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EFFECTS OF LATE PLANTING DATES, MATURITY GROUPS AND MANAGEMENT SYSTEMS ON GROWTH, DEVELOPMENT AND YIELD OF SOYBEAN IN SOUTH CAROLINA

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EFFECTS OF LATE PLANTING DATES, MATURITY GROUPS AND MANAGEMENT SYSTEMS ON GROWTH, DEVELOPMENT AND YIELD OF SOYBEAN IN SOUTH CAROLINA

A Thesis
Presented to
the Graduate School of
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In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Plant and Environmental Science

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by
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Accepted by:
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ABSTRACT

Planting date plays a significant role in determining soybean growth, development and seed yield. The objectives of this experiment were to evaluate the effects of late planting date, management system, and maturity group on the growth, development and seed yield of maturity group VII and VIII soybean under dry land conditions in the Southeastern coastal plain of the United States. Plant growth and development, seed yield, yield components, and seed oil and protein concentrations were evaluated throughout the season. These experiments were conducted in South Carolina at the Edisto Research and Education Center near Blackville and the Pee Dee Research and Education Center near Florence. Soybean was planted at four weekly intervals starting on 15-June in both 2011 and 2012. Pioneer 97M50 (a MG VII determinate variety) and Prichard Roundup Ready (a MG VIII determinate variety) were selected based on their adaptation to the Southeast. The two management systems were: a strip-till (ST) system using a John Deere MaxEmerge Vaccum planter + Unverferth 300 strip till with 96-cm row spacing and a drilled no-till (NT) planting system with 19-cm row spacing. Plant growth was evaluated based on leaf area index (LAI), Normalized Difference Vegetation Index (NDVI), and plant height (HT). Plant development was calculated based on the duration (days) of growth stages. Growth stages were recorded weekly from 10 randomly selected plants in each plot. The beginning of each stage was determined when at least 50% of plants were at that stage. Overall, planting after 22 June appeared to reduce seed yield. The ST system increased the seed yield compared to the drilled NT system. Yields were greater for the MG VIII variety than the MG VII variety. LAI, NDVI, and HT at R2 and

R4 were generally reduced with delayed planting dates. Later planting shortened the duration of both vegetative and reproductive growth stages for both MG VII and VIII soybeans. Shortened duration of vegetative growth and seed filling period might have contributed most to the lower yields observed in delayed planting dates. Planting date did not affect either protein or oil concentration. Protein concentration in the seed was found to be significantly higher and oil concentration lower in soybean grown in the ST system than in the drilled NT system. Positive correlations were found between: seed yield and LAI, NDVI, and HT at R2 and R4; seed yield and duration of vegetative and seed filling growth period; and seed yield and dry weight of each plant part (branches, stems, petioles, leaves, and pods).

DEDICATION

This thesis is dedicated to everyone who has loved and supported me while I was working on my M.S. degree at Clemson University, especially my parents. Their unconditional love and support gave me the spirit to accomplish all this.

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1 CHAPTER ONE

EFFECT OF PLANTING DATE ON SOYBEAN GROWTH, YIELD, AND GRAIN QUALITY: REVIEW

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Planting date can affect soybean growth, development, grain yield (Zhang et al., 2010), and grain quality (Rahman et al., 2005). Optimum planting date is important for soybeans to grow and develop healthily, and maintain the grain yield potential. The effect of planting date on soybean grain yield depends on genetic and environmental conditions greatly (Egli and Cornelius, 2009). For example, Robinson et al. (2009) reported that optimum planting dates for soybean grown in Indiana are from April to early May and yields would be lower for planting before or after that critical time. Mayers et al. (1991a) observed a marginal biomass and yield increase of late planted soybeans due to delayed flowering. Based on a planting date study conducted in Georgia from early April to early July, planting from May to early June was the optimum time for Maturity Group (MG) V to VIII soybean varieties (Parker et al., 1981). Decianzio et al. (1991) reported highest soybean yields from March and May plantings in cropping systems, based on a 2-yr study conducted in Puerto Rico in 1991. According to Tremblay et al. (2006), planting from mid- to late May resulted in highest soybean grain yields in Quebec, Canada.

Grain yields are generally greater from earlier planted soybeans due to longer duration of vegetative and reproductive growth stages (Chen and Wiatrak, 2010). Additionally, soybean grain yield is correlated with length of flowering, pod set (Egli and

Bruening, 2000), and seed filling (Andrade, 1995). Weaver et al. (1991) found that the duration of seed filling was reduced in later planting dates for both indeterminate and determinate soybean varieties. Heatherly (2005) reported that late planting date reduced duration of both vegetative and reproductive growth stages of MG IV through VI soybeans. He also indicated that the major difference was from the length of vegetative rather than reproductive stage.

Too early planting dates usually accompany with cool soil temperatures. Cool and wet soil conditions may delay the soybean seed emergence (Andales et al., 2000), reduce the canopy development and grain yield (Kane et al., 1997a; Steele and Grabau, 1997). Early planted soybean also has a higher chance to be exposed to late spring frost (Meyer and Badaruddin, 2001), and early season insects such as bean leaf beetles (Lam et al., 2001).

Planting after the optimum time usually leads to final yield loss. Delayed planting after May 1st decreased soybean grain yield in the north central (Bastidas et al., 2008) and upper Midwest US (De Bruin and Pedersen, 2008b). Popp et al. (2002) recorded lower grain yield from later than April and May planting in non-irrigated fields in the mid-southern US. Soybean planted in the northeastern US in mid-June had fewer pods per plant and lower seed yield compared to mid-May planting (Cox et al., 2008). Combined analysis from experiments conducted in different regions of the US (Midwest, Upper South, and Deep South) indicated that soybean yield rapidly declined for planting after the critical date, which varies from late May to early June (Egli and Cornelius, 2009).

1.1 Soybean Growth and Yield

Correlation between soybean plant growth indices like LAI (Board and Harville, 1996), NDVI (Sellers, 1985), canopy closure (Steele and Grabau, 1997), crop growth rate (Egli and Bruening, 2000), radiation efficiency (Egli and Bruening, 2000) and grain yield have been reported in several studies. Bhatia et al. (1999) indicated that the reduction in the seed yield, due to late planting dates, was a combined effect of reduced total biomass, pod number per plant, plant height, number of branches, seed weight, and time from planting to flowering and maturity.

Sincik et al. (2009) reported a significant relationship between grain yield and plant LAI in 2009. Based on their study, grain yield was negatively correlated with LAI at V5 stage, but positively correlated with LAI at R4 and R6 stages. Board and Harville (1996) also observed a positive correlation between LAI and grain yields. Another plant growth index, NDVI is closely related to the photosynthetic capacity and energy absorption of plant canopies (Sellers, 1985). Chlorophyll absorbs visible light (Tucker, 1979) and cell structure of plant strongly reflects near-infrared light (Flenet et al., 1996). The canopy reflectance of NIR and red (RED) light are used to calculate the plant NDVI: NDVI = (NIR – RED)/(NIR + RED) (Stone et al., 1996). Greater NDVI values can be observed in vigorously growing plants due to low RED and high NIR values.

Steele and Grabau (1997) found that canopy closure at R2 or R5 stage has a good correlation with soybean yield. Seed number per area was significantly correlated with crop growth rate during flowering stages (R1- R3) and pod set (R3- R5) stages (Egli and Bruening, 2000; Vega et al., 2001). Seed and pod numbers had the greatest impact on grain yields (Robinson et al., 2009; Kantolic and Slafer, 2001). More specifically, numbers of pods and seeds on the main stem (Ouattara and Weaver, 1995) and branches (Frederick et al., 2001) both positively correlated with yield. Akhter and Sneller (1996) reported that soybean planted in April had higher number of branches, more pods per branch, and higher percentage of grain yield from branches than June-planted soybeans. And these trends are more significant for indeterminate soybeans. Weaver et al. (1991) also indicated that indeterminate varieties had less yield loss due to delayed planting, although determinate soybean yielded higher than indeterminate plants.

Plant height is one important agronomic trait in soybean cultivar selection. This selection is based on the association of these agronomic traits with seed yield and stability (Byth et al., 1969; Lin and Nelson, 1988; Hiebsch et al., 1990; Akhter and Sneller, 1996). Hicks et al. (1969) indicate that soybean plant height increased with higher seeding rate and narrower row width. It can also be affected by planting date (Bastidas et al., 2008; Moosavi et al., 2011), and the effect varies according to different growth habits or locations (Pedersen and Lauer, 2003). Weaver et al. (1991) indicate that plant height of indeterminates was reduced more with late planting. Pedersen and Lauer (2003) found that plant height can be affected by planting date, but the result is location dependent. Early planting resulted in 4% taller plants in Arlington, WI, but no difference was observed between planting dates in Hancock, WI. Plant height was reduced for both determinate and indeterminate soybeans planted in April compared to May and June planting in mid-southern US (Akhter and Sneller, 1996). A 4-yr experiment conducted in Alabama showed that plant height was decreased more for July than June planting

(Weaver et al., 1991). Bastidas et al. (2008) observed a curved response of plant height to delayed planting, based on the result that earlier planting led to more nodes, but also resulted in shorter internodes between three and nine nodes.

Radiation use efficiency (RUE, intercepted photosynthetically active radiation in g dry matter MJ^{-1}) is an important function of crop productivity (Monteith, 1972). Radiation interception during the critical periods for grain set was significantly and directly correlated with soybean grain yield (Andrade et al., 2002). The RUE was found to be reduced in late planted MG III and IV soybean cultivars (Egli and Bruening, 2000). Final biomass responded linearly to cumulative intercepted photosynthetically active radiation until it reached 400 MJ m^{-2} and it began to decrease with radiation levels exceeding 400 MJ m^{-2} (Purcell et al., 2002). Light intercepting at reproductive stage were also suggested to affect nitrogen concentration in plant leaves (Asanome and Ikeda, 2000). They found that nitrogen accumulation in vegetative organs contributed to increased nitrogen partitioning into the pod and nitrogen partitioning from leaf and stem was higher in light use efficient plants.

Considering the importance of root function to soybean plant growth, Turman et al. (1995b) found that mid-May planted soybean in Missouri had more extended root depth at 30 d after emergence than mid-June and early July planting. Another experiment conducted by Turman et al. (1995a) indicated that earlier than normal planting date of four maturity group (MG III, IV, V, and VI) soybeans inhibited early root growth, but did not reduce yield, suggesting that the root may not be an important factor in cultivar selection.

1.2 Grain Quality

Planting dates change the seed composition by changing the content of oil (Muhammad et al., 2009), protein (Kumar et al., 2006), and some other components. Tremblay et al. (2006) and Kumar et al. (2006) found that oil content decreased with delayed planting dates and temperature is thought to be related with this response. Kane et al. (1997c) found that lower temperature during seed filling with delayed planting was strongly correlated with reduced oil content. Muhammad et al. (2009) also suggested that high temperature of early planting was related to high oil content.

Results showing planting date effect on soybean protein content were not consistent. Several studies found that protein content stays relatively constant across different planting dates (Tremblay et al., 2006; Bajaj et al., 2008). Billore et al. (2000) and Muhammad et al. (2009) reported that soybean protein content has decreased with delayed planting, and decreased seed size might have contributed to it. Kumar et al. (2006) indicated that the shortened duration from flowering to maturity might have contributed to reduction of protein accumulation. However, Kane et al. (1997c) and Tremblay et al. (2006) noted that delayed planting increased protein content of several soybean cultivars. Bellaloui et al. (2011) suggested that lower temperature during seed filling might be a possible reason for increased protein content.

It is well documented that there is a negative correlation between oil and protein concentration, which is affected not only by genetic variation, but also environmental factors (Hymowitz et al., 1972; Watanabe and Nagasawa, 1990). Gibson and Mullen (1996) found that the oil content increased with increasing temperature up to 28 ℃, above which the oil content began to decline; while the protein concentration remained relatively constant with temperature below 28 ℃, above which the protein concentration slightly increased. According to Rotundo and Westgate (2009), high temperature (>26 ℃) significantly decreased the oil concentration, while the protein concentration was less affected. High temperature has been found to decrease the seed-filling duration (Chimenti et al., 2001), which may be one of the most possible reasons to explain the reduction in oil and protein content. However, high temperature may also improve the N remobilization (Triboi and Triboi-Blondel, 2002), which may help explain why the protein content is less affected than oil content. Kane et al. (1997c) reported that higher temperatures during seed fill, associated with early planting, were strongly correlated with increased oil and oleic acid, and reduced linolenic acid content.

Rotundo and Westgate (2009) found that water stress during seed filling reduced protein, oil, cell walls, soluble carbohydrates, and minerals accumulation. However, protein content has been reduced to a lesser extent in the study, thus resulting in increased protein concentration and decreased oil concentration. It has been well reported that water stress shortened the seed filling duration (Westgate et al., 1989; Desclaux and Roumet, 1996; Egli and Bruening, 2004), which reduced the accumulation of many seed components. However, protein synthesis was less affected by water stress, because of the increased rate of N remobilization (Chapin et al., 1990; Turner et al., 2005).

1.3 Environmental Factors

Soybean grain yield can be influenced greatly by overall environmental conditions. Environmental factors such as photoperiod (Kumudini et al., 2007), precipitation, and temperature (Chen and Wiatrak, 2010) and the combination of them can greatly affect the yields. Photoperiod regulates soybean development from emergence to maturity (Han et al., 2006). Early planting time exposes soybean plants to longer post-flowering photoperiod (Kumudini et al., 2007). Reproductive development of several soybean varieties was found to be influenced by post-flowering photoperiod, and leaf senescence regulation seems to depend on photoperiod sensitivity too. Short photoperiod (10, 12 h) promoted leaf senescence, but long photoperiod (15, 16, or 18 h) during R1, R3, or R5 stages delayed s the leaf senescence and seed maturity of some late maturing soybean cultivars (Han et al., 2006). In addition, exposing soybean to long photoperiod during post-flowering stages extended the duration from R3 to R6, and increased the total number of seed (Kantolic and Slafer, 2005). In their study, extended artificial photoperiod (1.5, 3.0, 4.5, and 6.0 h) increased the duration from R3 to R6. Moreover, the extended photoperiod increased the number of nodes per plant, and the number of pods and seeds per unit area. Even though seed size was reduced by 20%, seed number was increased by more than 75%. Egli and Bruening (1992) suggested that lower insolation during reproductive growth stages with delayed planting is the primary reason for grain yield decrease.

Temperature also has a significant effect on soybean plant growth, development, seed yield, and seed composition. The increase in temperature may have negative or positive effects, depending on the range of the temperatures (Bellaloui et al., 2011). (Mayers et al., 1991b) indicated that temperature has a direct effect on soybean growth rate, since thermal time had a better correlation with plant dry matter accumulation than crop duration. Saitoh et al. (1998) reported an increase of soybean grain yields with higher temperature. Lal et al. (1999) indicated that plants are more sensitive to higher cumulative heat units, based on the result that 3 ℃ increase in maximum temperature led to 50% decrease in soybean seed yield. Zheng et al. (2009) concluded that grain yields increased by 6 to 10% for each 1 ℃ increase in daily maximum temperature during seed filling stages, but temperature above the optimum could reduce soybean growth and yields.

The effect of temperature stress on soybean seed yield and quality also depends on its occurring time. Khan et al. (2011) found that increase in mean air temperature from 23 to 30 ℃ during soybean growth stages led to varied effects on seed quality and vigor. Temperature increase during R6 to R7 improved germination rate, seedling dry weight, and seed protein and oil content. However, increased temperature from seed initiation (R5) to full seed (R6) reduced seed germination, protein, and oil content. They also noted that increase in maximum temperature from 32 to 37 ℃, during full bloom (R2) to seed initiation (R5), decreased seedling dry weight and seed oil content. Temperature during seed filling has showed greatest impact on soybean seed yield (Zheng et al., 2009; Mishra and Cherkauer, 2010).

Mishra and Cherkauer (2010) reported that soybean crop yields were strongly correlated with maximum daily temperature during seed filling (R5–R7) stages. Gibson and Mullen (1996) suggested that reduction in soybean seed yield and changes in seed composition was primarily the effect of high air daily temperatures. They found that the largest yield reduction (27%) occurred when the air temperature was 35 ℃ for 10 h d^{-1}

from flowering to maturity (R1–R8). Piper and Boote (1999) indicated that mean temperature has the highest correlation with oil and protein concentrations, rather than the highest or lowest temperature. Gibson and Mullen (1996) reported that both day and night temperature can affect the soybean seed composition. High daily air temperature imposed during flowering (R1–R3), pod set (R3–R5), and seed fill (R5–R7) stages decreased photosynthetic rates and seed growth (Gibson and Mullen, 1996). Wilhelm and Wortmann (2004) also indicated that extremely high temperature during summer has a negative effect on soybean yields. Djanaguiraman and Prasad (2010) showed that heat stress decreased photochemical efficiency by 5.8%, photosynthetic rate by 12.7%, and increased ethylene production rate, which triggered premature leaf senescence. In addition, heat stress decreased seed set by 18.6%, seed size by 64.5%, and seed yield per plant by 71.4% compared to optimum air temperature. Temperature effect on the yield also varied across different soybean maturity groups. Egli and Bruening (1992) indicated that 20% increase in maximum and minimum temperature reduced yield of June planted cultivar Williams, but increased yield of Essex soybean, based on a simulation model SOYGRO V5.41 and 17 yr of weather data from Kentucky, suggesting that low temperature may decrease yield of late-maturing soybean cultivars.

Soybean production is greatly influenced by precipitation (Egli and Bruening, 1992). The determination of optimum planting date should take the regional rainfall pattern into consideration, because without optimum water condition, the benefit of early planting time could be negated (Heatherly and Elmore, 1983). Early planting can decrease the risks of water stress during growing season in some regions (Bowers, 1995;

De Queiroz et al., 1998); however, planting is sometimes suggested to be delayed when there is adequate rainfall (Muchow et al., 1994). For example, a simulation model indicated the possibility to increase the soybean yield in Argentina through extending the growing season and delayed flowering stages to March and April when there is more adequate moisture (Sinclair et al., 1992).

The effect of water stress not only depends on the duration and intensity of the stress, but also the timing of occurrence (Desclaux and Roumet, 1996). Kirnak et al. (2008) found that drought stress imposed at R3, R5, and R6 stages resulted in high yield reduction compared to full irrigation treatment. Water stress before or during flowering increased the rate of soybean flower and pod abortion (Westgate and Peterson, 1993). Water stress imposed during seed development reduced seed size (DeSouza et al., 1997). Water stress during later phases of reproductive stages decreased the duration of the seed filling stage (Meckel et al., 1984), which was strongly correlated with seed try matter accumulation (Desclaux and Roumet, 1996; Frederick et al., 1991). Desclaux and Roumet (1996) also indicated that drought stress imposed during node emergence decreased node number and accelerated the development of reproductive stages. The most critical time of water stress are thought to be from late flowering to early seed development (Calvino et al., 2003). Frederick et al. (2001) noted that drought stress between initial flowering (R1) and seed filling (R5–R7) decreased the vegetative growth, seed number, and yield on branches, because most branch growth occurred between initial flowering and beginning of seed filling. Brevedan and Egli (2003) found that lower C exchange rate, which contributed to earlier maturity, also decreased with continuous water stress between R6 and R8 stages. Additionally, short period of water stress during the seed-filling stage accelerated leaf senescence. De Costa and Shanmugathasan (2002) reported that irrigation during the flowering stage increased the number of pods, the mean pod growth rate, and harvest index. During R4–R5 stages, the cells in the seeds and pods begin rapid expansion (Westgate and Peterson, 1993). Water stress during this period reduces photosynthesis and sugar production, and lower water potential in the leaves reduces the flow of metabolites to the expanding cells (Westgate and Peterson, 1993).

Jin et al. (2006) suggested that limited P translocation to seeds, due to drought stress, may be contributing to decreased grain yields of soybeans. In their experiment, the addition of P reduced the adverse effect of drought stress on plant growth and grain yield of soybean cultivars. They also observed greater yield decrease with drought stress occurring at R4 compared to R1 stage.

Soybean yield and seed number were also correlated with some other environmental factors such as carbon dioxide exchange rate (North Carolina soybean producers association). De Bruin et al. (2010) found that CER between R3 (beginning pod) and R6 (full seed) was positively correlated with the grain yield. However, early planting date did not increase the CER rate from R3 to R6 stage indicating that CER is less likely responsible for yield increase due to early planting. The experiments conducted in the outdoor, naturally sunlit, and environmentally controlled plant growth chambers in Florida, indicated that sufficient CO_2 improved soybean growth and grain yield (Baker and Allen, 1993). Delayed planting may also increase the occurrence of some late season diseases in soybean (Mcpherson and Bondari, 1991; Akem and

Dashiell, 1994; Grau et al., 1994). Delayed planting after 1 June increased the severity of frogeye leaf spot, which led to yield loss under Nigerian conditions (Akem and Dashiell, 1994). Grau et al. (1994) indicated that although delayed planting reduced the severity of brown stem rot, which is caused by *Phialophora gregata* W. Gams, the yield loss caused by delayed planting could not be compensated by disease control. Krell et al. (2005) showed that delayed planting from mid-March to mid-June is not an effective management tool for controlling disease caused by Bean pod mottle virus, based on a 3-yr experiment conducted in central Iowa. Mcpherson and Bondari (1991) investigated the influence of soybean planting date on abundance of velvet bean caterpillars [*Anticarsia gemmatalis* (Hübner)] and southern green stink bugs (*Nezara viridua* L.) and found that velvet bean caterpillar populations were more abundant in Braxton soybeans planted in early June than early May. However, southern green stink bugs number was higher in early May than mid-May or early June planted soybeans.

Altering planting dates between early May and late June was not effective in preventing yield decrease due to nematode *Hoplolaimus columbus* Sher, based on the research conducted in South Carolina (Perez et al., 1996). Todd (1993) suggested that delayed soybean planting does not appear to be a viable management option for cyst nematode *Heterodera glycines* Ichinohe management in southeastern Kansas. They reported that *H. glycines* density were lower for late planted than early planted susceptible soybeans in 1990; however, *H. glycines* population increase was more rapid for late planting dates in 1991. Koenning and Anand (1991) suggested that delayed soybean planting associated with double-cropping wheat may reduce nematode numbers and potential damage.

The effect of planting date on weed interference with soybeans varied across weed species. Mosier and Oliver (1995) found that soybean yield reduction from interference with entire leaf morning glory (*Ipomoea hederacea* (L.) Jacq. var. *integriuscula*) and common cocklebur (*Xanthium strumarium* L.) was not influenced by soybean planting date. Density of common cocklebur did not affect height, canopy width, or node number of MG IV soybean planted in April, May, and July (Rushing and Oliver, 1998). However, aboveground biomass of emerging common cocklebur was less from July than April or May planted soybean. Klingaman and Oliver (1994) found that soybean yield decreased due to entireleaf morning glory and sicklepod (*Senna obtusifolia* L.) as planting date was delayed from early May to early June. Young et al. (2003) found that overall soybean injury by postemergence herbicide was greater with late planting than early planting date in Iowa.

1.4 Conclusions

The yield reduction due to delayed planting seems to be a combined effect of photoperiod, temperature, and precipitation, which affect plant growth, vigor, and development. Delayed planting date may decrease the seed germination, root function, crop growth rate, plant height, duration of growth stages, radiation use efficiency, seed composition, LAI, NDVI, and thus grain yield of soybean. Photoperiod is one of the most important environmental factors that affect the soybean growth, because it regulates developmental processes of soybean. Shortened vegetative and reproductive stages, due to changes in photoperiod with delayed planting, contribute to yield loss. Temperature increases above a critical range and drought stress have a negative effect on plant development and yield. Other factors like shade stress, high light stress, pest interference (including disease, weeds, insects etc.) may also influence plant growth and grain yield. The effect of planting date on grain oil and protein content is not clear and varies for different locations. Generally, delayed planting will most likely decrease the plant growth, development, and yield due to combined effects of environmental conditions. Although the effect of planting date on soybean varies greatly across different locations and environmental conditions, it is important to plant soybean before the critical planting date to maintain high yield potential.

2 CHAPTER TWO

EVALUATING THE PLANTING DATE EFFECT ON MATURITY GROUP VII AND VIII SOYBEAN IN DIFFERENT MANAGEMENT SYSTEMS IN SOUTH CAROLINA

2.1 Introduction

2.1.1 Brief history of soybean and its uses

The center of origin of soybean is believed to be in Southeast Asia and it was first domesticated in China around 1100 BC. Now it is one of the most important field crops worldwide (Chen and Nelson, 2005). It is very widely used for human food, animal feed, and as an energy crop. Its high protein and oil content make it one of the most important cultivated crops around the world (Qiu and Chang, 2010). Soybean is now planted in many countries, with the United States, Brazil, Argentina, China and India being the top five soybean-producing countries (Masuda and Goldsmith, 2009). Soybean was first introduced to the US in 1765. Soybean was grown in the Midwestern US beginning in 1851 when they were first planted in Illinois. In 1879, farmers began planting soybean as forage for their livestock. By the end of 20th century, the US Department of Agriculture began to conduct research and encourage farmers to plant soybeans. In 1904, George Washington Carver found that soybean seeds were a good source of protein and oil. However, there were only a very limited number of soybean varieties available at that time. In 1929, William Morse, the first president of American Soybean Association, gathered more than 10,000 soybean varieties from China over two years and brought them back to the US for research projects. Eventually soybean became one of the major row crops in the US. According to the USDA National Agriculture Statistic Service, soybeans are planted on approximately 29 million hectares and currently produce 77 million metric tons on average each year. The Midwestern US soil types and climate are ideal for soybean production. Iowa, Illinois, and Minnesota were the top soybean producing states in 2012 (3,763,580 hectare, 3,609,800 hectares, and 2,828,750 hectare harvested, respectively). Recently, South Carolina has had approximately 200,000 hectares of soybeans in production each year. Approximately 150,000 hectares of soybean were harvested in South Carolina in 2012.

Soybean is mainly used as human food, animal feed and as an energy crop. Its high protein and oil concentration (38% protein and 18% oil) make it a good source of livestock feed. A smaller portion of soybean are processed for human consumption and made into food products such as soy milk, soy flour, and tofu, etc. (Gibson and Benson, 2005). Soybean seeds are usually processed first for their oil. The oil may be refined for cooking or other edible usage (Gibson and Benson, 2005), or sold for biodiesel production (Bernardes et al., 2007). The high protein meal that is left is then usually sold for animal feed. Soybean oil can be used for cooking and it can also be made into many other food products such as margarine, salad dressings, mayonnaises, etc. The high-protein meal is toasted and prepared into animal feed. Each year American livestock consume about 25 million tons of soybean meal. The poultry and swine industries are the major consumers of soybean feed. Over half of the soybeans processed for livestock feed are fed to poultry, about one-quarter is fed to swine, and the rest is used for beef cattle, dairy cattle and pet food products (North Carolina soybean producers association).

Besides protein and oil, soybean seeds also contain isoflavones, which have many biological properties including estrogenic, antifungal, and antibacterial activities (Wyman and Van Etten, 1978; Drane et al., 1980). Isoflavone concentration is usually cultivar dependent, and levels can be affected by environmental conditions during the seed filling stages (Eldridge and Kwolek, 1983; Wang and Murphy, 1994; Lee et al., 2003).

Biodiesel fuel for diesel engines can be produced from soybean oil through transesterification. This process removes the glycerin from the oil, leaving soy biodiesel. Soy biodiesel can be used in its pure form (neat biodiesel), or be blended with petroleum diesel. The most common mix is B20, which is a 20:80 blend of biodiesel to petroleum diesel (Pedersen, 2007). A lot of research has been conducted to investigate the production of biodiesel from soybean oil in recent years since it is renewable, biodegradable, and environmental friendly (Bernardes et al., 2007; Hu et al., 2008; Fan et al., 2010).

2.1.2 Planting date effects

In the US, soybean can be planted as early as April/May. However, more than 30% of fields are double cropped to soybeans in June or July after winter small grain crops, especially in the southern US (North Carolina soybean producers association). Soybean growth and development can be greatly affected by planting date (Heatherly, 2005; Chen and Wiatrak, 2010). Soybean seed yield (De Bruin and Pedersen, 2008a; Egli and Cornelius, 2009), yield components (Decianzio et al., 1991), and seed quality (Abdalla and Hassan, 1989; Bajaj et al., 2008; Arslanoglu et al., 2011; Bellaloui et al., 2011; Hu and Wiatrak, 2012) can also be affected by planting dates. Planting too early may not allow optimal canopy development of soybean plants due to cool temperatures (Kane et al., 1997b). An early season frost, or early season pests might also contribute to final yield loss (Steele and Grabau, 1997). Delayed planting dates often result in a suboptimal photoperiod, high temperatures, and traditionally low precipitation that can decrease the duration of vegetative and reproductive growth stages, reduce photosynthesis rate and therefore the growth and subsequent seed yield of soybean (Hu and Wiatrak, 2012).

Soybean yield components can be affected by planting dates (Abdalla and Hassan, 1989; Cox et al., 2008; Bellaloui et al., 2011). Cox et al. (2008) found that soybean planted in mid-May had lower plant densities than those planted in late May, but produced more pods per side branch, which contributed to more pods per plant and pods per unit area. The late May planting date, however, had more seeds per pod, which resulted in a similar seeds per unit area and thus similar final yields. Soybeans planted in mid-June had more plants per unit area but fewer pods per side branch, pods per plant, pods per unit area, seeds per unit area, and lower seed yield compared to those planted in mid-May. Seed composition can also be affected by environmental factors such as high air temperature (Gibson and Mullen, 1996; Khan et al., 2011) and water stress (Rotundo and Westgate, 2009). High day/night air temperatures and drought conditions during seed filling and maturation affected the oil, protein, and fatty acid composition of the soybean seed (Gibson and Mullen, 1996; Kirnak et al., 2008). Planting date effects on seed composition are genotype-dependent (Kumar et al., 2006). Board and Harville (1998) reported that yield of a determinate soybean variety is primarily determined by branch seed yield rather than mainstem seed yield. Frederick et al. (2001) found that drought stress had no effect on mainstem seed yield, but greatly reduced branch seed yield. Branch seed number per unit area was the most important yield component in determining branch and total yield. A close relationship between branch seed number per unit area and final branch length per unit area, as well as branch number per unit area was also reported. Board and Harville (1998) found that most branch growth occurred between initial flowering and the beginning of seed filling. Thus drought stress occurring between initial flowering and seed filling significantly decreased vegetative branch growth, branch seed number and branch seed yield (Board, 1987). Board and Settimi (1986) found that branch growth usually terminates 2 weeks after R5.

In South Carolina, soybeans are either planted in early May/June, or planted in late June/July as a double crop after small grain winter crops, such as wheat or rye. Seeds can be planted into moist ground using different planters, such as a drill planter or strip-tillage planter. To produce maximum yields in South Carolina deep tillage is required. It can take place immediately before planting or during planting or it may rely on residual deep tillage from the previous crop. In the strip tillage system shanks run in the furrow zone immediately before seed is dropped. This causes minimal disturbance to the soil surface but provides the soil drying and warming benefit of conventional tillage (Johnson et al., 2001). In the drill planting system no deep tillage occurs and the system relies on residual tillage effects from the previous crop. This method saves time, conserves moisture and decreases the possibility of soil erosion (Johnson et al., 2001; Singh et al., 2011).

2.1.3 Row spacing and plant density effects

Effects of row spacing and plant density on soybean growth and yield vary under different environmental situations. Row spacing can have significant effects on soybean growth and yield (Caliskan et al., 2007). Generally, narrow row spacing was found to be more profitable than wider row spacing systems (Lambert and Lowenberg-DeBoer, 2003). Drilled soybeans with 19-cm row spacing were reported to have higher yield than those with wider rows (Cox and Cherney, 2011). Kratochvil et al. (2004) reported that for all 48 soybean cultivars they have tested, most of them yielded higher in 19-cm rows than in 38-cm rows. Caliskan et al. (2007) indicated that row spacing had a significant effect on soybean seed yield and yield components such as number of nodes per plant, number of main stem pods and seeds, and number of branch pods and seeds in both full season and double crop systems in the eastern Mediterranean area. In a full season cropping system, higher seed yields were obtained from the 50-cm row spacing compared to 30-cm and 70-cm row width. In a double crop system, highest yields were obtained from the 30-cm row spacing. They suggested narrow row spacing can be used to alleviate the yield reduction observed in double crop systems.

Drilling soybeans in 19-cm rows resulted in a higher crop growth rate by R5 than those grown in 38- and 76-cm rows and had greater pod and seed density at harvest (Cox and Cherney, 2011). Row spacing can have a significant effect on soybean plant height in both full season and double crop systems (Caliskan et al., 2007). They found that the average HT was highest in the 30-cm row width in both crop systems while the lowest plant HT was found in a 50-cm row width in the full season system and a 70-cm row width in the double-cropping system. Photosynthetically active radiation, radiation utilization efficiency, leaf area index, and dry matter accumulation are reported to be negatively correlated with row spacing (Harder et al., 2007; De Bruin and Pedersen, 2008b; Walker et al., 2010; Zhou et al., 2011).

Boquet (1990) found that increasing plant population density (PPD) can decrease both branch and main stem yields per plant. It resulted in a decrease in total branch yield but an increase in total stem yield because the increase in PPD offsets the stem yield loss but not the branch yield loss (Boquet, 1990). An increase in PPD was necessary to obtain higher yields at later planting dates for determinate soybean planted in narrow rows. Soybean planted in narrow row spacings were more responsive to increases in PPD (Boquet, 1990). Epler and Staggenborg (2008) also indicated that plant density affected soybean yield and yield components in narrow rows. As plant population was increased, pods per plant decreased steadily; however, yield was not reduced by the loss of pods per plant, because pods per area increased as plant population increased (Robinson and Wilcox, 1998).

Usually soybean seed yield increases with decreasing row width up to a certain point (Oplinger and Philbrook, 1992), after that a further decrease in row width may negatively affect seed yields (Board and Harville, 1992). Yield responses to narrow row width can be affected by planting date, geography, and environmental stress (Boquet et al., 1982; Heatherly, 1988). Seed quality was also found to be affected by row spacing (Gibson and Mullen, 1996).

2.1.4 Tillage effects

Tillage system can affect soil temperature and soil water content. A no-till system was found to achieve the proper soil condition (>13 ˚C for 12 consecutive hours; water content less than or equal to the lower plastic limit) for planting 6-15 days later than a tillage system (Perez-Bidegain et al., 2007). No-till systems were developed as an option to reduce the severe soil erosion associated with traditional moldboard plowing. Compared to moldboard plowing, a no-till system increased the percent residue cover from 11% to 80%. Plants were found to emerge slower from the no-till system than from other tillage systems including fall moldboard plow, fall chisel plow, spring disk, ridge-till, and till plant (no ridge) (Lueschen et al., 1992). Anaele and Bishnoi (1992) reported that moisture content, organic matter content and total soil nitrogen were higher in no-till systems than in conventional tillage systems. Disease ratings and infestation of bacterial blight of soybean were significantly higher in a no-till system compared to tillage systems.

Soil compaction restricts root growth, and weather conditions may enhance or diminish the effect of root limitation on crop growth (Unger and Kaspar, 1994). Yusuf et al. (1999) found that total plant, stem, leaf, and pod dry biomass were all about 15 to 20% greater under a conventional tillage system than a no-till system at first, however the difference declined until the soybean plants reached R5 or R6. They deduced that compensatory growth occurred because final seed yield and seed protein and oil content were very similar for those two tillage systems. Pedersen and Lauer (2004a) found that no-till systems had 15, 9, and 9% greater seed mass, seed number per unit area, and pod number per unit area than the conventional tillage system, respectively. The no-till system averaged 6% more dry matter per plant and 7% taller plants than the conventional tillage system (Pedersen and Lauer, 2004b). The highest yield was found in conventional tillage systems (3283 kg ha^{-1}) and the lowest in no-till systems (2520 kg ha^{-1}) in 2004 (Sessiz et al., 2009). More intensive tillage positively affected the protein content in soybean seeds (Spoljar et al., 2009). Wilhelm and Wortmann (2004) found that temperature influenced the effect of tillage on soybean seed yield. No-till systems are usually associated with higher herbicide costs, which leads to lower net return than conventional and fallow production systems (Popp et al., 2002). However, Manning et al. (2001) found that the effect on soybean yield and net return of these two tillage systems varied between different locations.

2.1.5 LAI, NDVI and HT

Canopy development is an important factor in determining soybean yield potential. Total dry matter accumulation and crop growth rate are both highly correlated with seed yield and depend greatly on plant canopy development (De Bruin and Pedersen, 2009). Leaf area index (LAI) and Normalized Difference Vegetation Index (NDVI) are important agronomic indices of plant canopy growth.

LAI is defined as one-sided green leaf area per unit ground area. It is positively correlated with seed yields and a value of 3.5 - 4.0 is usually needed to achieve the 95% light interception for producing optimum seed yield (Board and Harville, 1993). LAI is very useful in monitoring plant growth condition and estimating crop yield in crop simulation models and can be used in improving the performance of crop yield models

(Doraiswamy et al., 2005; Mo et al., 2005; Fang et al., 2008). A typical LAI soybean growth pattern begins with a slow increase in the early season, followed by a rapid increase until it reaches the maximum, following a decline as leaves senesce (Setiyono et al., 2008).

NDVI is used to quantify canopy vigor and density (Carlson and Ripley, 1997; Price, 1992). NDVI is a measure of the amount and vigor of vegetation on the land surface. NDVI spatial composite images are developed to easily distinguish green vegetation from bare soils. In general, NDVI values range from -1.0 to 1.0. Negative values indicate clouds and water, positive values near zero indicate bare soil, higher positive values between 0.1 - 0.5 indicate sparse vegetation, and values of 0.6 or above indicate dense green vegetation (Kriegler, 1969; Stone et al., 1996). It is calculated by the following equation:

$$NDVI = (NIR - RED) / (NIR + RED)$$

Where: RED = the red portion of the electromagnetic spectrum and NIR = the near infrared portion of the electromagnetic spectrum.

Taking NDVI measurements at critical growing stages is very helpful in analyzing spatial variability, monitoring vegetative growth, estimating crop yields and forecasting crop growth and yield in crop simulation models (Benedetti and Rossini, 1993; Quarmby et al., 1993). NDVI increases almost linearly with LAI until LAI reaches 3-4 (Liu and Huete, 1995; Jasinski, 1996).

Plant height (HT) is a genetic trait that varies among soybean cultivars and can also be affected by planting date (Pedersen and Lauer, 2003), row spacing (Caliskan et al., 2007), and other factors. Epler and Staggenborg (2008) found that plant HT increased with plant density in a quadratic manner, and taller plants have a higher risk of lodging.

2.1.6 Soybean growth habit and development

Soybean varieties grown in the US are classified as indeterminate, semi-determinate or determinate growth habits. Indeterminate varieties continue vegetative growth after reproductive growth has started. Determinate varieties cease vegetative growth once reproductive initiation occurs (McWilliams et al., 1999). Most northern soybean varieties in the US are indeterminate in growth habit, and most southern varieties are determinate (McWilliams et al., 1999).

Soybean maturity groups are classified based on adaptation to different climate and latitudes. In the US maturity groups range from 000 in the extreme north to VIII in the southern Gulf Coast area and Florida. Short day length and warm temperature induce soybean flowering. Usually soybean varieties grown in the north have longer minimum day length requirements for flowering. Hence planting a certain variety further north than its adapted region will extend the vegetative growth duration. Flowering and maturation will be delayed because of long summer day length and cooler temperatures. Planting a variety further south than its adapted region will shorten the vegetative growth duration, and result in earlier flowering and maturing (McWilliams et al., 1999). Since soybean maturity is regulated by both photoperiod and temperature, it is typically more difficult to classify soybean on the basis of growing degree days as is done for corn and cotton (Croplan, 2010).

Soybean plant development measures the changes in phenological stages and the duration of each stage. The length of vegetative and reproductive stages is highly dependent upon cultivar, photoperiod, temperature, and their interactions (Boote et al., 1997; Heatherly, 2005). Both the vegetative and reproductive stages are further subdivided into several growth stages. According to Fehr et al. (1971), vegetative stages are determined by counting the number of nodes on the main stem. Vegetative stages start with emergence of the cotyledons. After emergence, unifoliolate leaves on the first node unroll and the VC stages start. The subsequent stages are defined by the number of nodes with fully developed trifoliates. The reproductive growth stages start when at least one flower is present on the plant. The reproductive stages are divided into 4 parts: R1 and R2 describe flowering; R3 and R4 describe pod development; R5 and R6 describe seed development; and R7 and R8 describe plant maturation (McWilliams et al., 1999). Specific stages are defined by Fehr et al. (1971) as shown in table A-1(see Appendix) . The duration of developmental stages is very critical for yield determination, and can be strongly influenced by genetic and environmental factors, such as planting date (Calvino et al., 2003; Heatherly, 2005; Chen and Wiatrak, 2010).

The objectives of this study were to evaluate the effect of planting date on: I) LAI, NDVI, and HT; and II) seed yield, yield components, and oil and protein concentrations of MG VII and VIII soybean in two management systems in South Carolina.

2.2 Materials and Methods

These experiments were conducted in South Carolina at the Edisto Research and Education Center (REC) near Blackville (33˚21' N, 81˚19' W) and the Pee Dee REC near Florence (34˚12' N, 79˚32' W) in 2011and 2012. Soil types used at the Edisto REC and Pee Dee REC were a Dothan loamy sand (fine-loamy, siliceous, thermic Plinthic Paleudult) and a Eunola loamy sand (fine-loamy, siliceous, thermic, Aquic Hapludults), respectively. Soybeans were rotated with wheat (*Triticum* spp.), variety Pioneer 26R12, at the Edisto REC and variety AGS2060 at the Pee Dee REC in both 2011 and 2012.

2.2.1 Treatments

Each treatment consisted of a combination of three factors: four planting dates, two maturity groups, and two management systems to create a $4 \times 2 \times 2$ factorial design at 2 locations in each of 2 years.

At the Edisto REC the four planting dates were 15 June, 22 June, 30 June, and 6 July in 2011 and 15 June, 22 June, 29 June, and 6 July in 2012 (Table 2-1). The two management systems were: 1) a strip-tillage system using a 4-row John Deere MaxEmerge 1700 Vaccum planter with 96-cm row spacing and in-furrow shanks (subsoils 38-cm deep) and 2) a Great Plains 1.6 m wide 3P606NT-0975 drill planter with 19-cm row spacings. A Maturity Group VII (Pioneer 97M50) and a MG VIII (Prichard Roundup Ready) variety were used at both locations for both years. Both varieties are determinate in growth habit. Pioneer 97M50 is recommended for late planting in the Southeastern Coastal Plain. It is metribuzin tolerant and resistant to southern root-knot nematode, soybean cyst (race 3) nematode and stem canker. However, it is susceptible to other races of soybean cyst nematode (races 9 and 14). Prichard Roundup Ready was developed by the Soybean Improvement Center at the University of Georgia Agricultural Experiment Station in Athens, GA. It is a glyphosate-tolerant variety, which has excellent resistance to shattering. It is resistant to soybean cyst nematode (races 3, 9, and 14), southern root-knot nematode and stem canker. It is tolerant to Columbia lance nematode but susceptible to reniform nematode and peanut and Javanese root-knot nematodes. Both varieties were selected based on their previous performance in South Carolina.

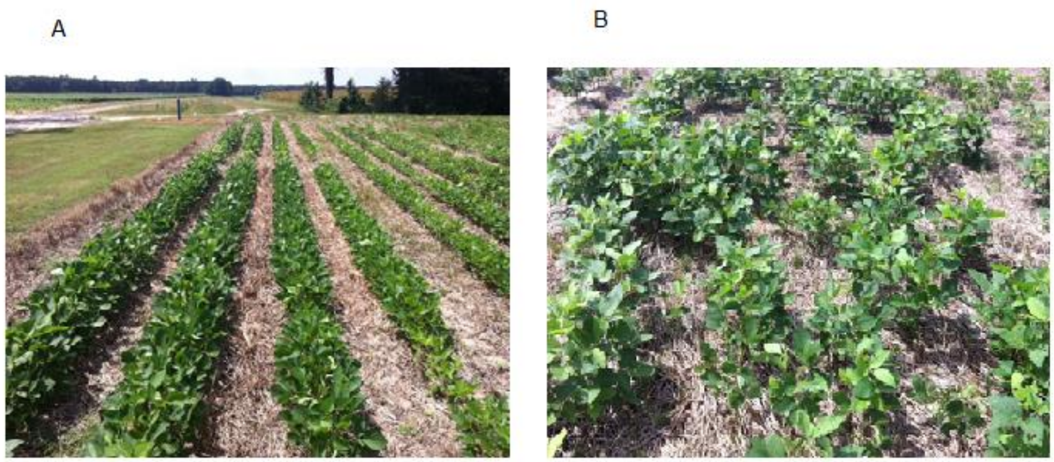

Figure 2-1. A. Plots of soybean plants in the strip-till system; B. Plots of soybean plants in the drilled no-till system (pictures were taken at the Pee Dee REC in 2012)

2.2.2 Experimental design

The experimental design was a split-plot design at both locations in 2011 and 2012. Planting date was the main plot, management systems and maturity groups were completely randomized within each planting date (planting date was not replicated within each trial). Each trial was considered one replication. Since the trial at the Pee Dee R.E.C. in 2011 was dropped due to severe drought, a total of 3 replications were available for data analysis.

2.2.3 Data collection

Data collection included LAI, NDVI, plant HT, growth stages, seed yield, yield components, seed protein and seed oil concentration. LAI was measured weekly beginning at 42-days after planting (DAP) using a LAI-2200 plant canopy analyzer (Li-Cor, Lincoln, NE). NDVI was taken weekly beginning at 21 DAP using a GreenSeeker^{TM} (NTech Industries, Inc. Ukiah, CA). NDVI and LAI were taken from the center two rows of each plot. Plant HT of the main stems was recorded on a weekly basis from 10 randomly selected plants from each plot beginning at 42-DAP. Growth stages were recorded weekly from 10 randomly selected plants in each plot. The beginning of each stage was determined when at least 50% of plants were at that stage. The stages were calculated as follows: 1). vegetative stage, planting to R1; 2). reproductive stage, R1 to R8; 3). flowering stage, R1-R2; 4). pod-set stage, R3 to R5; and 5). seed-filling stage, R5 to R7. Soybeans were harvested using a Massey Ferguson 8 XP grain plot combine (Kincaid Equip. Mfg., Haven, KS). Yield components measured included seed moisture, seed size, and seed number. Seed moisture was determined by Burrows Model DMC750 Digital Moisture Computer (Seedburo Equip. Co., Chicago, IL). Seed size was determined by counting and weighing 200 seeds after cleaning. Seed number was calculated from final seed yield and individual seed size. Soybean yield and 100 seed weight were adjusted to 130 g kg^{-1} moisture. Protein and oil content were analyzed by the Agriculture Service Laboratory of Clemson University in 2011and Soybean Breeding Laboratory at Delta Research Center of Missouri University in 2012. Samples for dry weight determination of each part (leaves, petioles, branches, stems, pods) were hand harvested from 10 random plants from each plot at R4-R5. Leaves, petioles, branches, stems and pods were separated by hand, dried at 80˚C for 36 hours, and then weighed. Samples for yield and yield component determinations on branches and main stems were hand harvested from 10 random plants from each plot before harvest. Leaves, petioles, and branches were separated from the main stems by hand. Pods from branches and stems were removed and counted separately, and then threshed to get the seed yield from each part. A DGPS-based, hydraulically operated penetrometer mounted on a John Deere Gator was used to diagnose the soil compaction condition of the soil profiles for the two management systems at the Edisto REC in 2012. Soil compaction values were calculated from the measured force required to push a 130-mm^2 base area, 30-degree cone into the soil (ASAE S313.3, 2004). The cone was pushed into the in-row subsoil slit in both management systems. Probe depth was measured using a circular potentiometer attached to the penetrometer with a sprocket and chain. A rod and an electric switch were used to detect the soil surface. A 16 bit based Data Acquisition System (KPCMCIA 16AI C, Keithley Instruments, Inc., Cleveland, OH) was used to read penetration data, depth and switch status 20 times a second. A program written in TESTPOINT software collected the GPS location soil compaction data, and probe depth data.

Figure 2-2. A. John Deere MaxEmerge 1700 Vaccum planter with in-furrow shanks; B. Great Plains 3P606NT-0975 drill planter; C. Massey Ferguson 8 XP grain plot combine (Kincaid Equip. Mfg., Haven, KS); D. DGPS-based soil compaction measurement system (Penetrometer).

Figure 2-3. A. LAI-2200 plant canopy analyzer (Li-Cor, Lincoln, NE); B. GreenSeeker™ (NTech Industries, Inc. Ukiah, CA); C. Burrows Model DMC750 Digital Moisture Computer (Seedburo Equip. Co., Chicago, IL).

2.2.4 Production practices used

Each variety was seeded at 257,000 seeds ha^{-1} regardless of the management system. No irrigation was applied in either year. Daily precipitation and temperature at the Edisto REC was recorded by the US Climate Reference Network weather station located at Edisto REC. Daily precipitation and temperature of Pee Dee REC was recorded by automated weather stations located near the experiment site. Soil fertility management and pesticide application both followed the standard management recommendations for South Carolina.

2.2.5 Statistical analysis

PROC MIXED procedure in SAS (SAS V. 8.2, SAS Institute, Cary, NC, US) was used to perform the Analysis of Variance (ANOVA). The fixed effects are planting dates (PD), management system (MS), maturity group (MG) and all their interactions. The random effects are trial, and interactions between trial and planting date. Treatment effects were considered significant when $P \leq 0.05$. If there were significant two way or three way interactions, further analysis was done to determine the effects of the interactions. The LSMEANS statement of PROC MIXED procedure was used to determine significant differences among treatments (each treatment consisted of a combination of three factors: four planting dates, two maturity groups, and two management systems to create a $4 \times 2 \times 2$ factorial design), and PDMIX800 macro was used to obtain separations ($P \leq 0.05$). Pearson correlation coefficients (r) between any two variables were analyzed using the PROC CORR procedure in SAS. PROC REG procedure in SAS was used to evaluate the relationship between seed yield and planting date; the relationship between seed yield and LAI; the relationship between LAI/NDVI/HT and WAP; and the relationship between seed oil and protein concentration. Fitted equations were selected based on model significance and coefficient of determination (R^2) values.

2.3 Results

2.3.1 Seed Yield

Mean values of the seed yield of different factorial treatments and analysis of variance (ANOVA) are presented in Tables 2-2 & 2-3 and Fig. 2-4. ANOVA indicated that planting date (PD) did not significantly affect seed yield. However, planting after 22 June showed a decreasing trend in mean seed yield across environments (years and locations), MS, and MG. Yield for PD 2 was numerically higher than for other dates (Fig. 2-4 A). PD 3 and PD 4 yielded 25% and 35% less than PD2, respectively. Soybean grown in a strip tillage system yielded significantly higher than those in the drilled no-till system (Fig. 2-4 B). The MG VIII variety yielded significantly higher than the MG VII variety (Fig. 2-4 C). A quadratic model was developed to describe the relationship between seed yield and PD for different MS and MG of the three trials (Table 2-4). The model was found to be significant for the two trials conducted at the Edisto REC in 2011 and 2012 and accounted for 27% to 67% of the variation in final seed yield.

Since the mean seed yields of the three trials are quite different, mean seed yields of the four PD were analyzed as three different trials (Fig. 2-5 A-C). The decreasing trend for seed yield was observed for both trials conducted at the Edisto REC (trials a and b). In general, seed yield began to decrease after the second PD (22 June). However, in the 2012 trial at the Pee Dee REC (trial c) the seed yields of the four different PD were very similar.

Figure 2-6 shows penetrometer data comparing the soil compaction of the drilled no-till system and the strip-till system of four PD for the Edisto REC location in the fall of 2012. Penetration resistance increased as depth increased for both the strip-till and drilled no-till system. This was true for all PD. Two MPa (a penetration level of 2 MPa defines where root growth of soybeans is adversely affected) was recorded at 5 cm depths for all PD of the no-till plots but not until 20-30 cm depths for the strip-till plots.

2.3.2 LAI, NDVI and HT

The most complete data sets for LAI, NDVI, and HT were collected at R2 and R4. LAI, NDVI, and HT across environments for each factorial treatment and ANOVA are shown in Tables 2-5 & 2-6. Planting date did not show any significant main effect, so further analysis was done within each PD. MS and PD by MS interaction effects were observed for LAI at R2. Additional analysis showed that MS did not affect LAI at R2 for PD 3 (3.58 for strip-till and 3.39 for drilled no-till) and PD 4 (3.16 for strip-till and 2.93 for drilled no-till), but strip till had significantly higher LAI than the drilled no-till systems for PD 1 (4.27 for strip-till and 3.35 for drilled no-till) and PD 2 (4.05 for strip-till and 3.57 for drilled no-till). Planting date and MG did not affect LAI at R4. Plants grown in the strip-till system had significantly higher LAI values at R4 than in the drilled no-till system. Although not significant, a decreasing trend of LAI was observed at R2 and R4 as planting was delayed.

Significant three way interactions made it hard to draw any broad generalizations about the main effects of PD, MS and MG on NDVI at R2. The mean value of each combination of PD, MS, and MG for NDVI at R2 is shown in Table 2-7. The MG VIII variety in the drilled no-till system of PD 2 had a significantly lower NDVI than the top three treatments. Management system had a significant main effect on NDVI at R4.

Plants in the strip-till system had higher NDVI values than those in the drilled no-till system. A PD by MG interaction significantly affected NDVI at R4, so additional analysis has been done within PD. Maturity group did not show a significant effect except for PD 2 for which MG VII had a higher NDVI value than the MG VIII soybean (0.8544 and 0.7744 respectively).

Management systems and MG affected plant HT at R2 (Table 2-5). Soybean in the strip till system was significantly taller than those in the drilled no-till systems, and the MG VIII variety was generally taller than the MG VII variety. MS and an MS by MG interaction affected HT at R4. For the strip-till system, the MG VIII variety was taller than the MG VII variety (76.1cm and 71 cm, respectively). For the drilled no-till system, HT at R4 was similar for the two maturity groups (59.9cm and 59.4 cm, respectively).

LAI, NDVI and HT were also analyzed on a weekly basis (Tables 2-8 through 2-13). LAI was not affected by PD or MG at any sample date (Table 2-8). A main effect of MS was observed at 6-, 8-, 10- and 11-WAP, and soybean in the strip-till systems had significantly higher LAI values than those in the drilled no-till systems. A PD by MS interaction was observed at 5-, 9- and 13-WAP. Mean value of the soybean LAI in the strip-till systems was generally higher than those in the drilled no-till systems.

NDVI values showed similar results for LAI (Table 2-10). Planting date and MG did not affect LAI at the different WAP, and soybean in the strip-till system showed a higher NDVI value than those in the drilled no-till system. A PD by MS by MG interaction was observed at 9-WAP and a PD by MS interaction was observed at 13-

WAP. Significantly higher NDVI values were observed in the strip-till system than the drilled no-till system at 5-, 6-, 7-, 8-, 10- and 11-WAP.

There was no effect of PD on HT (Table 2-12). Significantly taller plants were observed in the strip-till system than the drilled no-till system at 6- to 11-WAP. At every sampling date plants in the strip-till system were numerically taller than those in the drilled no-till system (Table 2-13, Fig. 2-7 C). This difference increased at each sampling date leading to a PD by MS interaction at 13 WAP. A PD by MG interaction was observed at 8- and 9-WAP. The MG VIII variety was significantly taller than the MG VII variety at 6-, 7- and 13-WAP.

Quadratic models were developed to estimate the relationship between LAI, NDVI, HT and WAP for soybeans in the two MS (Fig. 2-7 A-C). High R^2 and small P values indicated that the quadratic model was useful in predicting LAI, NDVI and HT changes over time.

Correlation analysis was done between seed yield and LAI, NDVI and HT based on growth stages and WAP (Tables 2-14 & 2-15). Positive correlations were observed between seed yield and LAI/NDVI/HT at R2 and R4. Based on a weekly basis, positive correlations were observed between seed yield and LAI from 7- to 12-WAP, and the correlation coefficient was highest at 9-WAP for MG VII soybean plants (r=0.71***) and 11-WAP for MG VIII soybean plants (r=0.58***). A positive correlation between seed yield and NDVI was found at all sample dates. The correlation coefficient was highest at 7- to 10-WAP for MG VII soybean plants (r=0.73***), and 11-WAP for MG VIII soybean plants (r=0.67***). Positive correlations were found between seed yield and

NDVI at almost all sample dates for the MG VII and VIII variety. The correlation coefficient between seed yield and plant height was highest at 10-WAP for MG VII soybean plants (r=0.68***) and 11-WAP for MG VIII soybean plants (r=0.60***). A simple linear model was built to describe the relationship between LAI at R2 and seed yield for each MS and environment (Fig. 2-8). LAI measured at R2 was found to be responsible for approximately 40-60% of the variation in seed yield in the strip-till system at the Edisto REC in 2011 and 2012, the drilled no-till system at the Edisto REC in 2012, and the strip-till system at the Pee Dee REC in 2012.

2.3.3 Developmental stages

Analysis of variance for the factorial analysis of mean values for duration of the total growth period, vegetative and reproductive development period, flowering, pod set and seed filling are presented in Table 2-16 .

Planting date and MG both affected total growth duration. A significant PD by MS by MG interaction was also observed. Mean value of the total growth duration of different treatment combinations are presented in Table 2-18. Since MS did not show any consistent effects, data were further analyzed across MS by MG (data not shown). For the MG VII variety, PD 3 and 4 had significantly shorter total growth durations than PD 1 and PD 2; for the MG VIII variety, total growth duration of PD 2 and PD 3 are significantly shorter than PD 1, and PD 4 had shorter duration than PD 2 and 3. In general, the MG VIII variety had longer total growth duration than the MG VII variety (Table 2-17).

There were significant effects of PD, MG and the PD by MG interaction on vegetative growth duration (Table 2-16). The four week delay in planting date led to approximately 20% and 22% decreases in vegetative growth duration for MG VII and VIII, respectively. In general, the MG VIII variety had a longer vegetative growth duration than the MG VII variety.

The effects of PD and MG on reproductive growth duration were identical to their effects on vegetative growth. The four week delay in planting date decreased reproductive growth duration by 10% (about 8 days) .The MG VIII variety had approximately 1 day longer duration than the MG VII variety. The only factor that affected flowering and pod set duration was a PD*MG interaction (Table 2-16). The four week delay in PD decreased flowering duration by 27% and 14% (3.9 and 1.9 days) for MG VII and VIII, respectively; and decreased pod set duration by 29% and 20% (3.5 and 3.0 days) for MG VII and VIII, respectively. Seed filling was significantly affected by PD, MS, and MG. A four weeks delay in PD decreased duration of seed filling by 7% (3 days). Soybeans in the drilled no-till system had about 0.8 days less seed filling duration than those in the strip-till system. The MG VII variety had 1.6 days longer duration of seed filling than the MG VIII variety. Correlation analysis was done between seed yield and duration of each growth stage (Table 2-20). Duration of vegetative growth and seed filling stages were found to be positively correlated with seed yield (r= 0.33*** and r=0.26***, respectively), which suggested that reduced duration of vegetative growth and seed filling might have contributed to the lower yields of the later planting dates.

A linear regression model was developed to describe the relationship between seed yield and the duration of each growth stage by different trials (Table 2-21). The model fitness was found to be low and insignificant for trials a and c. Significant regressions were found between seed yield and the duration of the vegetative and reproductive growth period, pod set, and seed filling period for trial b, but R^2 were relatively low and only accounted for a maximum of 39% of the variation.

2.3.4 Yield components

Yield and yield component data and their accompanying ANOVA are presented in Tables 2-2 & 2-3. MG, PD by MG and MS by MG were found to affect seed size. Additional analysis indicated that planting date did not affect the seed size of either the MG VII or MG VIII variety. Seed size of the MG VII variety was found to be significantly larger than MG VIII variety for PD 1 in the drilled no-till systems, and PD 2, 3 and 4 in the strip tillage systems.

Planting date did not significantly affect the seed number. However, a general decreasing trend in seed number was observed as the planting date was delayed. Management system and MG had significant effects on seed number. Soybean in the strip-till systems produced higher seed numbers than those in the drilled no-till systems and the MG VIII variety had higher seed number than the MG VII variety.

The relative percentage of pods and yield on branches vs. stems were analyzed based on trials b and c (Table 2-22). The MG VII variety had a higher percentage of pods and yield on its branches than did the MG VIII variety. Planting date and MS did not affect the relative percentage of pods or yield on branches vs. stems. But it appeared that the percentage of pods and yield on branches decreased with delayed planting date with a concomitant increase of pods and yield on the main stem because of less branch growth.

Seed yield was positively correlated to branch and main stem length, pod number on branches and stems, and yield on branches and stems (Table 2-24). The highest correlation coefficient for seed yield was with main stem pod number (r=0.58***).

2.3.5 Dry weight of each part

Dry weight of leaves, petioles, branches, stems and pods based on two trials (trials b and c) were analyzed (Table 2-25). Delayed planting date significantly decreased branch dry weight. Although planting date did not significantly affect the dry weight of leaves, petioles, stems, and pods, they showed a decreasing trend with delayed PD. Management system and MG did not have any significant effect on dry weight of each part except stems. Plants in the drilled no-till system were found to have higher main stem weights than those in strip-till systems. The MG VIII variety had generally higher dry weights for petioles, pods, and stems than the MG VII variety.

Correlation analysis was done between seed yield and dry weight of each plant part (Table 2-27). All of those variables were positively correlated to seed yield. The highest correlation coefficient was observed between seed yield and dry weight of the main stems (r=0.51***).

2.3.6 Seed protein and oil concentration

Planting date did not affect either seed protein or oil concentration (Tables 2-2 & 2-3). Seed protein concentration was found to be significantly higher while seed oil concentration was significantly lower for soybeans in the strip tillage system than those in the drill no-till system. The MG VIII variety had higher seed protein concentrations but lower seed oil concentration than the MG VII variety. A negative correlation was found between seed protein and seed oil concentration. A 10 mg g^{-1} increase in protein concentration corresponded with a decrease of 1.1 mg g^{-1} in seed oil concentration (Fig. 2-10).

2.4 Discussion

2.4.1 Seed Yield

Seasonal temperature and rainfall patterns during the two growing seasons were quite different, as were the soil properties of the two experimental sites. Therefore environmental effects created a large error term which made it very difficult to detect the potential differences between planting dates. Due to the experimental design, location by year was used as replications. Problems caused by the lack of main plot replication were exacerbated when one location was dropped due to extreme drought. A second problem limiting the interpretation of the data was that no residual tillage was conducted before planting the drilled no-till beans. However, the mean yields of the four planting dates across environments showed a decreasing trend after PD 2. Delaying planting from 22 June to 7 July led to approximately a 34% decrease in seed yield. According to Egli and Cornelius (2009), a seed yield decline begins at the end of May in the deep south of the US. Bhatia et al. (1999) found in India planting on 20 June produced higher soybean seed yields than later planting dates. Delaying planting 10, 20 and 30 days after 20 June reduced yields by 4.8, 8.5, 28.1 and 39.7%, respectively. Drilled soybeans in narrow-rows (45 cm) in their study out yielded those in wider rows (60, 90cm) (Anaele and Bishnoi, 1992). This is because the dense canopy of the narrow row width helped them to utilize light, water, and nutrients better than wider row soybeans (Parker et al., 1981; Cox and Cherney, 2011). Our intent was to use the drilled no-till and strip-till systems to compare the effects of row spacing (19 cm vs. 96 cm) on soybean growth and yield. However, as the penetrometer data shows, strip-tillage vs. no-till became the main difference between the MS. In the strip-till plots deep tillage occurred at planting and no hard pan was observed to have formed at the end of growing season (Fig. 2-6). Strip tillage systems can effectively reduce soil compaction and warm the soil quickly before planting. Penetration resistance in the drilled no-till system was much higher than in the strip-till system. Root growth decreases linearly with increasing penetration resistance and essentially stops above 2 MPa (300 psi) (USDA, 2003). As the penetrometer data shows, 2 MPa of penetration resistance was recorded at 5 cm depths for the 4 PD of the no-till plots but not until 10-30 cm depths for the strip-till plots. The severe soil compaction in the no-till system restricted root growth, water, and nutrient uptake, and the yield of the drilled no-till soybeans. In soils which typically reform hard pans in less than a year, no-till soybean are typically planted after a small seeded winter grain (tillage was performed before planting the winter crop) since no-till can increase the amount of water and organic matter in the soil and decrease the possibility of soil erosion. The soybean crop is dependent upon residual deep tillage from the previous crop to prevent the reformation of the hard pan. However, this did not occur in the drilled no-till soybean plots since deep tillage was not employed in the previous crop.

The MG VIII variety yielded higher than the MG VII variety in this experiment. This is a common phenomenon when comparing two maturity group soybean in a late planted situation in the Southern US (Wiatrak et al., 2009). Soybean flowering is a photoperiod response and later maturing varieties tend to grow vegetatively for a longer period of time, resulting in higher yields.

Since the mean seed yield of the three trials were quite different, mean seed yield of the 4 PD were analyzed as three different trials. Different soil properties and weather conditions at the two different locations might have contributed to the differences in seed yield among the three different trials. At the Edisto REC, poor soil condition, severe drought during flowering and pod set, and relatively low temperatures during seed filling might have contributed to the low yield observed in 2011. Yields at the Pee Dee REC were higher in general than at the Edisto REC. Although the accumulated precipitation at the Pee Dee REC was generally lower than at the Edisto REC, better soil condition might be the most important reason for the higher yields. Each PD had its own unique weather history relative to its plant growth stages. Thus the seed yield response to PD could vary depending upon environments. A positive correlation was observed between seed yield and total accumulated precipitation (0.84***) and average temperature (0.78***) at the Edisto REC in 2012 (see Appendix). More specifically, accumulated precipitation during vegetative, pod-set and seed filling stages were found to be positively correlated with the yield. Average temperatures during vegetative and seed filling stages were also found to be positively correlated with the final seed yield. However, no significant correlations were found between seed yield and the weather conditions for the other two trials.

2.4.2 LAI, NDVI and HT

LAI is an index to estimate the vegetative growth of soybean plants and has been found to be positively correlated with seed yields. A value of 3.5 - 4.0 is usually needed to achieve 95% of light interception, which is necessary for producing optimum seed yield (Board and Harville, 1993). In this experiment MS and a PD by MS interaction showed significant effects on LAI value at R2. Soybeans in the strip-till system showed significantly higher LAI than those in the drilled no-till system for PD 1 and 2, but not for PD 3 and 4 (data not shown). The mean LAI values at R4 did not show any differences among treatments and all reached 3.5. This suggests that LAI might not be the key component that is restricting yield potential in the trials.

NDVI was used to quantify canopy vigor and plant density in this experiment. Significant two-way and three-way interactions between PD, MS and MG made any broad generalizations about the main effect of PD, MS or MG on NDVI at R2 difficult. It appeared that soybeans planted in the strip tillage system had higher NDVI values at R2 than the drilled no-till soybean. Additionally, NDVI significantly increased with soybeans grown in strip-tillage when they reached R4 growth stage. NDVI has been found to be highly representative of plant photosynthetic capacity and efficiency (Benedetti and Rossini, 1993). Quarmby et al. (1993) found that the relationship between yield and NDVI for wheat, cotton, rice, and maize can be estimated using a simple linear model with a high degree of accuracy. A significant correlation was found between NDVI and seed yield at R2 and R4 (r=0.48*** and r=0.40***, respectively) in this experiment. A simple linear model was also developed to describe the relationship between soybean seed yield and NDVI at R2 (Seed Yield=-311.56+2667.87×NDVI, R^2=0.36***).

Height is primarily determined by genetics, but it can also be affected by environmental factors and the interaction between genetic and environment. At R2, soybean plants in the strip till system were significantly taller than those in the drilled no-till system across environments, PDs and MGs. The MG VIII variety was generally taller than the MG VII variety. A significant MS by MG interaction effect on HT was observed at R4. In the strip tillage system, the MG VIII variety was taller than the MG VII variety. However, in the drilled no-till system, HT of the two MG were very similar.

Analysis of variance suggested that MS significantly affected LAI, NDVI, and HT of the soybean plants during the entire growing season. A quadratic model was developed to estimate the relationships between LAI, NDVI and HT to WAP for soybeans within the two different MS. A high R^2 and low P value suggested that the quadratic model properly described the relationship between LAI, NDVI, HT, and WAP, for both the strip tillage and the drilled no-till systems. The LAI showed a rapid increase from 6 WAP until the soybean reached R6, which is consistent with the typical LAI pattern described by Setiyono et al. (2008). The trends observed here suggested that leaf senescence for the soybeans in the two different MS occurred at approximately the same time. NDVI showed an increasing trend until 12 WAP, and was very similar for plants in the two different MS. The strip till soybean NDVI was significantly higher than the drilled no-till NDVI at all sample dates. Plant HT showed smaller differences between strip-till and drilled no-till systems from 6- to 8-WAP, after which differences began to increase. Plants in the strip tillage system were approximately 15-cm taller compared to those in the drilled no-till systems at 12 WAP. Smaller vegetative mass at the beginning of seed filling (Kane et al., 1997b) is thought to be associated with lower yields of soybeans from delayed planting dates. In this experiment, LAI, NDVI, and HT at R2 and R4 were found to be highly correlated with seed yield, which is consistent with previous findings (Kane et al., 1997b). LAI measured at R2 was found to account for approximately 40-60% of the variation in seed yield for the strip-till system at the Edisto REC in 2011 and 2012, the drilled system at the Edisto REC in 2012, and the strip-till system at the Pee Dee REC in 2012. The low P value and relatively high R^2 suggested that differences in LAI played a significant role in causing the differences in seed yield. However, there are more factors involved in soybean seed yield determination than just the LAI.

2.4.3 Developmental stages

Total growth duration was affected by PD, MG, and a PD by MS by MG interaction. As expected, the MG VIII variety was found to have a longer duration of total growth period than the MG VII variety. This is reported by Heatherly (2005). Delayed planting shortened the duration of total growth period for both MG VII and VIII varieties, and the MG VIII variety was affected more than the MG VII variety. This is consistent with previous findings (Heatherly, 2005). They observed in May and later plantings dates, vegetative growth duration and total growth duration increased with increasing MG and decreased with later planting. Seed filling period is an important determinant of seed yield (Egli, 1998). Flowering and pod set are also reported to be critical in yield determination in late planted soybean (Egli and Bruening, 2000). In this experiment, duration of vegetative growth of the MG VII variety was less affected by PD than the MG VIII variety. For MG VII, duration of vegetative growth of different PD varied from 44.6 to 55.8 days, while MG VIII varied from 47.7 to 61.1 days.

Short vegetative and reproductive growth duration are thought to be associated with the lower yield of late-planted soybeans (Chen and Wiatrak, 2010). In this experiment, duration of vegetative growth and seed fill stage were found to be significantly correlated with the seed yields. This response suggested that reduced duration of vegetative growth and seed fill stage may have contributed most to the observed trend of yield decreasing with delayed planting dates.

2.4.4 Yield and yield components

Seed size of the MG VII variety was found to be significantly larger than the MG VIII variety for PD 1 in the drilled no-till systems and PD 2, 3, and 4 in the strip till systems. Although not significant, seed size of the MG VII variety was generally larger than the MG VIII variety for other PD by MS combinations. Planting date did not significantly affect seed size. However, a decreasing trend in seed size was observed after the second PD. This is consistent with the trend of decreasing seed yield and short seed-filling period. The idea that the primary cause of low yield in late-planted soybean is due to decreased seed number is well documented (Egli et al., 1987; Steele and Grabau, 1997; Egli and Bruening, 2000) . Egli et al. (1987) and Egli and Bruening (1992) reported that lower insolation and temperature were associated with lower yields of delayed planting.

Soybean has the ability to compensate for low plant population densities through increased branching (Carpenter and Board, 1997; Epler and Staggenborg, 2008), pods per plant, and seeds per plant (Board et al., 1990; Boquet, 1990; Ball et al., 2000). The MG VII variety had a higher percentage of pods and yield on branches vs. stems than the MG VIII variety. Planting date did not significantly affect the relative percentage of pods or yield on branches vs. stems. However, the percentage of pods and yield on branches vs. stems showed decreasing trend with delayed PD, which is consistent with the observed trend of decreasing seed yield. Branch and stem length, pod number and yield on branches and stems all showed positive correlations with seed yield.

2.4.5 Dry weight of each part

Although the mean dry weight of leaves, petioles, branches, stems, and pods of different planting dates showed a decreasing trend with delayed planting date, the effect was not significant except for the dry weight of branches. Branch dry weight of PD 4 was significantly lower than that of PD 1. Soybean in the strip-till systems had higher stem dry weights than those in the drilled no-till system. The MG VIII variety had a greater dry weight of petioles, pods, and stems than the MG VII variety. Frederick et al. (2001) found a close relationship between branch dry weight and branch seed number (r=0.93*), and branch seed number is highly correlated with seed yield (r=0.99**). In this experiment, a positive correlation was also found between seed yield and dry weight of branches, leaves, petioles, pods and stems.

2.4.6 Seed protein and oil

Planting date did not significantly affect either seed protein or oil concentration. However, there was a trend of decreasing protein and increasing oil concentration as PD was delayed. Bajaj et al. (2008) found similar results in their experiments. However, other studies have shown that protein and oil concentration can be affected by PD. Helms et al. (1990), Kane et al. (1997c), Bennett et al. (2004) and Tremblay et al. (2006) found that oil concentration decreased and protein concentration increased with delayed PD.

Protein concentration was found to be significantly higher for soybeans in the strip till system while oil concentration was significantly lower in the drilled no-till system. Spoljar et al. (2009) found that intensive tillage positively affected protein content. Temperly and Borges (2006) found that there was a significant tillage by rotation interaction on protein and oil concentration. The MG VIII variety was found to have a higher concentration of protein but a lower oil concentration than the MG VII variety. Seed composition is genetically determined, but it can also be affected by environmental factors such as temperature and water stress (Gibson and Mullen, 1996). It is well documented that protein and oil concentration are negatively correlated (Krober and Cartter, 1962; Hurburgh et al., 1987; Dornbos and Mullen, 1992; Gibson and Mullen, 1996). This is consistent with results observed in this study.

2.5 Conclusions

Delaying planting until after 22 June in South Carolina could adversely affect the growth and development of soybean, and result in a significant reduction in seed yield. It appeared that the yield reduction was greater as the planting date was delayed. In this test, yield was greater in the strip-till system compared to the drilled no-till system, primarily because of greater soil compaction. Yield of the MG VIII variety was greater than the MG VII variety. The shortened duration of vegetative growth and seed fill period probably contributed most to the yield decrease observed in later planted soybean. Vegetative growth, especially branch development was affected by delayed planting resulting in fewer pods and decreased yield. High temperature and severe drought conditions, which usually accompany late planting dates, could negatively affect the growth, development, and yield of soybean. LAI, NDVI, and HT at R2 and R4 are positively correlated to seed yield. They might be helpful in building a regression model to predict the final seed yield.

2.6 Tables

Table 2-1. Planting date information at both locations in 2011 and 2012.

	Planting Date							
	2011				2012			
Location	1	2	3	4	1	2	3	4
Edisto	15-Jun	22-Jun	30-Jun	6-Jul	15-Jun	22-Jun	29-Jun	6-Jul
Pee Dee	16-Jun	23-Jun	29-Jun	7-Jul	14-Jun	21-Jun	28-Jun	5-Jul

Table 2-2. Analysis of variance of soybean yield, yield components, and protein and oil concentrations across environments.

SOV	Pr > F				
	Yield	Seed size	Seed number	Protein	Oil
PD[1]	0.1935	0.06	0.4444	0.2198	0.7032
MS[2]	<.0001	0.9047	<.0001	0.001	0.0012
PD*MS	0.3645	0.8777	0.0841	0.2104	0.4785
MG[3]	0.0023	<.0001	0.0002	0.0028	<.0001
PD*MG	0.3713	0.0472	0.4956	0.9652	0.5121
MS*MG	0.8608	0.021	0.4821	0.0822	0.1737
PD*MS*MG	0.2824	0.0636	0.7081	0.3687	0.1687

[1]PD: planting date (1-4); [2]MS: management system (strip-till or drilled no-till)

[3]MG: maturity group (VII or VIII)

Table 2-3. Mean seed yield and yield components of different planting dates (PD) (across environments, management systems (MS) and maturity groups (MG)), MS (across environments, PD and MG), and MG (across environments, PD and MS).

Factor		Yield (kg ha^{-1})	Seed size (mg seed^{-1})	Seed number (m^{-2})	Protein (%)	Oil (%)
PD	1	1745 A	132 A	1356 A	36.68 A	18.22 A
	2	2013 A	132 A	1500 A	36.72 A	18.27 A
	3	1529 A	129 A	1193 A	36.16 A	18.45 A
	4	1317 A	124 A	1067 A	36.05 A	18.32 A
MS	ST[1]	1832 A	129	1440 A	36.62 A	18.21 B
	D[2]	1470 B	129	1119 B	36.19 B	18.42 A
MG	VII	1539 B	132	1164 B	36.60 A	18.10 B
	VIII	1764 A	127	1395 A	36.21 B	18.52 A

[1]ST: strip-till system; [2]D: drilled no-till system

LSMEANS followed by the same letter within a column are not significantly different at P≤0.05.

LSMEANS not followed by letters indicates there were significant interactions between treatments so there is no significant main effect.

Table 2-4. Estimated parameters and model fitness for the linear regression model (Seed Yield=Intercept + Slope × Planting date) for MG VII and VIII varieties in drilled no-till (D) and strip-till (ST) systems for 3 trials.

		Parameter Estimate			
		D		ST	
Trial	Variable	VII	VIII	VII	VIII
	Intercept	1953.5	589.1	-3652.1	1501.3
Edisto	PD	-45.1	70.6	426.2	40.3
2011	PD^2	0.1	-1.6	-8.3	-1.4
(trial a)	R^2	0.62	0.06	0.68	0.27
	P value	0.0020	0.6620	0.0006	0.1246
	Intercept	1414.4	861.0	157.7	337.9
Edisto	PD	102.2	148.2	219.8	218.0
2012	PD^2	-3.4	-4.1	-5.4	-5.3
(trial b)	R^2	0.55	0.57	0.37	0.67
	P value	0.0056	0.0070	0.0640	0.0005
	Intercept	-198.8	1601	2160.5	3383.2
Pee Dee	PD	145.5	-21.9	-5.5	-91.9
2012	PD^2	-2.6	1	-0.1	1.6
(trial c)	R^2	0.08	0.08	0.05	0.08
	P value	0.6581	0.6850	0.7564	0.5809

Table 2-5. Analysis of variance of LAI, NDVI, and HT at R2 and R4 across environments.

	Pr>F					
	LAI		NDVI		HT	
SOV	R2	R4	R2	R4	R2	R4
PD[1]	0.3533	0.2279	0.3622	0.3903	0.1276	0.1487
MS[2]	<.0001	0.0923	<.0001	<.0001	<.0001	<.0001
PD*MS	0.023	0.2603	0.6399	0.2074	0.171	0.3616
MG[3]	0.8152	0.5191	0.9246	0.4078	0.0008	0.0926
PD*MG	0.1834	0.6863	0.2621	0.0263	0.0895	0.122
MS*MG	0.3462	0.8691	0.9591	0.1044	0.5753	0.0414
PD*MS*MG	0.2511	0.8624	0.0348	0.1438	0.4395	0.3701

[1]PD: planting date (1-4); [2]MS: management system (strip-till or drilled no-till)

[3]MG: maturity group (VII or VIII)

Table 2-6. LAI, NDVI, and HT at R2 and R4 of 4 planting dates (PD) (across environments, management systems (MS) and maturity groups (MG)), 2 MS (across environments, PD and MG), and 2 MG (across environments, PD and MS).

Factor		LAI		NDVI		HT	
		R2	R4	R2	R4	R2	R4
PD	1	3.92	4.43	0.7627	0.8460	63.5	72.8
	2	3.81	4.24	0.7495	0.8157	59.3	70.6
	3	3.48	3.68	0.7025	0.8363	51.0	63.9
	4	3.04	3.6	0.699	0.7587	46.9	59.3
MS	ST[1]	3.85	4.10	0.7657	0.8480 A	60.6 A	73.5
	D[2]	3.28	3.87	0.6911	0.7803 B	49.8 B	59.7
MG	VII	3.58	4.03	0.7276	0.8194	53.2 B	65.5
	VIII	3.55	3.94	0.7292	0.8090	57.1 A	67.8

[1]ST: strip-till system; [2]D: drilled no-till system

LSMEANS within a column with same letter are not significantly different at P≤0.05.

LSMEANS not followed by letters indicates there were significant interactions between treatments so there is no significant main effect.

Table 2-7. Mean NDVI value of each treatment at R2 across environments.

Factor			
PD[1]	MS[2]	MG[3]	NDVI
1	ST[4]	VII	0.8082 A
1	ST	VIII	0.8080 A
3	ST	VII	0.8005 A
3	ST	VIII	0.7777 AB
3	D[5]	VIII	0.7679 AB
2	ST	VIII	0.7555 AB
2	ST	VII	0.7335 AB
1	D	VIII	0.7274 AB
4	ST	VIII	0.7266 AB
4	ST	VII	0.7157 AB
2	D	VII	0.7124 AB
1	D	VII	0.7070 AB
4	D	VII	0.6915 AB
4	D	VIII	0.6761 AB
3	D	VII	0.6521 AB
2	D	VIII	0.5945 B

[1]PD: planting date (1-4); [2]MS: management system (strip-till or drilled no-till)

[3]MG: maturity group (VII or VIII); [4]ST: strip-till system; [5]D: drilled no-till system

Average values within a column followed by the same letter are not significantly different at P≤0.05

Table 2-8. Analysis of variance of LAI measured at 5- to 13-WAP across environments.

	Pr>F								
	LAI								
	WAP								
SOV	5	6	7	8	9	10	11	12	13
PD[1]	0.7242	0.2034	0	0.3999	0.3342	0.1338	0.1492	0.1726	0.4309
MS[2]	<.0001	0.3459	0	0.0081	0.0114	0.0011	0.0113	0.1578	0.0005
PD*MS	0.001	0.9815	1	0.8547	0.0428	0.0809	0.9059	0.521	0.0237
MG[3]	0.3284	0.1342	1	0.201	0.1703	0.7636	0.7035	0.2002	0.2464
PD*MG	0.579	0.1533	1	0.0716	0.6324	0.0372	0.1767	0.0619	0.4865
MS*MG	0.3708	0.6617	0	0.1373	0.8572	0.8051	0.3476	0.7682	0.8048
PD*MS*MG	0.7087	0.9349	0	0.509	0.4599	0.1017	0.6001	0.8985	0.8257

[1]PD: planting date (1-4); [2]MS: management system (strip-till or drilled no-till)

[3]MG: maturity group (VII or VIII)

Table 2-9. Mean LAI at 5- to13-WAP of 4 planting dates (PD) (across environments, management systems (MS) and maturity groups (MG)), 2 MS (across environments, PD and MG), and 2 MG (across environments, PD and MS).

		LAI								
		WAP								
Factor		5	6	7	8	9	10	11	12	13
PD	1	1.6	2	1.8	2.1	3.7	3.9	3.4	4.3	3.1
	2	1.2	2.4	1.9	2.7	3	3.3	4.2	3.1	3.1
	3	1.7	1.9	2.3	3.1	2.8	3.6	2.6	2.9	3.2
	4	1.7	3.2	2.8	2.6	3.7	2	2.6	2.9	2.5
MS	ST	1.7	1.7 A	2.3	2.8 A	3.5	3.4 A	3.4 A	3.4	3.2
	D	1.4	1.4 B	2.1	2.5 B	3.1	3.0 B	3.0 B	3.2	2.8
MG	VIII	1.6	2.5	2.2	2.6	3.2	3.2	3.2	3.4	3.1
	VII	1.5	2.3	2.2	2.7	3.4	3.2	3.2	3.2	2.9

[1]ST: strip-till system; [2]D: drilled no-till system

Table 2-10. Analysis of variance of NDVI measured at 5- to 12-WAP across environments.

	Pr>F							
	NDVI							
	WAP							
SOV	5	6	7	8	9	10	11	12
PD[1]	0.2926	0.1862	0.1591	0.0835	0.1483	0.5104	0.8501	0.1295
MS[2]	0.001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
PD*MS	0.8346	0.2455	0.0877	0.1728	0.9147	0.212	0.1591	0.0164
MG[3]	0.4025	0.4371	0.8804	0.9565	0.2726	0.8079	0.9481	0.4964
PD*MG	0.28	0.3615	0.2587	0.2706	0.0876	0.0003	0.0085	0.004
MS*MG	0.6007	0.9473	0.5094	0.441	0.5691	0.9501	0.2469	0.4838
PD*MS*MG	0.3205	0.5282	0.0745	0.3245	0.003	0.0415	0.0736	0.5537

[1]PD: planting date (1-4); [2]MS: management system (strip-till or drilled no-till)

[3]MG: maturity group (VII or VIII)

Table 2-11. Mean NDVI at 5- to12-WAP of 4 planting dates (PD) (across environments, management systems (MS) and maturity groups (MG)), 2 MS (across environments, PD and MG), and 2 MG (across environments, PD and MS)

		NDVI							
		WAP							
Factor		5	6	7	8	9	10	11	12
PD	1	0.393	0.4108	0.4801	0.6387	0.6938	0.7642	0.8203	0.85
	2	0.4841	0.5551	0.5066	0.6474	0.699	0.7787	0.8136	0.7821
	3	0.3883	0.53	0.5373	0.733	0.7764	0.8109	0.8125	0.8748
	4	0.527	0.5678	0.7253	0.7462	0.7801	0.7426	0.773	0.7456
MS	ST[1]	0.5054	0.5596	0.6191	0.7343	0.7785	0.8162	0.8373	0.8442
	D[2]	0.3908	0.4723	0.5056	0.6484	0.6961	0.7319	0.7724	0.7821
MG	VIII	0.4338	0.5093	0.5606	0.6918	0.7456	0.7759	0.8044	0.8176
	VII	0.4624	0.5226	0.5641	0.6909	0.729	0.7723	0.8053	0.8087

[1]ST: strip-till system; [2]D: drilled no-till system

Table 2-12. Analysis of variance of HT measured at 5- to13-WAP across environments.

	Pr>F								
	HT								
	WAP								
SOV	5	6	7	8	9	10	11	12	13
PD[1]	0.8056	0.859	0.596	0.4361	0.3909	0.8588	0.4251	0.1699	0.0956
MS[2]	<.0001	0.0311	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
PD*MS	0.1703	0.3714	0.2883	0.7633	0.1482	0.7772	0.353	0.2367	0.0401
MG[3]	<.0001	0.0007	<.0001	<.0001	0.0186	0.7837	0.1986	0.1259	0.0317
PD*MG	0.4033	0.612	0.2083	0.026	0.0151	0.0664	0.6049	0.2652	0.194
MS*MG	0.8096	0.966	0.4113	0.6338	0.2008	0.2975	0.1013	0.0118	0.1757
PD*MS*MG	0.8852	0.675	0.4597	0.6006	0.3978	0.6055	0.3514	0.9657	0.4777

[1]PD: planting date (1-4); [2]MS: management system (strip-till or drilled no-till)

[3]MG: maturity group (VII or VIII)

Table 2-13. Mean HT at 5- to13-WAP of 4 planting dates (PD) (across environments, management systems (MS) and maturity groups (MG)), 2 MS (across environments, PD and MG), and 2 MG (across environments, PD and MS)

		HT (cm)								
		WAP								
Factor		5	6	7	8	9	10	11	12	13
PD	1	23.5	26.1	33.6	39.3	47.5	63.5	68.2	72.8	73.8
	2	21.4	27.6	33.7	41.4	59.3	66.6	70.6	71.2	72.7
	3	21.8	25.1	33.7	47.2	56.5	62.9	65	67.2	64.5
	4	20.6	29.1	41.8	49.5	57.4	61.3	61.1	59.7	58.3
MS	ST[1]	22.9	28	38.8	48.1	60.4	70.2	72.3	74.7	73.3
	D[2]	20.8	26	32.6	40.7	50	56.9	60.1	60.7	61.4
MG	VIII	20.6	25.3	34	42.2	53.8	63.4	67.1	68.8	68.9
	VII	23	28.7	37.4	46.5	56.5	63.8	65.3	66.6	65.8

[1]ST: strip-till system; [2]D: drilled no-till system

Table 2-14. Pearson correlation coefficients (r) between yield and HT, NDVI (N), LAI (L) at growth stages R2 and R4.

r	HT-R2	HT-R4	N-R2	N-R4	L-R2	L-R4
Yield	0.34***	0.45***	0.48***	0.40***	0.69***	0.65***
Ht-R2	-	0.81***	0.13†	0.27***	0.39***	0.28***
Ht-R4	-	-	0.22**	0.30***	0.41***	0.37***
N-R2	-	-	-	0.33***	0.54***	0.44***
N-R4	-	-	-	-	0.42***	0.72***
L-R2	-	-	-	-	-	0.73***

Table 2-15. Pearson correlation coefficients (r) between seed yield and LAI, NDVI, and HT measured at 5- to12-weeks after planting for MG VII and VIII varieties.

r	Weeks after planting							
	5	6	7	8	9	10	11	12
	LAI							
VII	-0.07†	0.29†	0.45***	0.59***	0.71***	0.64***	0.63***	0.43***
VIII	-0.06†	0.15†	0.39***	0.53***	0.54***	0.54***	0.58***	0.48***
	NDVI							
VII	0.30**	0.63***	0.73***	0.54***	0.57***	0.72***	0.68***	0.63***
VIII	0.39***	0.39***	0.66***	0.53***	0.47***	0.56***	0.67***	0.54***
	HT							
VII	0.40***	0.23*	0.44***	0.39***	0.59***	0.68***	0.64***	0.59***
VIII	0.32**	0.21†	0.22*	0.25*	0.42***	0.52***	0.60***	0.56***

*Significant at P≤0.05.

**Significant at P≤0.01.

***Significant at P≤0.001.

† Not significant at P≤0.05.

Table 2-16. Analysis of variance of duration (days) from planting (P) to R8, R1, R1-R8, R1-R3, R3-R5, R5-R7 across environments.

	Pr>F					
	Total	Vegetative	Reproductive	Flowering	Pod set	Seed filling
SOV	(P-R8)	(P-R1)	(R1-R8)	(R1-R3)	(R3-R5)	(R5-R7)
PD[1]	<.0001	<.0001	0.0004	0.2664	0.0867	0.0298
MS[2]	0.1159	0.3876	0.0749	0.8134	0.6101	0.0282
PD*MS	0.7602	0.976	0.7632	0.8080	0.8287	0.8906
MG[3]	<.0001	<.0001	0.0032	0.2410	0.0629	<.0001
PD*MG	0.5647	0.0272	0.1285	0.0303	0.0015	0.8718
MS*MG	0.7240	0.8740	0.9072	0.0744	0.2916	0.7847
PD*MS*MG	0.0217	0.1181	0.0537	0.8037	0.1974	0.8213

[1]PD: planting date (1-4); [2]MS: management system (strip-till or drilled no-till)

[3]MG: maturity group (VII or VIII)

Table 2-17. Mean duration of total growth period, vegetative and reproductive growth, flowering, pod set and seed filling of 4 planting dates (PD) (across environments, management systems (MS) and maturity groups (MG)), 2 MS (across environments, PD and MG), and 2 MG (across environments, PD and MS)

Factor		Total	Vegetative	Reproductive	Flowering	Pod set	Seed filling
		(P-R8)	(P-R1)	(R1-R8)	(R1-R3)	(R3-R5)	(R5-R7)
		days					
PD	1	136.0	58.5	77.6 A	13.7	11.6	41.0 A
	2	128.5	54.1	74.3 B	13.1	10.1	40.5 B
	3	122.2	50.2	72.0 C	12.4	8.9	39.1 C
	4	115.7	46.1	69.6 D	10.9	10.3	37.9 D
MS	ST[1]	125.8	52.1	73.7	12.6	10.2	40.0
	D[2]	125.4	52.4	73.0	12.5	10.3	39.2
MG	VII	124.4	50.5	74.0 A	12.3	10.0	40.4 A
	VIII	126.8	54.0	72.8 B	12.8	10.5	38.8 B

[1]ST: strip-till system; [2]D: drilled no-till system

LSMEANS followed by the same letter within a column are not significantly different at $P \leq 0.05$. LSMEANS without letters followed indicates there are significant interactions between treatments so the main effect is not valid.

Table 2-18. Mean duration (days) of total growth period (planting to R8) of each treatment across environments.

Factor			Duration (days)
PD[1]	MS[2]	MG[3]	P-R8
1	D	VIII	137.4 A
1	ST[4]	VIII	137.4 A
1	ST	VII	135.4 AB
1	D[5]	VII	133.9 B
2	ST	VIII	130.4 C
2	D	VIII	128.4 CD
2	D	VII	128.0 CD
2	ST	VII	127.0 DE
3	ST	VIII	123.7 EF
3	D	VIII	123.5 F
3	ST	VII	121.3 FG
3	D	VII	120.5 G
4	D	VIII	116.8 H
4	ST	VIII	116.6 H
4	ST	VII	114.7 H
4	D	VII	114.7 H

[1]PD: planting date; [2]MS: management system; [3]MG: maturity group (VII or VIII)

[4]ST: strip-till system; [5]D: drilled no-till system

LSMEANS followed by the same letter within a column are not significantly different at $P \leq 0.05$.

Table 2-19. Mean duration of vegetative growth (planting-R1), flowering (R1-R3) and pod set (R3-R5) of 4 planting dates (PD) for maturity group (MG) VII and VIII soybean across environments and management systems.

P-R1			R1-R3			R3-R5		
Factor		Duration	Factor		Duration	Factor		Duration
PD	MG	(days)	PD	MG	(days)	PD	MG	(days)
1	VIII	61.1 A	1	VII	14.4 A	1	VII	12.0 A
1	VII	55.8 B	3	VIII	13.4 A	4	VIII	11.6 A
2	VIII	55.8 B	2	VIII	13.2 A	1	VIII	11.2 AB
2	VII	52.5 C	1	VIII	13.1 A	2	VIII	10.2 AB
3	VIII	51.5 C	2	VII	13.0 A	2	VII	10.1 AB
3	VII	49.0 D	4	VIII	11.5 A	3	VIII	9.2 AB
4	VIII	47.7 D	3	VII	11.5 A	4	VII	9.1 B
4	VII	44.6 E	4	VII	10.4 A	3	VII	8.6 B

LSMEANS followed by the same letter within a column are not significantly different at $P \leq 0.05$.

Table 2-20. Pearson correlation coefficient (r) between seed yield and duration of total growth (P-R6, P-R8), vegetative growth (V), reproductive growth (R), flowering, pod set and seed filling.

r	P-R6	P-R8	V	R	Flowering	Pod set	Seed filling
Seed Yield	0.23**	0.25***	0.33***	0.06†	-0.09†	-0.03†	0.26***
P-R6	-	0.75***	0.71***	0.47***	0.32***	0.33***	0.27***
P-R8	-	-	0.82***	0.77***	0.36***	0.28***	0.47***
V	-	-	-	0.27***	0.03†	0.15*	0.18*
R	-	-	-	-	0.58***	0.31***	0.59***
Flowering	-	-	-	-	-	-0.14†	-0.001†
Pod	-	-	-	-	-	-	-0.02†

*Significant at $P \leq 0.05$.

**Significant at $P \leq 0.01$.

***Significant at $P \leq 0.001$.

† Not significant at $P \leq 0.05$.

Table 2-21. Estimated parameters and model fitness from the linear regression models (Seed Yield=intercept +slope ×duration) for soybeans of different trials.

Trial	Variable	Parameter Estimate				
		V	R1-R7	R1-R3	R3-R5	R5-R7
Edisto	Intercept	-824.7	498.3	881.6	1815.3	-426.7
2011	slope	39.7	11.4	25.0	-50.7	42.8
(trial a)	R^2	0.17***	0.01†	0.02†	0.03†	0.03†
Edisto	Intercept	-2497.9	-4799.7	1585.7	889.4	-2954.1
2012	slope	82.2	115.1	19.5	106.1	129.3
(trial b)	R^2	0.29***	0.39***	0.005†	0.17***	0.20***
Pee Dee	Intercept	1473.5	1939.3	2117.9	1948.3	1041.6
2012	slope	8.2	-0.5	-17.7	-4.3	20.1
(trial c)	R^2	0.01†	0.01†	0.01†	0.0004†	0.01†

*Significant at P≤0.05.

**Significant at P≤0.01.

***Significant at P≤0.001.

† Not significant at P≤0.05.

Table 2-22. Analysis of variance of relative percentage of pods and yield on branches vs. stems across locations (2012).

SOV	Pr>F			
	Percentage of pod on (%)		Percentage of yield on (%)	
	Branches	Stems	Branches	Stems
PD[1]	0.1609	0.1609	0.2737	0.2737
MS[2]	0.3868	0.3868	0.1284	0.1284
PD*MS	0.6517	0.6517	0.5744	0.5744
MG[3]	0.0433	0.0433	0.0329	0.0329
PD*MG	0.9426	0.9426	0.7936	0.7936
MS*MG	0.1993	0.1993	0.0630	0.0630
PD*MS*MG	0.5950	0.5950	0.9174	0.9174

[1]PD: planting date (1-4); [2]MS: management system (strip-till or drilled no-till)

[3]MG: maturity group (VII or VIII)

Table 2-23. Mean relative percentage of pods and yield on branches vs. stems of 4 planting dates (PD) (across environments, management systems (MS) and maturity groups (MG)), 2 MS (across environments, PD and MG), and 2 MG (across environments, PD and MS).

Factor		Percentage of pods on (%)		Percentage of yield on (%)	
		Branches	Stems	Branches	Stems
PD	1	67 A	33 A	65 A	35 A
	2	61 A	39 A	62 A	38 A
	3	60 A	40 A	61 A	39 A
	4	55 A	45 A	56 A	44 A
MS	ST[1]	60 A	40 A	59 A	41 A
	D[2]	61 A	39 A	62 A	38 A
MG	VII	63 A	37 B	63 A	37 B
	VIII	59 B	41 A	58 B	42 A

[1]ST: strip-till system; [2]D: drilled no-till system

LSMEANS followed by the same letter within a column are not significantly different at P≤0.05; LSMEANS not followed by letters indicates there were significant interactions between treatments so there is no significant main effect.

Table 2-24. Pearson correlation coefficients (r) between length, pod number and yield of branches and main stems.

r	Main stem length	Branch length	Stem pod number	Branch pod number	Stem yield	Branch yield
Total yield	0.51***	0.43***	0.58***	0.30***	0.51***	0.23*
Main stem length	-	0.73***	0.48***	0.27**	0.55***	0.26**
Branch length	-	-	0.47***	0.43***	0.53***	0.43***
Stem pod number	-	-	-	0.49***	0.82***	0.44***
Branch pod number	-	-	-	-	0.55***	0.97***
Stem yield	-	-	-	-	-	0.54***

* Significant at P≤0.05.

**Significant at P≤0.01.

***Significant at P≤0.001.

† Not significant at P≤0.05.

Table 2-25. Analysis of variance of dry weight of branches, leaves, petioles, pods and stems of each plant across locations (2012).

	Pr>F				
	Dry weight (g)				
SOV	Branches	Leaves	Petioles	Pods	Stems
PD[1]	0.0297	0.0636	0.1563	0.3461	0.1943
MS[2]	0.3255	0.9247	0.0719	0.7282	0.0198
PD*MS	0.6307	0.8121	0.9716	0.9474	0.7341
MG[3]	0.1317	0.4286	0.0006	0.0067	0.0264
PD*MG	0.6863	0.4759	0.8693	0.3187	0.1595
MS*MG	0.3241	0.7439	0.7712	0.2291	0.2464
PD*MS*MG	0.3226	0.4638	0.2944	0.3171	0.3579

[1]PD: planting date (1-4); [2]MS: management system (strip-till or drilled no-till)

[3]MG: maturity group (VII or VIII)

Table 2-26. Mean dry weight of branches, leaves, petioles, pods and stems from each plant of 4 planting dates (PD) (across environments, management systems (MS) and maturity groups (MG)), 2 MS (across environments, PD and MG), and 2 MG (across environments, PD and MS).

Factor		Dry weight (g)				
		Branches	Leaves	Petioles	Pods	Stems
PD	1	38.9 A	84.5 A	40.3 A	44.9 A	32.6 A
	2	27.4 AB	70.1 A	32.1 A	40.0 A	27.8 A
	3	18.2 AB	54.5 A	25.2 A	39.4 A	23.2 A
	4	13.4 B	42.2 A	20.1 A	30.4 A	19.0 A
MS	ST[1]	25.5 A	63.0 A	31.4 A	39.2 A	27.1 A
	D[2]	23.4 A	62.6 A	27.4 A	38.2 A	24.1 B
MG	VII	22.8 A	61.3 A	25.6 B	34.4 B	24.2 B
	VIII	26.1 A	64.3 A	33.2 A	43.0 A	27.1 A

[1]ST: strip-till system; [2]D: drilled no-till system

LSMEANS followed by the same letter within a column are not significantly different for each treatment at P≤0.05

Table 2-27. Pearson correlation coefficients (r) between yield and dry weight of total branches, leaves, petiole, pods and stems.

r	Dry weight				
	Branches	Leaves	Petiole	Pods	Stem
Seed yield	0.36***	0.40***	0.44***	0.29*	0.51***
Branches	-	0.83***	0.86***	0.61***	0.66***
Leaves	-	-	0.836***	0.68***	0.71***
Petiole	-	-	-	0.67***	0.79***
Pods	-	-	-	-	0.52***

*Significant at P≤0.05.

**Significant at P≤0.01.

***Significant at P≤0.001.

† Not significant at P≤0.05.

2.7 Figures

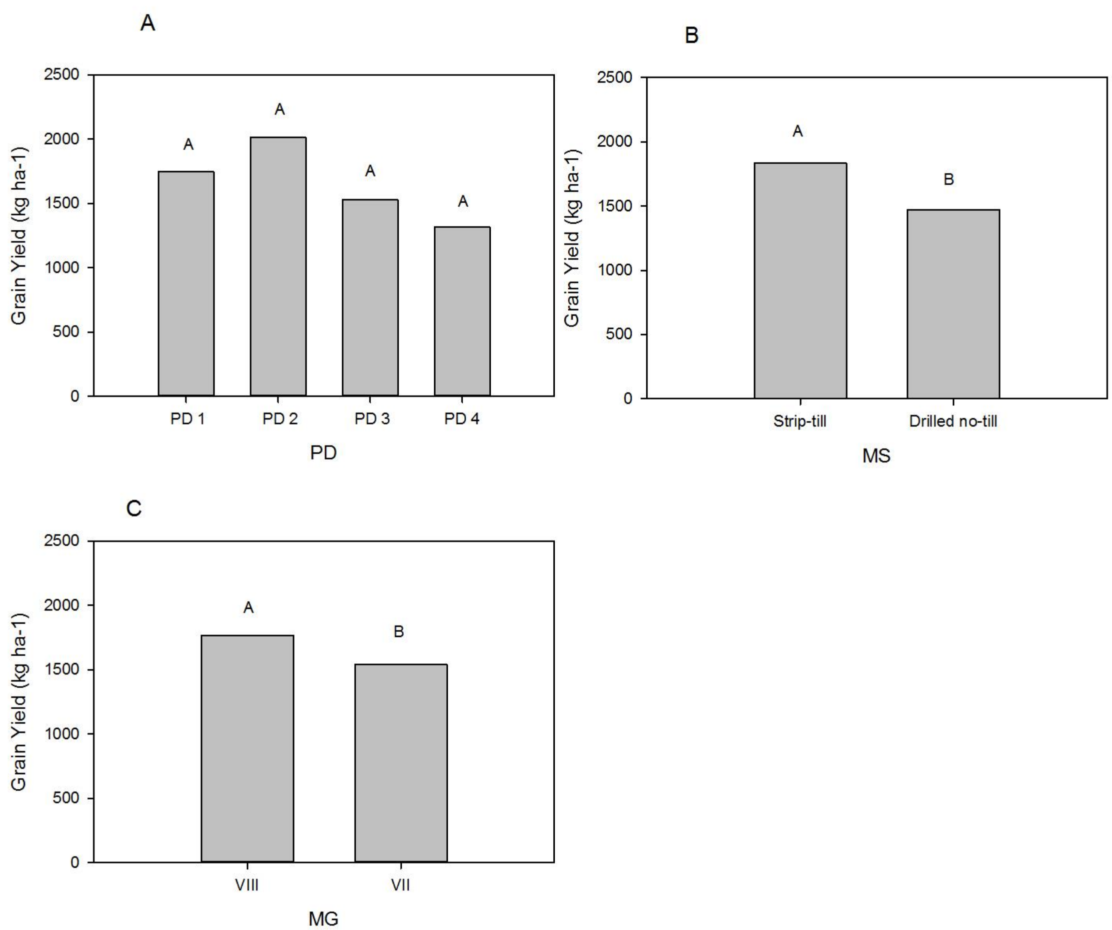

Figure 2-4 A. Mean seed yield of each planting date (PD) across environments, management systems (MS) and maturity groups (MG); B. Mean seed yield of each MS across environments, PD and MG; C. Mean seed yield of each MG across environments, PD and MS.

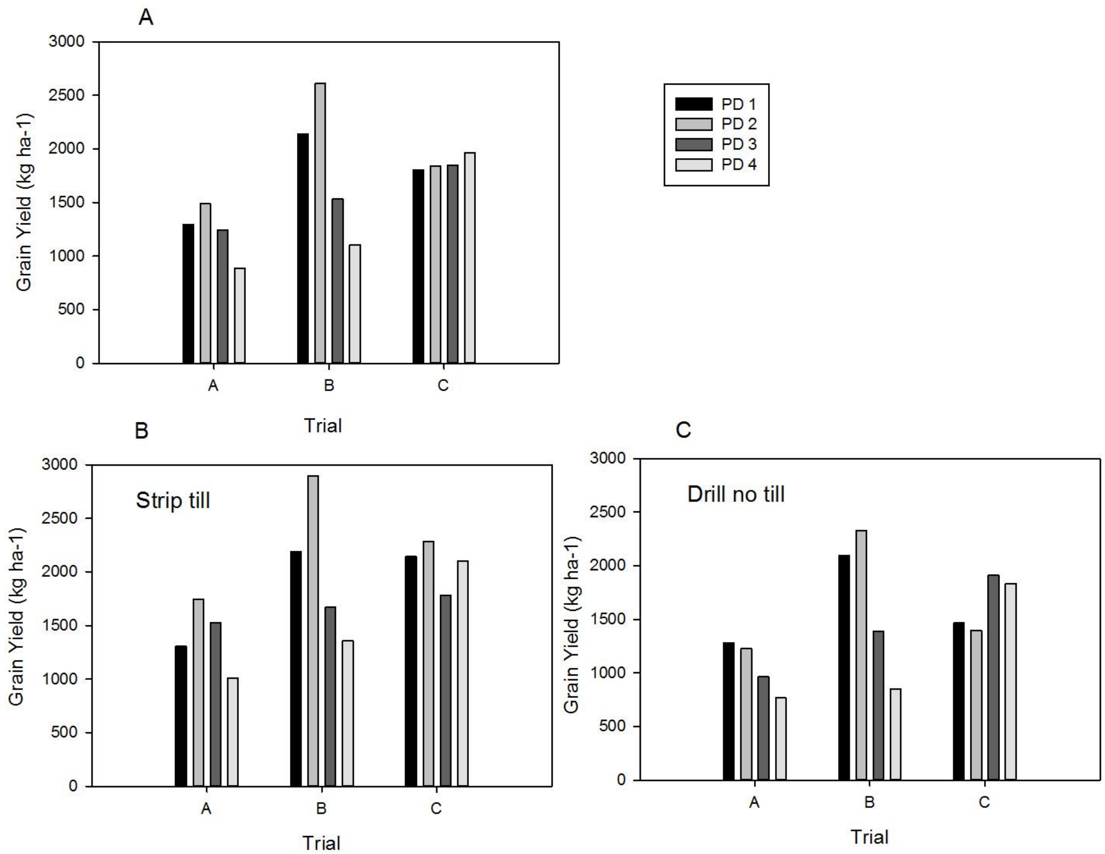

Figure 2-5 A. Mean seed yield of four planting dates (PD) across management systems (MS) and maturity groups (MG) for 3 trials; B. Mean seed yield of four PD across MG of strip-till system for 3 trials; C. Mean seed yield of four PD across MG of drilled no-till system for 3 trials.

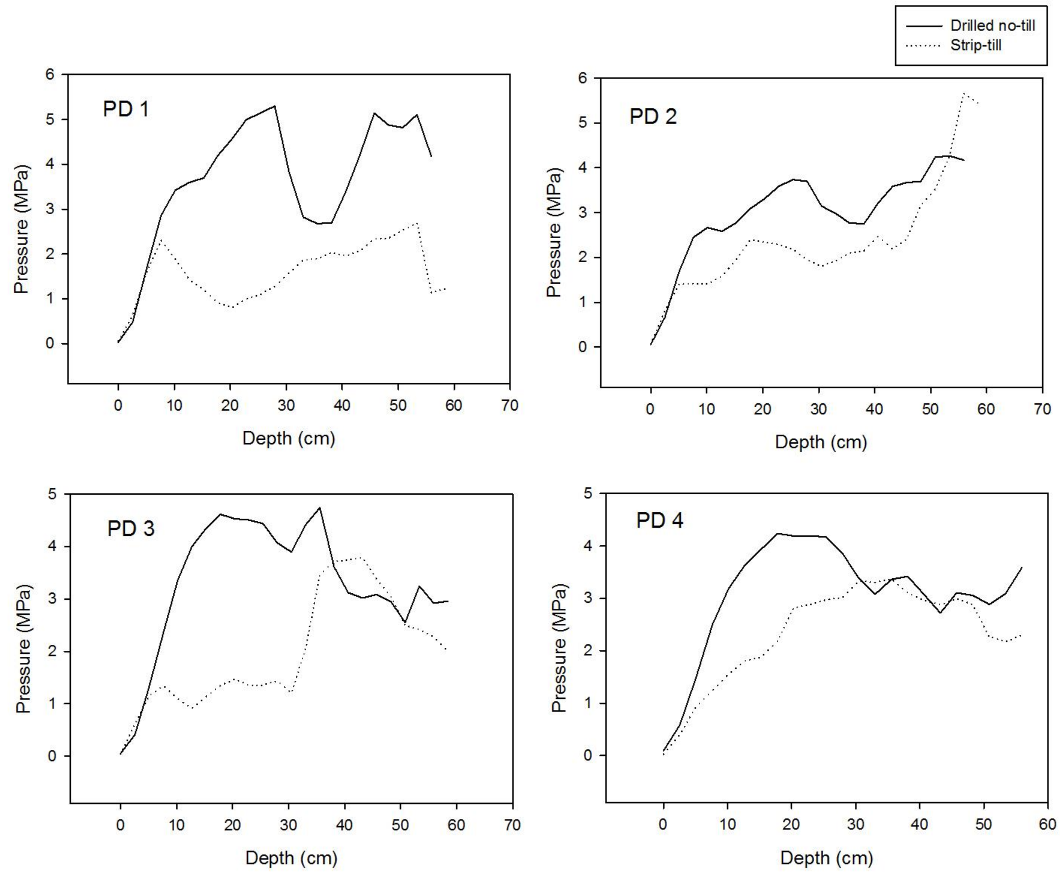

Figure 2-6. Post harvest soil compaction comparison of strip-till and drilled no-till system for four planting dates (PD) at the Edisto REC in 2012.

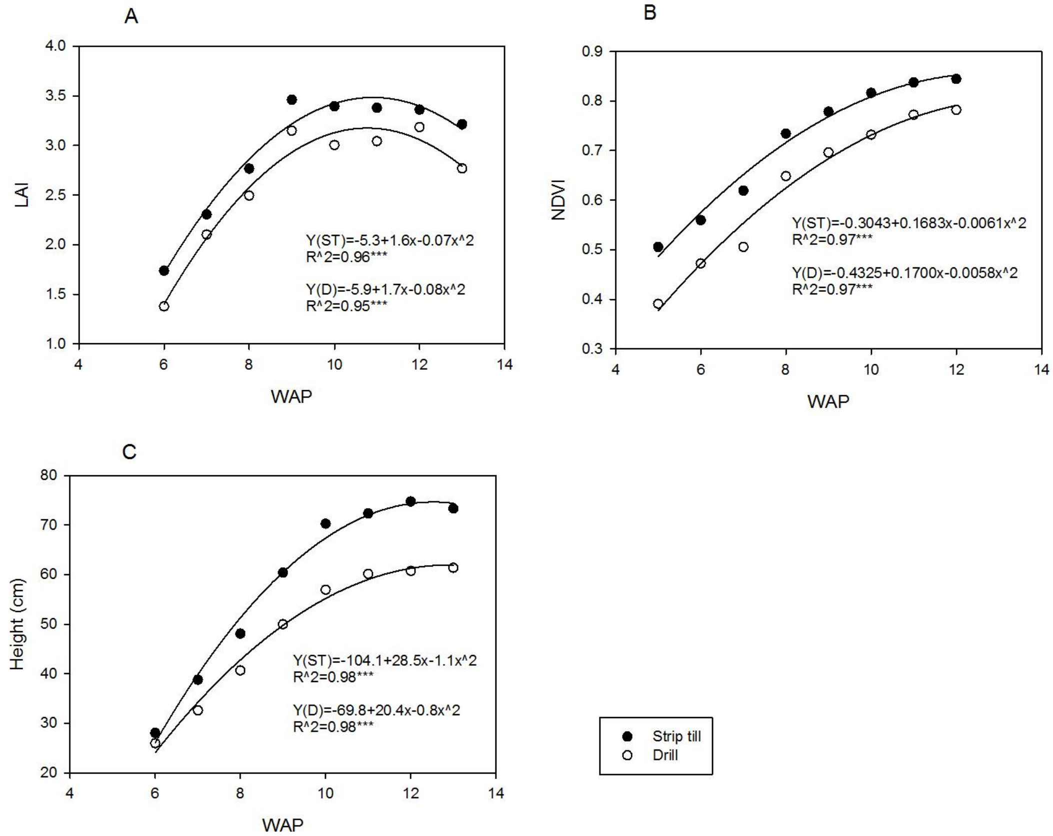

Figure 2-7. LAI (A), NDVI (B), and HT (C) as a function of weeks after planting (WAP) for soybeans in two different management systems (data were averaged across environments, planting dates and maturity groups).

Note: R^2=R^2 within the figures

*,**, and *** indicate that the regression analysis for all data points was significant at $P \leq 0.05$, $P \leq 0.01$and $P \leq 0.001$, respectively.

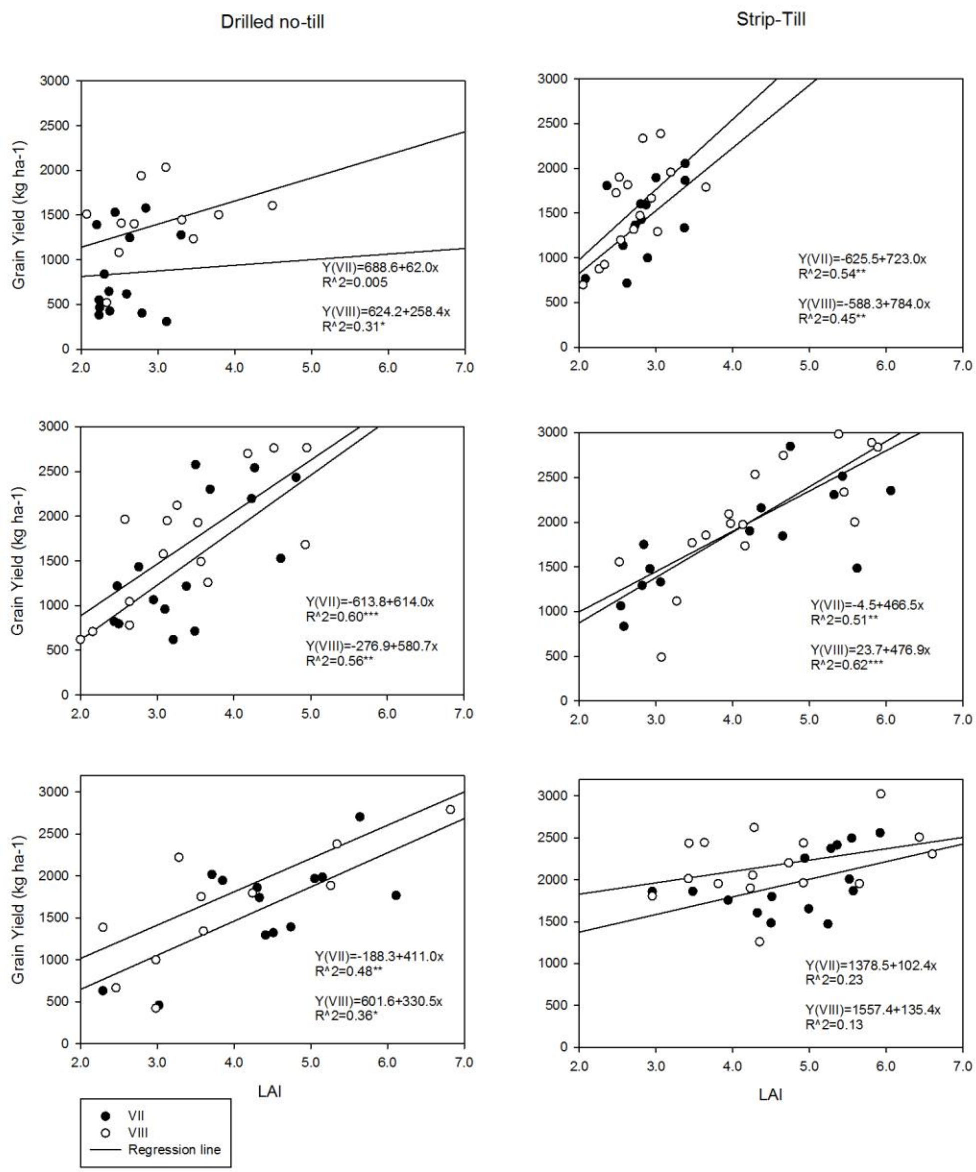

Figure 2-8. Relationship between seed yield and LAI at R2 for maturity group VII and VIII varieties in drilled no-till and strip-till systems of 3 trials at 2 locations.

Note: R^2=R^2 within the figures

*,**, and *** indicate that the regression analysis for all data points was significant at P≤0.05, P≤0.01and P≤0.001, respectively.

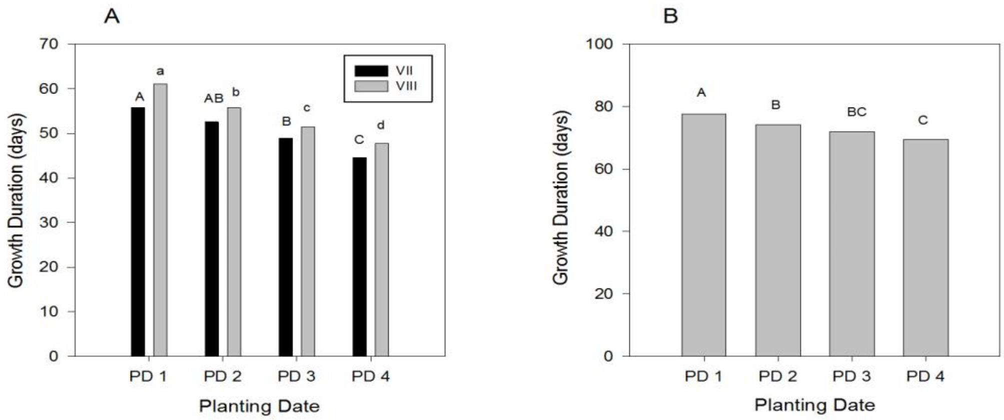

Figure 2-9. A. Mean vegetative growth duration (P-R1) for maturity group (MG) VII and VIII varieties of 4 planting dates (PD) across environments and management systems (MS); B. Mean reproductive growth duration (R1-R8) of soybeans of 4 PD across environments, MS, and MG.

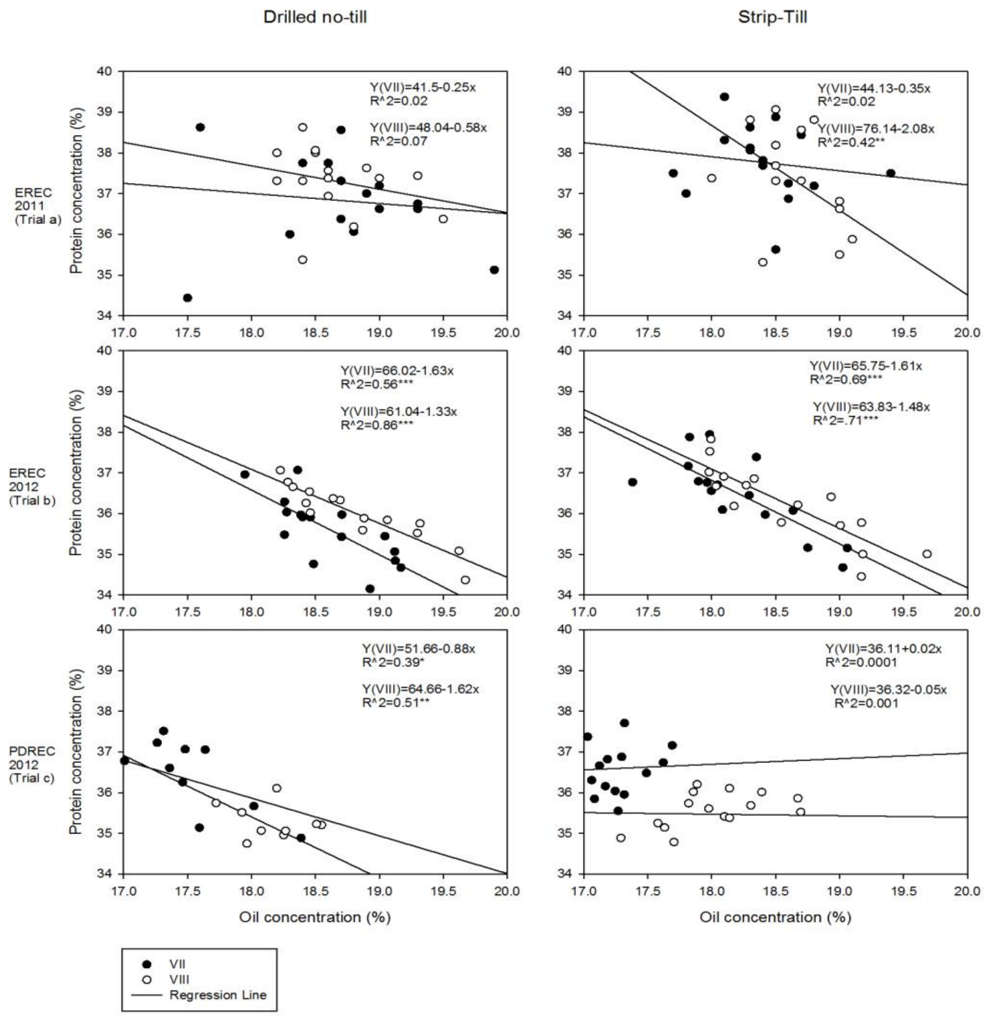

Figure 2-10. Relationship between protein and oil concentration of soybean seeds for 2 maturity group soybean varieties in drilled and strip-till systems of 3 trials at 2 locations.

Note: R^2=R^2

*,**, and *** indicate that the regression analysis for all data points was significant at $P \leq 0.05$, $P \leq 0.01$and $P \leq 0.001$, respectively.

APPENDIX

ADDITIONAL TABLES AND FIGURES

Table A-1. Stage of development descriptions for soybeans (Fehr et al., 1971).

Stage No.	Vegetative stages
	Vegetative stages are determined by counting the number of nodes on the main stem, beginning with the unifoliolate node, which have or have had a completely unrolled leaf. A leaf is considered completely unrolled when the leaf at the node immediately above it has unrolled sufficiently so the two edges of each leaflet are no longer touching. At the terminal node on the main stem, the leaf is considered completely unrolled when the leaflets are flat and similar in appearance to older leaves on the plants.
	Description
V1	Completely unrolled leaf at the unifoliolate node.
V2	Completely unrolled leaf at the first node above the unifoliolate node.
V3	Three nodes on main stem beginning with the unifoliolate node.
V(n)	N nodes on main stem beginning with the unifoliolate node.
	Reproductive stages
	Description
R1	One flower at any node.
R2	Flower at node immediately below the uppermost node with a completely unrolled leaf.
R3	Pod 0.5 cm long at one of the four uppermost nodes with a completely unrolled leaf.
R4	Pod 2 cm long at one of the four uppermost nodes with a completely unrolled leaf.
R5	Beans beginning to develop at one of the four uppermost nodes with a completely unrolled leaf.
R6	Pod containing full size green beans at one of the four uppermost nodes with a completely unrolled leaf.
R7	Pods yellowing; 50% of leaves yellow. Physiological maturity.
R8	95% of pods brown. Harvest maturity.

Table A-2. Monthly mean air temperature and total precipitation at the Edisto REC and Pee Dee REC in 2011 and 2012.

Location	Year	Jun	Jul	Aug	Sep	Oct	Nov
		Temperature (℃)					
Edisto REC	2011	27.1	27.3	24.4	22.7	15.6	12.9
	2012	23.7	27	24.3	22.3	18	10.7
	30-yr avg	25.2	26.7	25.9	23.4	18.2	12.5
		Precipitation (mm)					
	2011	57.2	140.3	182.3	142.1	111.2	28.0
	2012	79.5	97.0	309.1	19.1	14.1	44.4
	30-yr avg	129.0	130.0	123.0	92.2	80.0	68.6
Pee Dee REC		Temperature (℃)					
	2011	27.1	29.0	26.8	23.1	16.3	12.4
	2012	23.9	28.8	25.6	21.4	17.9	8.9
		Precipitation (mm)					
	2011	38.9	57.4	77.0	107.4	40.1	88.6
	2012	52.6	129.0	128.8	86.9	35.3	48.3

Table A-3. Pearson correlation coefficients between seed yield and accumulated precipitation and temperatures during the total growing season (P-R7), vegetative (P-R1), flowering (R1-R3), pod-set (R3-R5), and seed-filling(R5-R7) stages for three different trials.

r	Precipitation				
	P-R7	P-R1	R1-R3	R3-R5	R5-R7
Edisto 2011 (trial a)	0.20†	-0.37†	0.34†	0.24†	.
Edisto 2012 (trial b)	0.84***	0.75***	-0.25†	0.85***	0.86***
Pee Dee 2012 (trial c)	-0.17†	-0.17†	0.11†	-0.003†	-0.06†
r	Temperature				
	P-R7	P-R1	R1-R3	R3-R5	R5-R7
Edisto 2011 (trial a)	0.39†	0.26†	0.08†	0.31†	0.40†
Edisto 2012 (trial b)	0.78***	0.61*	-0.39†	0.49†	0.83***
Pee Dee 2012 (trial c)	-0.15†	0.11†	-0.18†	-0.02†	-0.19†

* Significant at $P \leq 0.05$.

**Significant at $P \leq 0.01$.

***Significant at $P \leq 0.001$.

† Not significant at $P \leq 0.05$.

Table A-4. Analysis of variance of duration (days) from planting to each vegetative growth stage (VE-V6) across environments.

	Pr > F							
	Days from planting to							
SOV	VE	VC	V1	V2	V3	V4	V5	V6
PD[1]	0.9063	0.8522	0.5021	0.2096	0.1614	0.5088	0.4931	0.8911
MS[2]	0.4452	0.0865	0.0105	0.0105	0.1838	0.0715	0.0164	0.0288
PD*MS	0.4027	0.7412	0.0213	0.5219	0.1737	0.6195	0.9397	0.8683
MG[3]	0.0283	0.0036	0.9594	0.9404	0.8838	0.9623	0.5631	0.5698
PD*MG	0.2308	0.0616	0.1671	0.1812	0.6152	0.8231	0.8003	0.2279
MS*MG	0.2737	0.324	0.2591	0.4695	0.5392	0.7459	0.9387	0.9624
PD*MS*MG	0.5154	0.0108	0.0243	0.619	0.4553	0.889	0.8534	0.9333

[1]PD: planting date (1-4); [2]MS: management system (strip-till or drilled no-till)

[3]MG: maturity group (VII or VIII)

Table A-5. Mean value of duration (days) from planting to each vegetative growth stages of 4 planting dates (PD) (across environments, management systems (MS) and maturity groups (MG)), 2 MS (across environments, PD and MG), and 2 MG (across environments, PD and MS).

Factor		Days from planting to							
		VE	VC	V1	V2	V3	V4	V5	V6
PD	1	5.6	9.2	13.8	17.5	21.1	27.1	31.8	38.7
	2	5.5	9.4	13.3	18.7	22.6	27.0	31.5	38.1
	3	5.8	9.3	13.0	17.1	22.6	27.9	33.4	38.5
	4	5.9	8.7	13.9	19.0	23.6	28.9	33.1	37.2
MS	ST[1]	5.7	9.0	13.2	17.8 B	22.3	27.5	32.0 B	37.6 B
	D[2]	5.8	9.3	13.8	18.3 A	22.6	28.0	32.9 A	38.7 A
MG	VII	5.8 A	9.4	13.5	18.1	22.5	27.7	32.5	38.3
	VIII	5.6 B	8.9	13.5	18.1	22.4	27.8	32.3	38.0

[1]ST: strip-till system; [2]D: drilled no-till system

LSMEANS followed the same letter within a column are not significantly different at P≤0.05.

LSMEANS not followed by letters means there were significant interactions between treatments so there is no significant main effect.

Table A-6. Analysis of variance of duration (days) from planting to each reproductive growth stage (R2-R7) across environments.

	Pr>F					
	Days from planting to					
SOV	R2	R3	R4	R5	R6	R7
PD[1]	<.0001	<.0001	<.0001	<.0001	0.0048	<.0001
MS[2]	0.687	0.5458	0.1602	0.2164	0.9282	0.1422
PD*MS	0.9928	0.9064	0.9544	0.9143	0.9524	0.9934
MG[3]	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
PD*MG	0.0834	0.7004	0.0021	<.0001	<.0001	<.0001
MS*MG	0.6366	0.0211	0.2588	0.1326	0.0063	0.1784
PD*MS*MG	0.116	0.4638	0.9787	0.3585	0.002	0.0710

[1]PD: planting date (1-4); [2]MS: management system (strip-till or drilled no-till)

[3]MG: maturity group (VII or VIII)

Table A-7. Mean duration (days) from planting to each reproductive growth stage of 4 planting dates (PD) (across environments, management systems (MS) and maturity groups (MG)), 2 MS (across environments, PD and MG), and 2 MG (across environments, PD and MS).

Factor		Days from planting to					
		R2	R3	R4	R5	R6	R7
PD	1	61.4 A	72.2 A	78.5	83.8	104.2	124.8
	2	56.8 B	67.2 B	72.1	77.4	99.9	117.8
	3	52.9 C	62.6 C	67	71.5	93.1	110.6
	4	49.0 D	57.1 D	62.5	67.4	91.1	105.3
MS	ST[1]	54.9	64.7	69.8	74.8	97.1	114.8
	D[2]	55.1	64.9	70.2	75.2	97.1	114.5
MG	VII	53.1 B	62.8 B	67.7	72.7	93.7	113.1
	VIII	56.9 A	66.8 A	72.4	77.3	100.5	116.1

[1]ST: strip-till system; [2]D: drilled no-till system

LSMEANS followed by the same letter within a column are not significantly different at P≤0.05. LSMEANS not followed by letters means there were significant interactions between treatments so there is no significant main effect.

Table A-8. Mean growth duration of days from planting to R4, R5, R6 and R7 for MG VII and VIII of 4 planting dates (PD) (across environments and management systems (MSs)), and 2 MS (across environments and PDs).

Factor		Duration (days)							
		MG VII				MG VIII			
		P - R4	P- R5	P - R6	P- R7	P - R4	P- R5	P - R6	P- R7
PD	1	76.8 A	82.3 A	100.4 A	123.8 A	80.3 A	85.3 A	108.0 A	125.8 A
	2	70.3 B	75.7 B	98.8 A	117.0 B	74.0 B	79.1 B	101.1 AB	118.7 B
	3	64.6 C	69.0 C	89.8 B	108.9 C	69.4 BC	74.1 C	96.5 B	112.3 C
	4	59.2 D	64.1 D	85.8 B	102.9 D	65.8 C	70.7 C	96.5 B	107.8 C
MS	ST[1]	67.3 B	72.3 B	93.0 B	113.1 A	72.3 A	77.4 A	101.3 A	116. 5 A
	D[2]	68.1 A	73.2 A	94.4 A	113.2 A	72.4 A	77.3 A	99.8 A	115.8 B

[1]ST: strip-till system; [2]D: drilled no-till system

LSMEANS followed by the same letter within a column are not significantly different at P≤0.05.

Table A-9. Mean duration (days) from planting to R4, R5, R6 and R7 for 4 planting dates (PD) of maturity group (MG) VII and VIII varieties across environments and management systems.

Factor		Duration (days)			
PD	MG	P-R4	P-R5	P - R6	P-R7
1	VII	76.8 B	82.3 B	100.4 B	123.8 B
1	VIII	80.3 A	85.3 A	108.0 A	125.8 A
2	VII	70.2 C	75.6 D	98.8 B	117.0 D
2	VIII	74.0 B	79.1 C	101.1 AB	118.7 C
3	VII	64.6 D	69.0 E	89.8 CD	108.9 F
3	VIII	69.4 C	74.1 D	96.5 B	112.3 E
4	VII	59.2 E	64.1 F	85.8 D	102.9 G
5	VIII	65.8 D	70.7 E	96.5 BC	107.8 F

LSMEANS followed by the same letter within a column are not significantly different at P≤0.05.

Table A-10. Results of analysis of variance for duration from R1 to each reproductive growth stages.

Source of variation (Pr > F)	Days from R1 to					
	R2	R3	R4	R5	R6	R7
PD[1]	0.8954	0.2664	0.0925	0.0512	0.6624	0.006
MS[2]	0.4298	0.8134	0.6872	0.8595	0.5589	0.0969
PD*MS	0.6658	0.808	0.9004	0.8694	0.9911	0.9729
MG[3]	0.1494	0.241	0.0025	0.0048	<.0001	0.1747
PD*MG	0.1283	0.0303	<.0001	<.0001	<.0001	<.0001
MS*MG	0.2914	0.0744	0.4145	0.2945	0.0157	0.4565
PD*MS*MG	0.8456	0.8037	0.1625	0.1767	0.0131	0.3406

[1]PD: planting date (1-4); [2]MS: management system (strip-till or drilled no-till)

[3]MG: maturity group (VII or VIII)

Table A-11. Mean days from R1 to each reproductive stage for different PDs of MG VII and VIII across year, location, and MS.

Factor		Duration (days)				
PD	MG	R1R3	R1R4	R1R5	R1R6	R1R7
1	VII	14.4 A	20.9 A	26.4 A	44.6 ABC	68.0 A
	VIII	13.1 A	19.2 AB	24.2 A	46.9 ABC	64.7 B
2	VII	13.0 A	17.6 ABC	23.1 ABC	46.3 ABC	64.5 ABC
	VIII	13.2 A	18.2 ABC	23.3 ABC	45.3 ABC	62.9 BCD
3	VII	11.5 A	15.6 BC	20.0 BD	40.8 BD	56.0 DE
	VIII	13.4 A	18.0 ABC	22.6 AC	45.0 AC	60.8 BCDE
4	VII	10.4 A	14.6 C	19.5 CD	41.2 CD	58.3 E
	VIII	11.5 A	18.1 AB	23.1 AB	48.8 AB	60.1 CDE

LSMEANS followed the same letter within a column are not significantly different at P≤0.05.

Table A-12. Analysis of variance for duration (days) between growth stages.

Source of variation (Pr > F)	Duration (days)						
	VE-VC	VC-V1	V1-V2	V2-V3	V3-V4	V4-V5	V5-V6
PD	0.5732	0.2596	0.3210	0.1018	0.2214	0.3621	0.3434
MS	0.4594	0.0725	0.8466	0.4533	0.4609	0.3342	0.6182
PD*MS	0.5931	0.0638	0.1932	0.097	0.2477	0.3644	0.6647
MG	0.3383	0.0091	0.9171	0.7462	0.8538	0.6664	0.9395
PD*MG	0.1069	0.1256	0.7707	0.5113	0.2855	0.9229	0.2163
MS*MG	0.4090	0.4342	0.0616	0.1605	0.8284	0.2992	0.8310
PD*MS*MG	0.0204	0.7633	0.0367	0.6841	0.9060	0.1030	0.6540
Source of variation (Pr > F)	Duration						
	R1-R2	R2-R3	R3-R4	R4-R5	R5-R6	R6-R7	R7-R8
PD	0.8954	0.382	0.0684	0.2039	0.4837	0.0384	0.5629
MS	0.4298	0.8662	0.4016	0.5444	0.4385	0.4464	0.8612
PD*MS	0.6658	0.9816	0.8368	0.958	0.8451	0.9092	0.7264
MG	0.1494	0.6089	0.0197	0.4414	<.0001	<.0001	0.0158
PD*MG	0.1283	0.0852	0.0045	0.3063	0.0005	<.0001	<.0001
MS*MG	0.2914	0.0114	0.1627	0.6038	0.0525	0.0117	0.3343
PD*MS*MG	0.8456	0.6083	0.2899	0.0560	0.0231	0.0178	0.4807

TRIAL A (EDISTO REC, 2011)

PD 2	ST-VIII-1	D-VIII-1	ST-VII-3	D-VIII-3	D-VII-4	D-VIII-4
	D-VII-1	D-VII-2	D-VIII-2	ST-VIII-3	ST-VIII-4	ST-VIII-x
	ST-VII-1	ST-VII-2	ST-VIII-2	D-VII-3	ST-VII-4	D-VII-x

PD 3	ST-VIII-1	D-VIII-1	ST-VII-3	D-VIII-3	D-VIII-4	D-VII-4
	ST-VII-1	D-VIII-2	ST-VII-2	D-VII-3	ST-VII-4	ST-VII-x
	D-VII-1	ST-VIII-2	D-VII-2	ST-VIII-3	ST-VIII-4	D-VIII-x

PD 1	ST-VII-1	D-VIII-1	ST-VII-3	D-VIII-3	D-VIII-4	D-VII-4
	ST-VIII-1	D-VII-2	ST-VII-2	ST-VIII-3	ST-VIII-4	D-VIII-x
	D-VII-1	D-VIII-2	ST-VIII-2	D-VII-3	ST-VII-4	ST-VIII-x

PD 4	ST-VIII-1	D-VII-1	D-VII-3	D-VIII-3	D-VII-4	D-VIII-4
	D-VIII-1	D-VIII-2	ST-VIII-2	ST-VII-3	ST-VIII-4	D-VII-x
	ST-VII-1	D-VII-2	ST-VII-2	ST-VIII-3	ST-VII-4	ST-VIII-x

TRIAL B (EDISTO REC, 2012)

PD 4	D-VIII-1	ST-VII-1	D-VIII-2	ST-VIII3	ST-VIII-4	D-VIII-4	D-VIII-x
	ST-VIII-1	D-VII-2	ST-VII-2	ST-VII-3	D-VII-4	D-VII-x	D-VIII-x
	D-VII-1	ST-VIII-2	D-VIII-3	D-VII-3	ST-VII-4	D-VII-x	D-VIII-x

PD 3	D-VII-1	ST-VII-1	ST-VII-2	D-VII-3	ST-VIII-4	ST-VII-4	D-VIII-x
	ST-VIII-1	D-VIII-2	ST-VIII-2	D-VIII-3	D-VII-4	D-VII-x	D-VIII-x
	D-VIII-1	D-VII-2	ST-VIII-3	ST-VII-3	D-VIII-4	D-VII-x	D-VIII-x

PD 1	ST-VIII-1	ST-VII-1	D-VII-2	ST-VIII-3	D-VIII-4	ST-VIII-4	D-VIII-x
	D-VII-1	ST-VIII-2	D-VIII-2	ST-VII-3	ST-VII-4	D-VII-x	D-VIII-x
	D-VIII-1	ST-VII-2	D-VIII-3	D-VII-3	D-VII-4	D-VII-x	D-VIII-x

PD 2	D-VIII-1	ST-VIII-1	ST-VIII-2	ST-VIII-3	ST-VII-4	D-VIII-4	D-VII-x
	ST-VII-1	D-VIII-2	D-VII-2	ST-VII-3	D-VII-4	D-VIII-x	D-VII-x
	D-VII-1	ST-VII-2	D-VIII-3	D-VII-3	ST-VIII-4	D-VIII-x	D-VII-x

TRIAL C (PEE DEE REC, 2012)

D-VIII-2	D-VI-2	D-VIII-1	D-VII-1	D-VIII-4	D-VII-4	D-VIII-3	D-VII-3	D-VIII-2	D-VII-2	x
ST-VII-2	ST-VIII-2	ST-VIII-1	ST-VII-1	ST-VIII-4	ST-VII-4	ST-VII-3	ST-VIII-3	ST-VII-2	ST-VIII-2	x
D-VII-1	ST-VIII-3	D-VII-4	D-VII-2	ST-VIII-3	D-VIII-1	ST-VIII-2	D-VII-4	D-VII-1	ST-VII-3	ST-VIII-4
ST-VII-1	D-VII-3	D-VIII-4	ST-VII-2	ST-VII-3	D-VII-1	D-VII-2	ST-VII-4	D-VIII-1	ST-VIII-3	D-VII-4
ST-VIII-1	ST-VII-3	ST-VII-4	ST-VIII-2	D-VII-3	ST-VIII-1	ST-VII-2	D-VIII-4	ST-VIII-1	D-VII-3	ST-VII-4
D-VIII-1	D-VIII-3	ST-VIII-4	D-VIII-2	D-VIII-3	ST-VII-1	D-VIII-2	ST-VIII-4	ST-VII-1	D-VIII-3	D-VIII-4

PD 3 PD 2 PD 4 PD 1

Figure A-1. Experimental design of trials a (Edisto REC, 2011), b (Edisto REC, 2012) and c (Pee Dee REC, 2012).

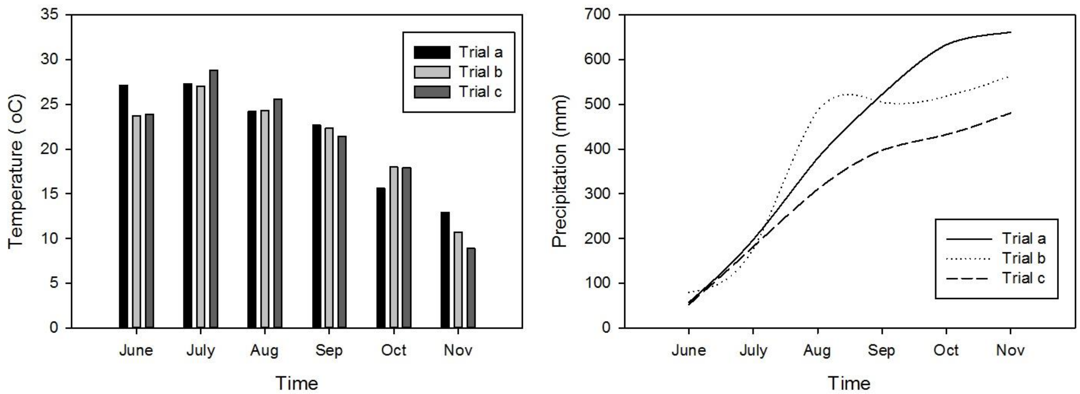

Figure A-2. Accumulated precipitation (since 1 June) and mean daily air temperature at the Edisto REC in 2011 and 2012, and at Pee Dee REC in 2012.

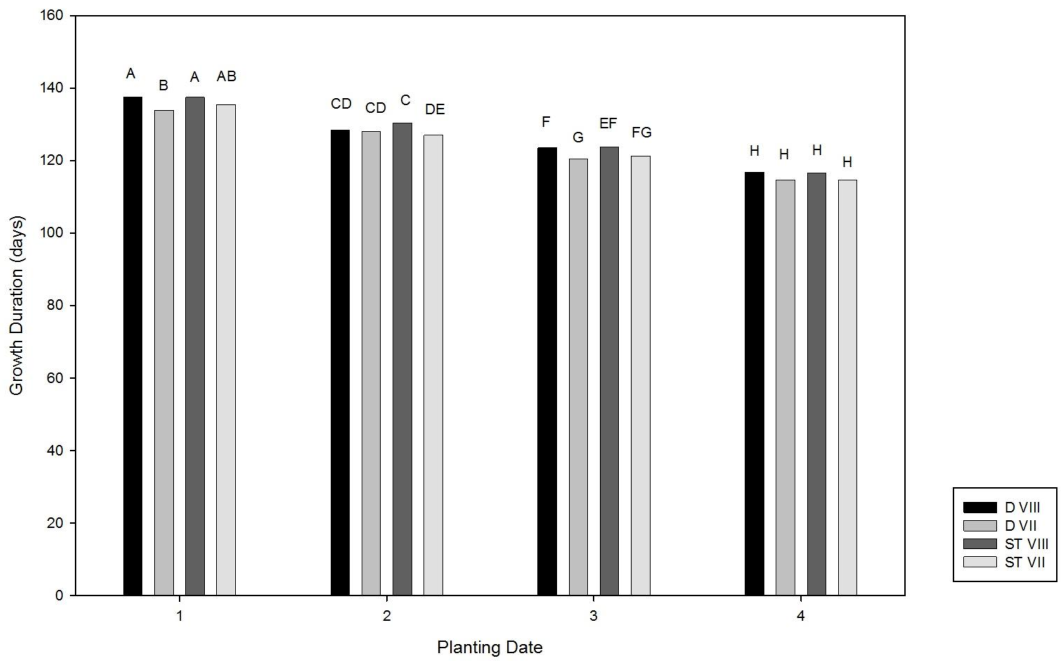

Figure A-3. Mean total growth duration (days, planting to R8) of each treatment across environments.

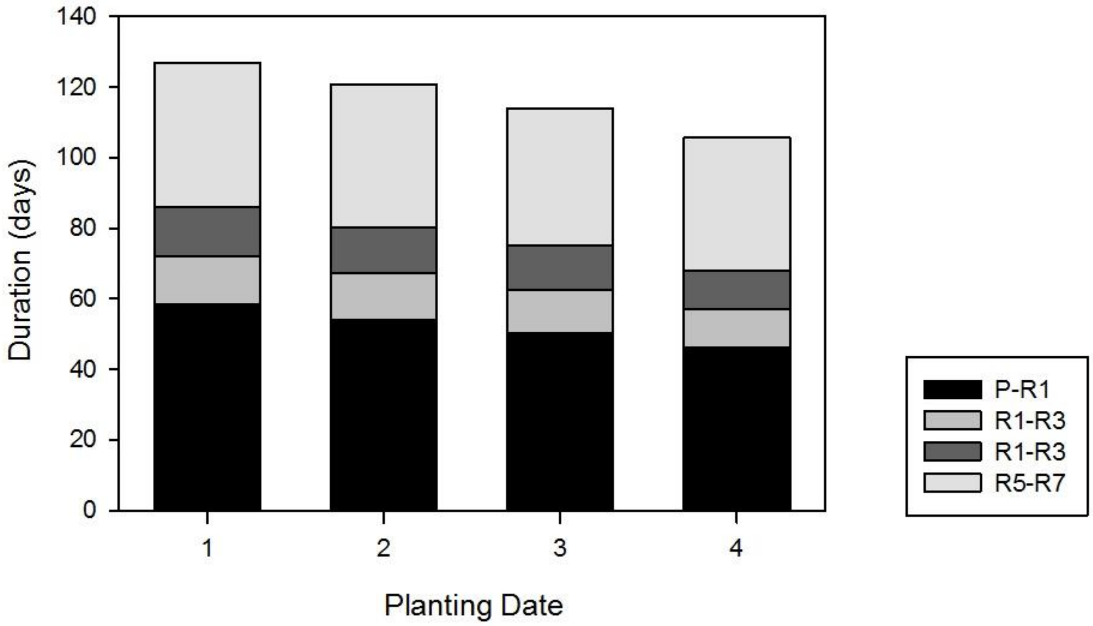

Figure A-4. Duration of each growth period (planting to R1, R1 to R3, R3 to R5, R5 to R7) of soybeans for four different planting dates.

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