, ND, in 2014 and 2015.

Seeding date†	2014	2015
Date 1 (25 May)	0.00	0.23
Date 2 (3 June)	0.00	0.22
Date 3 (12 June)	0.50	0.78
Date 4 (21 June)	0.58	0.28
Date 5 (1 July)	3.33	0.38
Date 6 (9 July)	6.23	0.95
LSD (0.05)	3.60	

†Calendar date is averaged across environments for each seeding date

Results indicated that the number of unfilled pods plant^{-1}, in relation to the environment by cultivar interaction (Table 7), had soybean with a cultivar maturity rating of 1.4 in 2014 had significantly higher unfilled pods plant^{-1} (3.94) than the other two CMRs, which had similar amounts of unfilled pods plant^{-1} (Table 14). No significance was seen for the number of unfilled pods plant^{-1} in the 2015 growing season. This increase in the amount of unfilled pods plant^{-1} at the later seeding dates in 2014, compared to those in 2015, is likely due to the differences in both temperature and the amount of average monthly precipitation that was observed at these two environments (Table 4). In 2014, the temperatures in September and October were normal compared to the long-term average for the area; however, in 2015 the temperatures for September and October were 2-3° warmer than the long-term average for this environment (Table 4). This increase in the average temperature would lead to an increase in the amount of accumulated growing degree days by soybean plants that were seeded later in the growing season.

Seeds pod^{-1}

The number of seeds pod^{-1} was significant for the interaction of environment by cultivar (Table 11). Soybean CMRs at the Prosper 2015 environment produced a similar number of seeds pod^{-1} across all cultivar maturity ratings (Table 14). At Prosper 2014, soybean with a CMR of 00.9 and 0.7 produced the highest number of seeds pod^{-1} at 2.38 and 2.31, respectively. The 1.4 CMR had fewer seeds pod^{-1} than the earlier maturing CMRs with 1.99 seeds pod^{-1}. This difference, as discussed earlier, is most likely related to the lack of precipitation starting in July 2014 that didn't provide enough moisture for the soybean to develop properly and would lead to the abortion of flowers and/or pods during the early reproductive stages, especially in the soybean that had a cultivar maturity rating of 1.4 that were planted later in the growing season.

Seed yield plant^{-1}

Seed yield plant^{-1} obtained from individual plants at the Prosper 2014 and 2015 environments was significant for the interaction of environment by cultivar (Table 11). Cultivar maturity ratings at the Prosper 2015 environment were all similar for seed yield plant^{-1} (Table 14). Cultivars with a maturity rating of 00.9 and 1.4 were similar at the Prosper 2014 environment and had the largest seed yield plant^{-1} at 8.93 and 9.53 g, respectively. Soybean with a cultivar maturity rating of 1.4 had the lowest seed yield plant^{-1} at this environment with 6.29 g.

Harvest index

The interaction of date by CMR was significant for harvest index in the statistical analysis across two environments (Table 11). The harvest index for soybean with a cultivar maturity rating of 00.9 was similar at seeding dates 1, 2, 3, 4, and 5. Seeding date 6 had the lowest harvest index for soybean with a CMR of 00.9 with a harvest index of 0.39. Soybean seeding dates with a cultivar maturity rating of 0.7 were all statistically similar for harvest index (Table 16). Seeding dates 1 and 3 had the highest harvest index for the maturity rating 1.4 soybean with 0.45 and 0.49, respectively. Seeding dates 5 and 6 had the lowest harvest index for soybean with a cultivar maturity rating of 1.4 with seeding date 5 having a harvest index of 0.33 and seeding date 6 having a harvest index of 0.28. Seeding date 6 for the 1.4 maturity rating was also the lowest harvest index across all maturity ratings.

Table 16. Mean harvest index of three cultivar maturity ratings at six seeding dates averaged across two environments at Prosper, ND during 2014 and 2015.

	Cultivar maturity rating (CMR)		
Seeding date	00.9	0.7	1.4
Date 1 (25 May)	0.44	0.45	0.45
Date 2 (2 June)	0.46	0.45	0.36
Date 3 (11 June)	0.42	0.41	0.49
Date 4 (21 June)	0.42	0.42	0.36
Date 5 (1 July)	0.42	0.41	0.33
Date 6 (10 July)	0.39	0.42	0.28
LSD (0.05)		0.06	

Yield component summary

The commonality among the yield components from individual plant sampling analysis was that a soybean CMR of 1.4 in 2014 was the main source of differences observed, and often produced yield components that were less than the other two cultivar maturity ratings. This is most likely attributed to the lack of moisture during the 2014 growing season, but more specifically, from the month of July that had 54.6 mm less than the average monthly precipitation when compared to the long-term average. This lack of precipitation would have made it difficult for soybean that was seeded in late June and early July to aquire the adequate amount of moisture needed for proper growth and development during germination as well as the early vegetative growth stages. In contrast to 2015, where there were no trait differences for CMR, there were above average amounts of precipitation in the month July, which would have allowed soybean that was seeded later in the season to obtain the amount of moisture necessary to germinate and develop before becoming stressed from a lack of water.

Calendar days to growth stages

Introduction

The interaction of environment by date was significant for the number of days to reach all growth stages when statistically combined across 5 environments (Table 17). The main effect of date was also significant for all growth stages, except R7, and the main effect of CMR was significant for growth stages V5 to R7 (Table 17). The observed trend across all environments indicated that as the seeding dates were delayed further into the growing season, the number of days required to progress through the growth stages decreased. There were exceptions to this at some environments, but this was the general trend.

Table 17. Sources of variation (SOV), degrees of freedom (df), and trait mean squares for vegetative soybean growth stage progression in calendar days and growing degree days (GDD) combined across five North Dakota environments in 2014 and 2015.

		Growth stage†					
SOV	df	V1	V2	V3	V4	V5	GDD‡ Planting to R1
Environment (ENV)	4	70.5**	64.4**	107.4**	173.2**	122.6**	21645.6**
Rep (ENV)	15	2.35*	9.33	11.3	23.2	7.36	831.7
Date (D)	5	707.1*	902.3*	931.7*	1464.0*	764.1**	45705.9**
Cultivar maturity rating (CMR)	2	2.14	6.18	5.21	15.2	38.4*	288964.8**
Env × D	20	88.5**	103.2**	107.4**	215.5*	39.1**	796.3*
Env × CMR	8	1.92	10.7	5.27	28.7*	6.55	1509.3*
D × CMR	10	1.52	6.7	6.08	12.7	11.6	1628.8
Env × D × CMR	40	0.82	6.7	6.12	14.2	10.9	1380.1**
Error	255	342.0	6.51	10.1	13.6	10.6	
Total	359						
CV%		5.9	10.5	10.9	10.8	8.4	

*, ** significant at 0.05 and 0.01 levels, respectively

†Growth stage descriptions are presented in Appendix table

‡Growing degree days (GDD) are based on minimum of 10°C and a maximum of 30°C

Table 17. Sources of variation (SOV), degrees of freedom (df), and trait mean squares for reproductive soybean growth stage progression in calendar days and growing degree days (GDD) combined across five North Dakota environments in 2014 and 2015 (continued).

SOV	df	Growth stage†							
		R1	R2	R3	R4	R5	R6	R7	GDD‡ R1 to R7
Environment (ENV)	4	497.3**	712.7**	772.8**	708.2**	382.8**	464.5**	642.2**	507887.6**
Rep (ENV)	15	5.8	11.0	10.0	16.6	17.7	16.2	35.7*	3008.2
Date (D)	5	1275.6**	1326.1**	1533.9**	1987.5**	2004.0**	1779.0**	646.4	284594.9**
Cultivar maturity rating (CMR)	2	2435.6**	2039.7**	2388.6**	1486.0*	2542.5**	2050.4**	2144.5**	25478.4*
Env × D	20	63.0**	68.1**	127.2**	166.5**	130.5**	167.4**	312.5**	5261.6**
Env × CMR	8	29.5**	14.5	20.9*	112.2**	47.5*	17.7	16.4	4263.6*
D × CMR	10	18.9	19.0	30.7	97.0	81.2	78.5	26.9	3546.7
Env × D × CMR	40	11.1*	30.0**	20.5**	102.3**	47.3**	63.5**	54.4**	2904.5*
Error	255	5.69	8.97	8.22	15.9	13.9	11.8	14.8	
Total	359								
CV%		5.8	6.4	5.4	6.7	5.6	4.6	3.7	

*, ** significant at 0.05 and 0.01 levels, respectively

†Growth stage descriptions are presented in Appendix table

‡Growing degree days (GDD) are based on minimum of 10°C and a maximum of 30°C

Environment: Carrington 2014

Soybean progressing through the vegetative growth stages at the Carrington 2014 environment had significant differences amongst all seeding dates when it came to the soybean progressing from germination to growth stage V1 (Table 18). Seeding date 2 took the longest number of days to reach growth stage V1 at 27.9 days from seeding. Seeding date 2 continued to take the longest number of days in order to progress through the vegetative growth stages until growth stage V4, where seeding date 1 took the longest number of days when averaged across cultivars. Seeding date 6 took the shortest amount of time to reach stage V1 at 15.7 days, but then took a larger number of days to reach growth stage V2 where seeding dates 4 and 5 took the shortest number of days at 19.0 and 20.0 days, respectively.

Table 18. Mean calendar days to reach growth stages from planting averaged across three cultivars maturity ratings at Carrington, ND, in 2014.

	V1	V2	V3	V4	V5	R1	R2	R3	R4	R5	R6	R7
						— calendar days —						
D1	21.8	28.1	33.2	41.0	45.6	52.7	57.2	63.0	69.7	76.8	85.9	111.8
D2	27.9	31.8	35.8	40.3	44.5	48.7	56.0	67.2	69.9	78.3	85.7	109.9
D3	24.0	27.0	33.2	38.0	39.5	45.4	54.8	59.2	66.8	74.3	81.7	104.3
D4	20.0	20.0	28.3	32.3	39.0	42.8	48.5	55.5	62.7	57.0	76.9	108.0
D5	17.6	19.0	29.3	34.0	38.8	39.7	46.7	46.7	59.3	66.1	68.7	111.0
D6	15.7	23.9	27.3	32.2	37.1	38.3	44.7	51.3	57.6	64.6	71.5	-----†
LSD‡	0.8	2.1	2.0	3.1	2.7	2.8	4.5	3.7	8.4	5.7	6.6	6.4
LSD§												11.5
LSD¶												11.6

† Soybeans at seeding date 6 failed to reach growth stage R7 at this environment
‡ LSD to compare seeding dates 1, 2, & 3 to seeding date 4 at 0.05 level of significance
§ LSD to compare seeding dates 1, 2, & 3 to seeding date 5 at 0.05 level of significance
¶ LSD to compare seeding date 4 to seeding date 5 at 0.05 level of significance

Seeding date 2 had the largest amount of days to reach stage V3 at 35.8 days. Seeding dates 4, 5, and 6, all took the least amount of days to reach stage V3, in which they took 28.3, 29.3, and 27.3 days, respectively. The amount of statistical similarities were most prevalent at stages V4 and V5 where seeding dates 1, 2, and 3 all took a similar amount of days to reach stage

V4 at 41.0, 40.3, and 38.0 days. Seeding dates 4, 5, and 6 were also all similar to each other at 34.0, 32.3, and 32.2 days, respectively. Calendars days to reach V5 was similar for seeding dates 1 and 2, but were different from all other seeding dates. Seeding dates 3, 4, 5, and 6 were all similar to each other.

When the soybean changed from the vegetative to reproductive growth stages there were more statistical differences than what was observed in the later vegetative growth stages. Seeding dates 1 and 2 took the longest amount of days to reach stage R1 at 52.7 and 56.0 calendar days, respectively. These two seeding dates continued this trend throughout the rest of the growth stages. Seeding dates 5 and 6 took the shortest amount of days to reach growth stage R1 39.7 and 38.3 calendar days, respectively.

There was a large amount of similarity between the days it took for all the seeding dates to reach stage R2. Seeding dates 1, 2, and 3 took the longest number of days to reach growth stage R2 and were similar to one another at 57.2, 56.0, and 54.8 days, respectively. Seeding date 5 took the shortest amount of time to reach growth stage R3 at 46.7 days. There were no statistical differences between any of the seeding dates when it came to reaching growth stage R4.

While investigating the amount of time to reaching growth stage R7, seeding dates 1, 2, 4, and 5 were all similar, with seeding date 1 taking the longest number of days to reach stage R7 at 111.8 days, and seeding date 3 taking the shortest amount of time at 104.3 days. Seeding date 3 was the only date that was different from all the rest. None of the soybean planted on date 6 reached stage R7 at Carrington in 2014. This could be attributed to the lack of soil moisture that would not allow the plants to properly develop throughout the growing season.

Environment: Lisbon 2014

Soybean planted at the Lisbon 2014 environment emerged at a number of days that was similar across all seeding dates (Table 19). The number of days to reach growth stage V1 decreased as seeding date progressed further into the growing season with the exception of seeding date 3, which took the same amount of days as seeding date 1 (Table 19). Seeding dates 1 and 3 took the longest amount of days to reach growth stage V1 with both seeding dates taking 22.0 days to do so. Seeding dates 2 and 4 were different from seeding dates 1 and 3 and took 20.3 and 20.1 days, respectively. Seeding date 6 was different from all previous seeding dates and took 14.0 calendar days to reach growth stage V1. Seeding date 2 took the longest amount of time to reach stage V2 at 31.2 days and was different from all other seeding dates with a sharp decrease in the number of days for the rest of the seeding dates to reach growth stage V2.

Table 19. Mean calendar days to reach growth stages from planting averaged across three cultivar maturity ratings at Lisbon, ND, in 2014.

	V1	V2	V3	V4	V5	R1	R2	R3	R4	R5	R6	R7
						— calendar days —						
D1	22.0	26.6	32.0	54.5	46.2	47.4	52.8	59.3	66.9	75.7	83.7	89.8
D2	20.3	31.2	32.6	35.8	41.3	43.9	48.9	53.6	61.2	70.1	76.8	107.5
D3	22.0	26.5	29.6	35.8	38.7	41.7	46.1	52.3	67.3	66.5	70.6	106.0
D4	20.1	24.3	26.5	30.0	34.4	38.0	43.6	50.3	57.0	60.8	69.7	98.3
D5	16.2	21.0	26.0	22.3	36.0	36.9	41.7	48.6	52.6	61.2	69.2	93.5
D6	14.0	22.0	26.3	30.0	34.8	36.5	39.3	45.9	41.4	60.8	69.1	91.0
LSD†	0.8	2.1	2.0	3.1	2.7	2.8	4.5	3.7	8.4	5.7	6.6	6.3
LSD‡												7.2
LSD§												7.3

† LSD to compare seeding dates 1, 2, 3, & 4 to seeding date 5 at 0.05 level of significance
‡ LSD to compare seeding dates 1, 2, 3, & 4 to seeding date 6 at 0.05 level of significance
§ LSD to compare seeding date 5 to seeding date 6 at 0.05 level of significance

Seeding dates 1 and 3 were similar to each other with date 1 taking 26.6 calendar days to reach stage V2 and date 3 taking 26.5 days. Seeding dates 5 and 6 took the least amount of days to reach growth stage V2 and were similar to each other at 22.0 and 21.0 calendar days, respectively. Looking at the number of days it took each seeding date to reach stage V3, seeding dates 1 and 2 were similar and took the longest amount of days at 32.0 and 32.6 days, respectively. Seeding dates 4, 5, and 6 were all similar to each other at this growth stage taking 26.5, 26.3, and 26.0 calendar days to reach stage V3, respectively.

Seeding date 1 took the longest amount of time to reach growth stage V4 at 54.5 days, which was the first time that seeding date 2 did not have the longest amount of days to progress through a growth stage at this environment. There was a sharp decrease in the number of days after seeding date 1 where dates 2 and 3 took the same amount of time at 35.8 calendar days. Seeding dates 4 and 6 were different from the previous seeding dates and both took 30.0 days to reach stage V4. Seeding date 5 took the shortest amount of days to reach stage V4 and was different from all other seeding dates at 22.3 days. Seeding date 1 took the longest amount of time to reach stage V5 at 46.2 days and was statistically different from all other seeding dates. Seeding dates 2 and 3 were similar to each other at 41.3 and 38.7 days, respectively, but seeding date 3 was also statistically similar to seeding date 5, which took 36.0 days to reach growth stage V5. Seeding dates 4 and 6 were similar to each other and took the shortest amount of time to reach growth stage V5 at 34.4 and 34.8 days, respectively.

When soybean changed from the vegetative to reproductive growth stages, there were not a lot of observed differences among the seeding dates when it came to reaching growth stage R1. Seeding date 1 took the longest amount of time to reach stage R1 at 47.4 days. Dates 2 and 3 were similar and took 41.3 and 38.7 calendar days to reach stage R1, respectively. Seeding dates 4, 5, and 6 were all similar to each other with dates 5 and 6 taking 36.0 and 34.8 days, respectively, and seeding date 4 taking the shortest amount of time to reach growth stage R1 at 34.4 calendar days.

There were many similarities between the days it took each of the seeding dates to reach stage R2. Seeding date 1 taking the longest amount of time at 52.8 days and was similar to seeding date 2, which took 48.9 calendar days. Seeding date 2 was also similar to seeding date 3 at 46.1 days. Date 3 was similar to dates 4 and 5 at 43.6 and 41.7 calendar days, respectively. Seeding date 6 took the shortest amount of time to reach stage R2 at 39.3 days, but was also similar to dates 4 and 5. Similar to stage R2, the number of days it took seeding dates to reach stage R3 also had a large amount of statistical similarities. Seeding date 1 took the longest amount of time to reach stage R3 at 59.3 days, but was different from all other seeding dates. Seeding dates 2, 3, and 4 were all similar to each other at 53.6, 52.3, and 50.3 days, respectively, but dates 3 and 4 were also similar to seeding date 5, which took 48.6 days to reach stage R3. Seeding date 5 was similar to seeding date 6, which took the shortest amount of time to reach stage R3 at 45.9 days.

Seeding date 1 continued to take the longest number of days to reach successive growth stages, where it took 75.7 days to reach stage R5. This was statistically similar to seeding date 2 that took 70.1 days to reach stage R5, and date 2 was also similar to date 3 at 66.5 days. Seeding date 3 was statistically similar to date 4 at 60.8 calendar days, and date 4 was statistically similar to both dates 5 and 6 at 61.2 and 60.8 days, respectively. The large amount of statistical similarities seen between stages R2, R3, and R5 started to subside when the soybean reached growth stage R6. Seeding date 1 took the longest amount of time to reach this stage at 83.7 days and was statistically different from all other seeding dates. Seeding dates 2 and 3 were statistically similar to each other at 76.8 and 70.6 days, respectively. Seeding date 3 was also similar to seeding dates 4, 5, and 6 where there were no statistical differences. Seeding date 5 took 61.2 days to reach growth stage R6 and dates 4 and 6 took the shortest amount of time where they both averaged 60.8 calendar days. Seeding date 2 took the longest amount of time to reach the final growth stage, R7, at 107.5 calendar days and was statistically similar to seeding date 3 at 106.0 days. Seeding dates 4 and 5 were also statistically similar to each other at 98.3 and 93.5 days, respectively. Conversely, from what was seen in previous growth stages, seeding date 1 took the shortest amount of time to reach growth stage R7 at 89.8 calendar days and was statistically similar to seeding date 6, which took 91.0 days.

Environment: Prosper 2014

The number of days to reach growth stage V1 at Prosper 2014 had statistically significant groupings of two (Table 20). Seeding date 1 took the longest amount of time to reach growth stage V1 at 23.5 days and was significantly similar to date 2, which took 23.0 days. Seeding dates 3 and 4 were also significantly similar to each other at 18.8 and 18.0 days, respectively, and dates 5 and 6 were similar at 16.3 and 16.0 days, with seeding date 6 taking the shortest amount of time to reach stage V1. This lack of strong statistical differences continued into stage V2 where seeding date 1 once again took the longest amount of time to reach stage V2 at 28.3 days and was statistically similar to seeding date 2 at 27.3 days.

Seeding date 3 was statistically different from all other seeding dates at 23.6 days. Seeding dates 4, 5, and 6 were all statistically similar to each other when reaching growth stage V2 where it took them 21.0, 19.3, and 19.0 calendar days, respectively. Seeding date 2 took the longest amount of time to reach growth stage V3 at 40.0 days and was statistically different from all other seeding dates. Seeding dates 1 and 3 were statistically similar to each other at 29.2 and 28.4 days, respectively. Dates 4, 5, and 6 were, once again, all statistically similar to each other where date 4 took 26.0 days and dates 5 and 6 took the shortest amount of time at 25.3 days.

There was a minimal amount of statistical difference in the number of days it took soybean to reach growth stage V4.

Table 20. Mean calendar days to reach growth stages from planting averaged across three cultivar maturity ratings at Prosper, ND, in 2014.

	V1	V2	V3	V4	V5	R1	R2	R3	R4	R5	R6	R7
						— calendar days —						
D1	23.5	28.3	29.2	36.0	40.3	47.0	53.5	60.5	67.4	75.0	82.0	110.9
D2	23.0	27.3	40.0	35.3	40.3	45.9	46.6	58.7	66.8	74.4	71.4	110.0
D3	18.8	23.6	28.4	32.0	37.5	41.3	48.5	56.1	62.6	69.8	76.6	104.5
D4	18.0	21.0	26.0	29.3	35.0	40.9	47.3	54.8	54.7	69.2	76.3	100.5
D5	16.3	19.3	25.3	30.8	36.3	38.8	45.3	51.2	57.7	64.5	71.5	96.0
D6	16.0	19.0	25.3	29.5	33.7	36.9	42.9	50.3	56.6	61.5	68.6	89.0
LSD†	0.8	2.1	2.0	3.1	2.7	2.8	4.5	3.7	8.4	5.7	6.6	6.3
LSD‡												7.2
LSD§												15.6
LSD¶												7.3
LSD#												15.7
LSD††												16.1

† LSD to compare seeding dates 1, 2, & 3 to seeding date 4 at 0.05 level of significance
‡ LSD to compare seeding dates 1, 2, & 3 to seeding date 5 to 0.05 level of significance
§ LSD to compare seeding dates 1, 2, & 3 to seeding date 6 to 00.5 level of significance
¶ LSD to compare seeding date 4 to seeding date 5 at 0.05 level of significance
# LSD to compare seeding date 4 to seeding date 6 at 0.05 level of significance
†† LSD to compare seeding date 5 to seeding date 6 at 0.05 level of significance

Seeding date 1 took the longest amount of time at 36.0 days and was statistically similar to seeding date 2 at 35.3 days. After these two initial seeding dates, dates 3-6 were all similar to each other where the amount of days to reach stage V4 was 32.0 days for date 3, 30.8 for date 5, 29.5 for date 6, and date 4 took the shortest amount of time at 29.3 days. Seeding dates 1 and 2 both took the longest amount of time to reach growth stage V5 at 40.3 days, but were statistically different from the rest of the seeding dates. Seeding date 3 took 37.5 days to reach stage V5 and was statistically similar to date 4, which took 35.0 days and date 5 at 36.3. Seeding dates 4 and 5 were also statistically similar to seeding date 6, which took the shortest amount of time at 33.7 days.

When the soybean entered the reproductive stages there was a shift to more statistical similarities as compared to the vegetative stages at Prosper 2014. Seeding date 1 took the longest amount of time to reach stage R1 at 47.0 days and was statistically similar to seeding date 2, which took 45.9 days. Seeding dates 3, 4, and 5 were all statistically similar to each other at 41.3, 40.9, and 38.8 days, respectively, but dates 4 and 5 were also statistically similar to seeding date 6, which took 36.9 calendar days to reach growth stage R1.

Environment: Lisbon 2015

The difference of calendar days between the first seeding date to reach a specific growth stage and the last seeding date to reach that same growth stage at the Lisbon 2015 environment (Table 21) was larger than its 2014 counterpart (Table 19). The only vegetative growth stage that had a difference of less than 10 days was V3 at 9.3 calendar days. The vegetative stage with the largest difference was V2, which had a 14 day difference. The difference in calendar days began to widen as the soybean shifted from vegetative to reproductive growth stages. In the reproductive stages there was no growth stage that had a difference less than 15 calendar days. The number of days between the first and last seeding date to reach the growth stage began to widen with each successive growth stage, culminating in a difference of 24.5 calendar days at the growth stage R7.

Although Lisbon 2015 began the growing season with 79.1 mm of precipitation above the normal for this environment it became increasingly drier as the growing season progressed (Table 4). In the month of July the amount of precipitation was 44.7 mm below the normal and September had even less at 58.2 mm below the normal (Table 4). This dry weather would have made it difficult for the soybean to obtain the proper amounts of water they need to grow and develop, especially at the later seeding dates. This late season dry weather was also coupled with above average temperatures with September being 3°C above the normal and October being 2°C above normal. These warmer temperatures coupled with the dry conditions would have created a large amount of drought stress for the soybean plants that were planted later in the year, which would have been in the later reproductive stages where the pods were beginning to fill.

Table 21. Mean calendar days to reach growth stages from planting averaged across three cultivar maturity ratings at Lisbon, ND, in 2015.

	V1	V2	V3	V4	V5	R1	R2	R3	R4	R5	R6	R7
					— calendar days —							
D1	25.0	31.0	36.3	40.3	46.1	45.8	52.0	58.5	66.3	73.6	85.5	113.7
D2	22.0	27.6	31.8	36.8	41.3	40.8	46.3	52.5	60.8	67.9	68.0	100.0
D3	20.0	26.8	29.9	34.9	37.0	38.5	43.8	49.5	56.8	64.3	73.3	101.8
D4	16.0	19.6	24.3	31.1	37.4	34.8	39.3	45.3	53.5	60.0	69.3	97.5
D5	17.0	20.8	24.5	30.0	36.5	33.3	38.8	45.1	52.4	60.8	70.3	95.6
D6	13.5	17.0	20.3	27.0	32.6	30.8	36.1	41.9	49.1	57.3	64.9	89.2
LSD†	0.8	2.1	2.0	3.1	3.2	2.8	4.5	3.7	8.4	5.7	6.6	6.1
LSD‡					3.5							
LSD§					3.6							
LSD¶					3.3							
LSD#					3.5							
LSD††					3.7							

† LSD to compare seeding dates 1, 4, & 6 to seeding date 2 at 0.05 level of significance
‡ LSD to compare seeding dates 1, 4, & 6 to seeding date 3 at 0.05 level of significance
§ LSD to compare seeding dates 1, 4, & 6 to seeding date 5 at 0.05 level of significance
¶ LSD to compare seeding date 2 to seeding date 3 at 0.05 level of significance
# LSD to compare seeding date 2 to seeding date 5 at 0.05 level of significance
†† LSD to compare seeding date 3 to seeding date 5 at 0.05 level of significance

Environment: Prosper 2015

Prosper 2015 was very consistent in the difference of calendar days between the seeding dates throughout the growing season (Table 22). In the vegetative growth stages, the largest difference was seen at stage V3, which had a 14-calendar day difference between the first to reach the growth stage and the last. Stage V5 had a 13.6 calendar day difference and V2 had an 11.6 day difference, which were very similar to stage V3 in the amount of calendar day difference. Stages V1 and V4 had a calendar day difference of 12.3 and 12.4, respectively, which further illustrates the lack of variation between the number of days it took the seeding dates to reach their respective growth stages.

Table 22. Mean calendar days to reach growth stages from planting averaged across three cultivar maturity ratings at Prosper, ND, in 2015.

	V1	V2	V3	V4	V5	R1	R2	R3	R4	R5	R6	R7
						— calendar days —						
D1	25.3	29.3	35.6	39.0	44.6	47.3	53.1	59.1	62.3	75.3	84.7	111.8
D2	22.5	26.8	30.2	37.0	40.3	42.2	47.7	54.4	60.8	67.1	78.5	105.8
D3	19.2	24.3	30.0	34.3	36.9	38.3	44.8	50.7	57.5	65.9	74.6	100.7
D4	16.1	21.0	25.8	29.4	34.4	36.4	41.2	47.3	54.8	62.1	70.6	100.1
D5	27.0	31.2	34.3	38.8	42.4	45.9	50.6	57.3	63.7	71.0	80.3	107.6
D6	13.0	17.7	21.6	26.6	31.0	32.5	37.7	42.7	49.5	57.5	67.4	95.7
LSD†	0.8	2.1	2.0	3.1	3.1	2.8	4.5	3.7	8.4	5.7	6.6	6.1
LSD‡					3.2							
LSD§					2.9							
LSD¶					2.9							
LSD#					3.3							
LSD††					3.0							
LSD‡‡					3.0							
LSD§§					3.1							
LSD¶¶					3.1							
LSD##					2.9							
LSD†††					2.8							

† LSD to compare seeding date 1 to seeding date 2 at 0.05 level of significance
‡ LSD to compare seeding date 1 to seeding date 3 at 0.05 level of significance
§ LSD to compare seeding date 1 to seeding dates 4 & 6 at 0.05 level of significance
¶ LSD to compare seeding date 1 to seeding date 5 at 0.05 level of significance
# LSD to compare seeding date 2 to seeding date 3 at 0.05 level of significance
†† LSD to compare seeding date 2 to seeding dates 4 & 6 at 0.05 level of significance
‡‡ LSD to compare seeding date 2 to seeding date 5 at 0.05 level of significance
§§ LSD to compare seeding date 3 to seeding dates 4 & 6 at 0.05 level of significance
¶¶ LSD to compare seeding date 3 to seeding date 5 at 0.05 level of significance
LSD to compare seeding date 4 to seeding date 6 at 0.05 level of significance
††† LSD to compare seeding dates 4 & 6 to seeding date 5 at 0.05 level of significance

The reproductive growth stages at Prosper 2015 also had the same lack of variation when it came to the calendar day differences in relation to the seeding dates. Growth stage R5 had the largest difference between the first and last seeding date to reach this growth stage at 17.8 calendar days, but was followed closely by stage R6 at 17.3 calendar days. The smallest difference in the reproductive growth stages was seen at stage R1, which had a 14.8 calendar day difference.

When comparing the number of days it took the maturity ratings to progress from seeding to growth stage R7, the observed trend was that the soybean planted later in the growing season the shorter number of days it took for them to reach physiological maturity. This is in comparison to the soybean that were planted at the early seeding dates, which took a longer number of days to mature. This decrease in the number of days would have detrimental effect on the yield of the soybean because of the inadequate amount of time that the plants have to mature and would be pushed to quickly produce seeds to continue its genetic lineage. These seeds would be lighter and possibly less viable than the ones at the early seeding dates that would have time to adequately allocate nutrients to producing full-sized and high yielding seeds. This would also emphasis the decrease in yield that was observed from the early to late seeding dates.

Calendar days summary

When approaching the number of days it took for the soybean to reach their growth stages, the commonality across all environments was that the number of days between the first and last seeding date to reach a growth stage increased with each successive stage. Soybean progressing through the vegetative stages had less of a difference between the first and the last seeding date to reach a stage where they were mostly in the single digits or in the low teens as far as separation between the days. This is compared to the reproductive stages that had wider ranges that were typically in the higher teens and low twenties as far as number of days. Soybean plants also took less days to reach maturity from seeding as the seeding dates were delayed further into the growing season. This is in contrast to what Lussenden (1987) reported where there was no difference in the number of days for soybean seeded early in the growing season and those that were seeded late.

Soybean at each environment and seeding date took a longer amount of time to progress through the reproductive growth stages as opposed to the vegetative growth stages (Tables 22 to 27). The percentage of time that soybean were in the vegetative growth stages also decreased as seeding dates were delayed further into the growing season at each environment. This is what would be expected due to the photosensitive nature of soybean where the later seeding dates would have been exposed to a change in the photoperiod early in their development which would have triggered the plants to progress into the reproductive growth stages earlier than soybean that were planted earlier in the growing season.

This separation between the vegetative and reproductive growth stages illustrates that soybean planted later in the growing season progress through the stages at a quicker rate than those that are planted early in the season. This could be due to multiple factors including an increased amount of growing degree days early on in the plant's life, or due to the shortening photoperiod that would trigger the reproductive stages in the soybean plants. Overall, the decreased amount of time that the plants have to develop when planted later in the season most likely has a negative effect on the ability of the soybean plants to adequately produce full seeds and obtain higher yields.

Accumulated growing degree days

The amount of accumulated growing degree days was significant for the interaction of environment by date (Table 17). Across all cultivars and environments, the amount of accumulated growing degree days decreased as seeding was delayed further into the growing season when looking at the total amount of growing degree days from seeding to growth stage

R1 and from stage R1 to R7. This would indicate that there are physiological differences in the vegetative and reproductive growth periods when soybean are planted later in the growing season.

Environment: Carrington 2014

While investigating the amount of accumulated growing degree days (AGDDs) for the soybean to progress from seeding to R1, soybean at seeding date 1 had the highest amount of AGDDs at 431.2 and was significantly different from all other seeding dates (Table 23). Seeding dates 2, 3, and 4 were all similar with the amount of AGDDs being 394.5, 396.3, and 371.5, respectively. Seeding dates 5 and 6 took less time than seeding dates 1, 2, and 3, but were similar to seeding date 4 where seeding date 5 took 364.0 AGDDs to reach stage R1, while seeding date 6 took 349.7 AGDDs.

Table 23. Growing degree days (GDD) from planting to growth stage R1 and stage R1 to R7 averaged across three cultivar maturity ratings at Carrington, ND, in 2014.

Seeding date	Planting – R1	% total GDD	R1-R7	% total GDD	Total
	GDD		GDD		GDD
Date 1	431.2	47	550.0	53	981.2
Date 2	394.5	46	471.1	54	865.6
Date 3	396.3	47	443.3	53	839.6
Date 4	371.5	47	415.8	53	787.3
Date 5	364.0	48	393.0	52	757.0
Date 6	349.7	51	339.7†	49	689.4†
LSD (0.05)	31.6		45.9		

†Soybean at seeding date 6 failed to reach growth stage R7 for this environment. The amount of accumulated GDD was measured from planting to harvest.

Similar to the trend that was observed in the amount of AGDDs for the soybean to progress from seeding to stage R1, soybean progressing from stage R1 to R7 was comparable to what was noted before, but the difference between the longest and shortest amount of AGDDs was much less (Table 23). Seeding date 1 took the greatest amount of AGDDs to reach stage R7 with 550.0 days and was significantly different from all other seeding dates. Seeding date 6 took the fewest AGDDs to progress through the growing stages with 339.7 days and was also significantly different from all other seeding dates. The wide range of AGDDs at this environment is emphasized by the difference between the highest and lowest amount of AGDDs increasing from 81.5 days from seeding to R1 to 210.3 days from R1 to R7. This increase in the range would indicate that the soybean weren't developing at an efficient rate due to a lack of precipitation that was seen later in the growing season. Soybean seeded at date 6 failed to reach growth stage R7, which was most likely due to this lack of moisture, which wouldn't have allowed the soybean plants to fill their pods properly and produce yield.

Environment: Lisbon 2014

At the Lisbon 2014 environment, seeding date 1 had the greatest amount of AGDDs to go from seeding to stage R1 with 432.8 days, which was statistically similar to seeding date 2 that had a total of 405.4 AGDDs to reach stage R1 (Table 24). The decrease in the amount of AGDDs as seeding was delayed further into the growing season at Lisbon 2014 was steady and gradual with the amount of AGDDs decreasing by about 20 GDDs with each successive seeding date. Seeding date 6 took the shortest amount of time to reach growth stage R1 with 343.1 AGDDs, but was statistically similar to both seeding date 4 and 5 with 370.5 and 365.3 AGDDs, respectively. This environment also had the largest amount of separation between the highest and lowest number of AGDDs for soybean to progress from seeding to R1 with a decrease of 89.7 AGGDs between seeding date 1 and 6.

The amount of AGDDs it took soybean at each of the seeding dates to progress from R1 to R7 produced three distinct groupings**.** Soybean planted at date 1 had the highest amount of AGDDs to progress from stage R1 to R7 with 588.9 days, but was also statistically similar to seeding dates 2 and 3 at 565.4 and 552.7 AGDDs, respectively. Following this initial group of seeding dates, there was a sharp drop in the amount of AGDDs at seeding dates 4 with this date taking 498.8 AGDDs to progress from stage R1 to R7. A sizable drop in the amount of AGDDs was observed after seeding date 4, where date 5 took 445.6 AGDDs to progress through the reproductive stages, and seeding date 6 had the smallest amount at 421.6 days.

Table 24. Growing degree days (GDD) from planting to growth stage R1 and stage R1 to R7 averaged across three cultivar maturity ratings at Lisbon, ND, in 2014.

Seeding date	Planting – R1	% total GDD	R1 – R7	% total GDD	Total
	GDD		GDD		GDD
D1	432.8	42	588.9	58	1021.7
D2	405.4	42	565.4	58	970.8
D3	395.8	42	552.7	58	948.5
D4	370.5	43	498.8	57	869.3
D5	365.3	45	445.6	55	810.9
D6	343.1	45	421.6	55	764.7
LSD (0.05)	31.6		45.9		

Environment: Prosper 2014

Soybean planted on date 1 at the Prosper 2014 environment had the greatest amount of AGDDs to go from seeding to growth stage R1 (Table 25). This was also significantly similar to seeding date 2 which took 452.8 AGDDs. Seeding date 6 had the lowest amount of AGDDs to reach stage R1 with 379.2 days and was significantly similar to seeding date 5 at 405.3 GDDs.

Table 25. Growing degree days (GDD) from planting to growth stage R1 and stage R1 to R7 averaged across three cultivar maturity ratings at Prosper, ND, in 2014.

Date	Planting –R1	% total GDD	R1 – R7	% total GDD	Total
	GDD		GDD		GDD
D1	468.0	44	599.8	56	1067.8
D2	452.8	44	584.1	56	1036.9
D3	432.4	44	559.2	56	991.6
D4	426.8	47	489.0	53	916.8
D5	405.3	46	481.3	54	886.6
D6	379.2	45	468.9	55	848.1
LSD (0.05)	31.6		45.9		

When looking at the amount of AGDDs it took the soybean to progress from growth stage R1 to R7, the Prosper 2014 environment had the most parity amongst all the environment as well as having the least amount of separation between the largest and smallest amount of AGDDs for the soybean to progress through the reproductive stages. Seeding date 1 had the highest amount of AGDDs to go from growth stage R1 to R7 at 599.8 day, but this was also statistically similar to seeding dates 2 and 3 that took 584.1 and 559.2 AGDDs to reach stage R7, respectively. Seeding date 6 had the least amount of AGDDs to reach stage R7 with 468.9 days. This was also similar to seeding dates 4 and 5 that had 489.0 and 481.3 days, respectively. These two groups of statistically similar seeding dates are highlighted by a major decrease in the amount of AGDDs between dates 3 and 4 and could possibly show a point, at this environment, in which the soybean were pushed to progress through the reproductive growth stages at a much faster rate than their early season planted counterparts.

Environment: Lisbon 2015

The difference between the largest and smallest number of AGDDs was the lowest at the Lisbon 2015 environment in regards to the amount of GDDs for the soybean to progress from seeding to growth stage R1 with a separation of 55.2 AGDDs between seeding date 1, which had 430.2 AGDDs, and seeding date 5, which had a total of 374.6 days (Table 26). Seeding dates 2 and 3 were statistically similar to seeding date 1 where seeding date 2 took 418.3 days and seeding date 3 took 404.2 AGDDs. Seeding dates 3, 4 and 5 were also significantly similar to seeding date 5 with dates 4 and 6 taking 380.5 and 375.0 AGDDs to reach stage R1, respectively. This presents two groupings that all the seeding dates fall into with the separation between early planted and late planted soybean at this environment; however, this is different from the groupings that were seen at the Prosper 2014 environment where there was a sharp drop in the amount of AGDDs between seeding dates 3 and 4.

Table 26. Growing degree days (GDD) from planting to growth stage R1 and stage R1 to R7 averaged across three cultivar maturity ratings at Lisbon, ND, in 2015.

Date	Planting – R1	% total GDD	R1 – R7	% total GDD	Total
	GDD		GDD		GDD
D1	430.2	37	743.6	63	1173.8
D2	418.3	36	740.0	64	1158.3
D3	404.2	37	688.4	63	1092.6
D4	380.5	38	623.3	62	1003.8
D5	374.6	38	613.5	62	988.1
D6	375.0	42	525.2	58	900.2
LSD (0.05)	31.6		45.9		

Although Lisbon 2015 had the smallest difference between AGDDs for the soybean to progress from seeding to growth stage R1, the difference in the amount of AGDDs for the plants to go from R1 to R7 was the highest at this environment with a separation of 218.4 GDDs. Seeding date 1 had the largest amount of AGDDs to reach stage R7 with 743.6 days and was only statistically similar to seeding date 2 with 740.0 GDDs. From that point there were two sharp drops in the amount of AGDDs at this environment. The first was between dates 3 and 4, where the amount of AGDDs went from 688.4 days at seeding date 3 to 623.3 days at seeding date 4. The second sharp drop was seen between dates 5 and 6 where seeding date 5 accumulated 613.5 AGDDs to reach growth stage R7 and date 6 had the smallest amount of AGDDs to reach R7 with 525.2 days.

Environment: Prosper 2015

At the Prosper 2015 environment, the largest amount of AGDDs for soybean to progress from seeding to stage R1 was observed at seeding date 1 where there it took a total of 434.0 GDDs (Table 27). This was statistically similar to seeding date 2 at 416.7 GDDs. The least amount of AGDDs to reach growth stage R1 was seen at seeding date 6, which had 368.8 days. It is interesting to note that while this seeding date had the smallest amount of AGDDs it was statistically similar to seeding dates 3, 4, and 5, which had 392.0, 384.8, and 394.3 days to reach growth stage R1, respectively.

Table 27. Growing degree days (GDD) from planting to growth stage R1 and growth stage R1 to R7 averaged across three cultivar maturity ratings at Prosper, ND, in 2015.

Date	Planting – R1	% total GDD	R1-R7	% total GDD	Total
	GDD		GDD		GDD
D1	434.0	39	670.7	61	1104.7
D2	416.7	39	651.3	61	1063.0
D3	392.0	38	628.9	62	1020.9
D4	384.8	38	615.8	62	1000.6
D5	394.3	43	518.5	57	912.8
D6	368.8	43	495.8	57	864.6
LSD (0.05)	31.6		45.9		

For the amount of AGDDs for the soybean to go from growth stage R1 to R7, the largest amount was seen at seeding date 1, which had a total of 670.7 days. Seeding date 1 was also statistically similar to seeding dates 2 and 3, which had totals of 651.3 and 628.9 AGDDs, respectively. A very sharp decline in the amount of AGDDs was seen between dates 4 and 5 where seeding date 4 had a total of 615.8 days to reach R7 and then fell to 518.5 AGDDs for seeding date 5 to reach growth stage R7. The smallest amount of AGDDs was seen at seeding date 6, which had a total of 495.8 days.

Accumulated growing degree days summary

The number of AGDDs decreased as seeding was delayed into the growing season at each environment with the later seeding dates taking a significantly shorter amount of AGDDs to reach growth stages R1 and R7 than their early season counter parts. The most probable explanation for this is that soybean planted on dates 1 to 3 were reaching growth stage R1 around the same time that dates 5 and 6 were being planted. This later seeding would have caused an increase in the total amount of AGDDs that were accumulated initially as the soybean were germinated and increased the rate of metabolism in the plant that may have been unsustainable in the long-term. The late seeding dates would have also been after the shortening of the photoperiod, or 21 June, which triggers reproduction in soybean; therefore, emerged plants that were seeded later in the growing season would have sensed the shortening of the photoperiod and tried to reproduce as quickly as possible. In multiple instances, there were also steep drops in the number of accumulated AGDDs at different environments showing that there might be some kind of tipping point at these dates where the plant is triggered to progress through its growth stages at a faster rate. This could lead to inadequate development of the soybean plants, which would lead to lower yields for a grower. Growers who are forced to replant soybean in mid to late June should expect this as a result.

SUMMARY/CONCLUSION

Changes in seeding date can have many effects on the growth and development of soybean. Whether it's seeding too early and getting a late spring frost that kills germinating plants, or seeding too late thus causing the plants to progress through their growth process at a more expedited rate where the effects on crop yield can be seen by a grower. This makes it important to understand what seeding dates are more successful than others and define a point when the loss of yield would no longer be acceptable economically.

Seeding date, maturity ratings, and environmental influences for three soybean cultivars were studied at Carrington, Lisbon, and Prosper, ND in 2014, and Lisbon and Prosper in 2015. Factors evaluated included grain yield, plant height, plant lodging, seed oil content, filled pods plant^{-1}, unfilled pods plant^{-1}, seeds pod^{-1}, seed weight, seeds plant^{-1}, harvest index, calendar and growing degree days in relation to the various growth stage.

In North Dakota, a yield less than 2016 kg ha^{-1} would be marginally economical to a soybean grower at current prices. Delayed seeding caused lower yields across all cultivar maturity ratings. Seeding date 3 was the critical stage at which soybean yield was approaching a yield that was less than 2016 kg ha^{-1} with seeding date 4 hovering on or below that threshold. Soybean with a maturity rating of 1.4 had the most dramatic response in terms of yield loss when seeding was delayed further into the growing season.

The effects of location on soybean was most prominent at the cooler and shorter growing season Carrington 2014 environment where plants produced yield that was lower than the other four environments. In addition, the Carrington 2014 environment had the lowest 1000 seed weights and there was less seed oil content. Soybean plants at this environment also took longer to reach physiological maturity. Soybean planted at the Lisbon and Prosper environments were similar in their growth and development with yields being equal to each other and the development of the plants taking roughly the same number of days.

Soybean that was planted later in the growing season took less days and growing degree days to reach physiological maturity. This can mostly be attributed to the shortening of the photoperiod at the earlier growth stages when the soybean were planted later, especially in seeding dates 5 and 6, which were planted after 1 July when the photoperiod begins to shorten. As seeding was delayed further into the growing season, soybean also spend a larger percentage of time in the vegetative growth stages compared to ones that were seeded earlier in the growing season. This would contribute to the lower yields as the soybean had less time to properly develop mature seeds.

Ultimately, the decision about spring seeding date and replanting at a later date involves many factors that a grower needs to consider such as the economic costs and agronomic information about the location and plant characteristics. Growers should be advised that seeding soybean in mid to late June will result in lower yields than soybeans planted at the recommended seeding dates around 31 May and will lead to less profits. Conversely, should a grower be put in a position where they would need to replant their soybean crop, soybean could be planted as late as 22 June and still achieve marginally economical yields if planting a CMR of 00.9 or 0.7.

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APPENDIX. DESCRIPTION OF SOYBEAN GROWTH STAGES

Growth Stage	Description
VE	Cotyledons above soil surface.
VC	Unifoliate leaves unrolled where leaf edges are not touching.
V1	Fully developed leaves at unifoliate node
V(n)	"n" represents the number of nodes with fully developed leaves. Example: V3 would have 3 nodes, including the unifoliate, with fully developed leaves
R1	One open flower at any node on the stem
R2	One open flower on the two uppermost nodes
R3	3/16" long pod at one of the four uppermost nodes
R4	3/4" long pod at one of the four uppermost nodes
R5	1/8" long seed in a pod on one of the four uppermost nodes
R6	Pod at one of the four uppermost nodes contains a green seed that fills the pod cavity
R7	One full pod on the main stem has reached mature pod color
R8	95% of pods have reached mature pod color.

†Growth stages defined by Endres and Kandel (2015)