EFFECT OF PLANTING DATE ON GROWTH, DEVELOPMENT, AND YIELD OF GRAIN SORGHUM HYBRIDS

by

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Abstract

In Kansas, productivity of grain sorghum [*Sorghum bicolor* (L.) Moench] is affected by weather conditions at planting and during pollination. Planting date management and selection of hybrid maturity group can help to avoid severe environmental stresses during these sensitive stages. The hypothesis of the study was that late May planting improves grain sorghum yield, growth and development compared with late June planting. The objectives of this research were to investigate the influence of planting dates on growth, development, and yield of different grain sorghum hybrids, and to determine the optimal planting date and hybrid combination for maximum biomass and grains production. Three sorghum hybrids (early, medium , and late maturing) were planted in late May and late June without irrigation in Kansas at Manhattan/Ashland Bottom Research Station, and Hutchinson in 2010; and at Manhattan/North Farm and Hutchinson in 2011. Data on leaf area index, dry matter production, harvest index, yield and yield components were collected. Grain yield and yield components were influenced by planting date depending on environmental conditions. At Manhattan (2010), greater grain yield, number of heads per plant, harvest index, and leaf-area were obtained with late-June planting compared with late May planting, while at Hutchinson (2010) greater yield was obtained with late May planting for all hybrids. The yield component most affected at Hutchinson was the number of kernels panicle^{-1} and plant density. Late-May planting was favorable for late maturing hybrid (P84G62) in all locations. However, the yield of early maturing hybrid (DKS 28-05) and medium maturing hybrid (DKS 37-07) was less affected by delayed planting. The effects of planting dates on growth, development, and yield of grain sorghum hybrids were found to be variable among hybrid maturity groups and locations.

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Dedication

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Chapter 1 - Introduction and Background about Grain Sorghum

1.1 Origin, Taxonomy and Distribution of Sorghum

Sorghum originated in Africa, more precisely in Ethiopia, between 5000 and 7000 years ago (ICRISAT, 2005). From there, it was distributed along the trade and shipping routes around the African continent, and through the Middle East to India at least 3000 years ago. It then journeyed along the Silk Route into China (Dicko et al., 2006). It was first taken to North America in the 1700-1800's through the slave trade from West Africa and was re-introduced in Africa in the late 19th century for commercial cultivation and spread to South America and Australia. Sorghum is now widely found in the dry areas of Africa, Asia (India and China), the Americas and Australia (Dicko et al., 2006). Grain sorghum belongs to the family of Poaceae (grass), tribe Andopogoneae, sub-tribe Sorghinae, genus Sorghum. In 1794, Moench established the genus Sorghum and brought the sorghums under the name *S. bicolor*. All cultivated sorghum belongs to S*orghum bicolor* subsp. Bicolor (Dicko et al., 2006).

There are five basic races: bicolor, guinea, caudatum, kafir, durra; and ten intermediate races under *S. bicolor*. It is a cereal of a remarkable genetic variability; with more than 30,000 selections present in the world genetic collections (Assefa and Staggenborg, 2010). The morphological characteristics change with genotype and growing conditions. Most of the tropical sorghums are short day plants and their response to day length is an important adaptation. However, the selection of early-maturing varieties and hybridation helped its spread in the USA (Prasad and Staggenborg, 2009).

1.2 Importance of Sorghum

Sorghum is the fourth most important cereal crop grown in the United States, and the fifth most important cereal crop grown in the world (Bryden et al., 2009). The world's four largest producers of grain sorghum during 2010 included Nigeria with 11.5 million metric tons, the United States with 9.7 million metric tons, India with 6.98 million metric tons, Mexico with 6.25 million metric tons, and others 25.08 tons for a total worldwide production of 59.51 million metric tons (USDA, 2010). Globally the total area cropped with sorghum was 43.8 million hectares in 2007 (Prasad and Staggenborg, 2009).

Sorghum is used primary as animal feed in the United States of America, Australia, Brazil and other developed nations. But it is a staple food in many semi-arid and tropical areas of the World. Dicko et al. (2006) estimated that more than 300 million people in developing countries consume sorghum as their principal food energy source. In West Africa for example, sorghum grains are used for the preparation of different recipes such as "tô", porridge, and couscous. It is also used in the production of local beer "dolo", infant porridge and non-fermented beverages (Dicko et al., 2006). Anglani (1998) stated that sorghum plays double role in farmers' life in Africa by providing income and insuring food security.

Sorghum grain has high nutritive value, with 70-80% carbohydrate, 11-13% protein, 2-5% fat, 1-3% fiber, and 1-2% ash. Protein in sorghum is gluten free and, thus, it is a specialty food for people who suffer from celiac disease, as well as diabetic patients (Prasad and Staggenborg, 2009). Sorghum fibers are used in wallboard, fences, biodegradable packaging materials, and solvents. Dried stalks are used for cooking fuel, and dye can be extracted from the plant to color leather (Maunder, 2006).

In the United States, grain sorghum is used primarily as an animal feed, but also is used in food products and ethanol production. In the U.S about 35.4% of the sorghum produced is used as feed, 22.7% is used as food, seed, and industrial applications (including 12% used for ethanol and its various co-products), and the remaining 41.9% is exported to other countries (USDA, 2010).

1.3 Growth and Development Stages of Grain Sorghum

Grain sorghum has nine different growth stages from emergence to maturity (Vanderlip, 1979). These stages are briefly described below.

The first stage (Stage 0) of grain sorghum development is emergence. Emergence is the stage when the plant first breaks through the soil surface. Generally it occurs 3 to 10 days after planting. The time required for emergence depends on soil temperature, moisture conditions, depth of planting, and vigor of the seed. During this period growth depends on the seed for nutrients and food reserves. Cool, wet conditions during this time may favor disease organisms that seriously damage stands.

The second stage (Stage 1) is the three-leaf stage. Leaves are counted when the collar of the leaf can be seen without tearing the plant apart. At this stage, the growing point is still below the soil surface. While the plant's growth rate depends largely on temperature, this stage usually occurs about 10 days after emergence.

The third stage (Stage 2) is the five-leaf stage. This stage occurs approximately 21 days after emergence. At this stage a sorghum plant has five leaves fully expanded; its root system is developing rapidly, and roots produced at the lower nodes may push the lower leaves off the plant. This usually does not cause difficulty in identifying the five-leaf stage because the lower leaf has a rounded tip and the second leaf is pointed. The plant enters its "grand period of growth” in this stage. Dry matter accumulates at nearly a constant rate until maturity if growing conditions are satisfactory.

The fourth stage (Stage 3) is growing point differentiation. This stage occurs about 30 days after emergence. At this growth stage, the plant changes from the vegetative phase (leaf producing) to the reproductive phase (head producing). The total number of leaves has been determined, and potential head size soon will be determined. About one-third of the total leaf area has fully developed (7 to 10 leaves depending on maturity class) and the lower 1 to 3 leaves may have been lost. Culm or stalk growth increases rapidly following growing point differentiation. Nutrient uptake is rapid. Time from planting to growing point differentiation generally is about one-third of the time from planting to physiological maturity (maximum dry weight).

The fifth stage (Stage 4) is flag leaf visible. This stage is characterized by a visible flag leaf (final leaf) in the whorl. All except the final 3 to 4 leaves are fully expanded and about 80 percent of the total leaf area is present. Light interception is approaching maximum, and growth and nutrient uptake continue at a rapid rate. The head is developing, during this stage. The lower 2 to 5 leaves typically have been lost. Any reference to leaf number from this stage should be from the top, counting the flag leaf as leaf number 1. While only about one-fifth of the total growth has occurred, nutrient uptake is far greater with more than 40% of the potassium already taken up.

At boot stage (Stage 5), all leaves are fully expanded, providing maximum leaf area and light interception. The head has developed to nearly full size and is enclosed in the flag-leaf sheath. Except for the peduncle, culm elongation is essentially complete. Peduncle elongation is beginning and will result in the panicle exsertion from the flag-leaf sheath. Potential head size has been determined.

Half-bloom (Stage 6) follows the boot stage and is defined as when one-half of the plants in a field or area are in some stage of bloom. However, because an individual sorghum head flowers from the tip downward over 4 to 9 days, half-bloom on an individual plant is when the flowering has progressed half-way down the head. At half-bloom, approximately one half of the total dry weight of the plant has been produced. However, nutrient uptake has reached nearly 70, 60, and 80% of total for N, P, and K, respectively. Time required from planting to half-bloom depends on the maturity of the hybrid and environmental conditions. However, it usually represents two-thirds of the time from planting to physiological maturity.

Soft-dough (Stage 7) is the stage between half-bloom and hard-dough. At this stage the grain fills rapidly, and approximately half of its dry weight is accumulated. The culm weight increases slightly following half-bloom; then, decreases as grain is forming. This loss in culm weight may account for as much as 10% of the grain weight. Lower leaves are still being lost with 8 to 12 functional leaves remaining.

In Hard-dough (Stage 8) about three-fourth of the grain dry weight has accumulated. The culm has declined to its lowest weight. Nutrient uptake is essentially complete. Additional leaves may have been lost.

Physiological maturity (Stage 9) is the last stage before harvest. Physiological maturity can be determined by the dark spot on the opposite side of the kernel from the embryo. At this stage the maximum total dry weight of the plant has occurred. The time from flowering to physiological maturity varies with hybrid and environmental conditions; however, it represents about one-third of the total time from planting. Grain moisture content at physiological maturity usually is between 25 and 35% moisture, but varies with hybrid and growing conditions. After physiological maturity, the remaining functional leaves may stay green or die and brown rapidly. If temperature and moisture conditions are favorable, branches may start to grow from several of the upper nodes. Also, the culm or stalk weight may increase slightly near physiological maturity.

These development stages can be grouped in three growth stages. Growth Stage 1 (GS1) represents the vegetative period from emergence to growing point differentiation; Growth Stage 2 (GS2) represents the reproductive period from growing point differentiation to flowering; Growth Stage 3 or grain filling stage (GS3) from flowering to physiological maturity (Table 1.1). The duration of each of stages and its impact of yield and yield components may depend on the environmental conditions, planting dates, hybrids; and may change from year to year and from one location to another.

1.4 Factors Influencing Grain Sorghum Growth and Development

Grain sorghum productivity is highly influenced by plant-available water, soil water content at planting, growing–season rainfall amount and distribution, crop management practices, and other climatic conditions (Assefa et al., 2010). Among factors that influence grain sorghum yield, water stress and temperature are of particular importance.

Water stress has diverse effects on physiology and development of sorghum that determines its final yield depending on the development stage at which stress occurs. Assefa et al. (2010) found a 36% sorghum yield reduction when water stress occurred during the vegetative stage and more than 55% yield reduction with water stress occurring during the reproductive stage. Water stress affects crop establishment (Blum, 1996), reduces growth rate, stem elongation, leaf number and leaf expansion rate, and thus leaf area (Hale and Orcutt, 1987).

According to Garrity et al. (1984), 14 to 26% of the observed reduction in photosynthetic rate of water-stressed sorghum is due to reduction in leaf area. These reductions may lead to a decrease in total dry matter production under drought conditions (Perry et al., 1983).

Prasad et al. (2008) reported lowered yield due to heat and drought stress occurring during flowering and anthesis. They stated that yield reduction was caused by the failure of fertilization because of the impairment of pollen and ovule function. The results of their study indicated that moisture stress early in the season will limit panicle size (number of seeds per panicle) and delay maturity. If the stress occurs later in the season, the seed size is greatly reduced. In addition, temperature stress can delay flowering, reduce stem and root growth, plant height, pollen and ovule viability, pollen number, stigma receptivity, seed number, seed filling duration, thus yield (Prasad and Staggenborg, 2009).

Different strategies are available to avoid or reduce the effect of these stresses on grain sorghum growth, development and yield. Planting sorghum so that growth stages with high water requirement take place when better rainfall is expected, irrigating during critical growth stages, selection of drought-tolerant hybrids, or cultural practices such as optimum plant population and optimum row spacing are some of the options available to manage drought stress in grain sorghum (Assefa et al., 2010).

Table 1.1 Grain sorghum growth stages, approximate time interval between growth stages and identifying characteristics.

Development Stage	Growth Stage	DAE	Visual Characteristics
0	GS1	0	Emergence, coleoptile visible at soil surface
1	GS1	5	Collar of 3rd leaf visible
2	GS1	10-15	Collar of 5th leaf visible
3	GS1	25-30	Growing point differentiation or panicle initiation (approximately 8th leaf visible).
4	GS2	35-50	Final leaf (flag leaf) visible in whorl; last three leaves may not be expanded.
5	GS2	40-55	Booting; head extended into flag leaf sheath; potential panicle size has been determined.
6	GS2	55-65	Flowering (bloom); 50% of plants flower.
7	GS3	65-80	Soft dough; grain can be easily squeezed between the fingers; 8 to 10 functional leaves; one half of the grain weight accumulated.
8	GS3	80-90	Hard dough; cannot squeeze grain between fingers; three-fourth of the grain dry weight has accumulated.
9	GS3	90-110	Physiological maturity; dark spot at the tip of the kernel; maximum total dry weight accumulated; grain has 25 to 35% moisture.

DAE=Day After Emergence. Source: (Prasad and Staggenborg 2009).

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Chapter 2 - Grain Sorghum Maturity and Planting Date Influence on Plant Growth, Development and Yield: A Review

2.1 Introduction

Grain sorghum growth, development, and yield depend on environmental conditions such temperatures and precipitations. The extent of the effect of these environmental conditions may vary depending on planting date. Planting date influences sorghum through temperature and soil available water at seed germination (Vanderlip, 1993), vegetative and reproductive success (Prasad et al., 2008), and hence, yield and yield components (Evans and Wardlaw, 1976). Jones and Johnson (1991) reported that effect of stress due to environmental factors on final yield may depend upon the growth stage in which it occurs and the genotype. Deciding on early or late planting depends on a farmer's ability to deal with the risk of poor crop establishment with early planting or the effect of water or heat stress at reproductive stages with late planting. In northeast and south-central Kansas, planting time for grain sorghum moved from early to late planting, while in southwest Kansas no change has been made despite the risk (Williams et al., 1999). However, recently, Assefa and Staggenborg (2010) stated that in Kansas the mean planting date has moved from early June (from 1957 to 1966) to late May (from 1996 to 2008).

The objective of this review is to understand the current knowledge on the effect of planting date and hybrid selection on growth and development of grain sorghum. The review may help also in the definition of future research.

2.2 Grain Sorghum Growth and Development as Impacted by Planting Date

2.2.1 Effect of Planting Date on Crop Establishment:

Seedling emergence rate is affected by planting depth, soil temperature and soil available water content. Eastin et al. (1976) stated that the minimum temperature for grain sorghum growth is 15^{o}C, but Amathauer (1997) suggested that a soil temperature of 18^{o}C at the 5 cm soil depth for three mornings in a row is recommended for even, vigorous seedling emergence. Heiniger et al. (1997) stated that early planting may result in an unfavorable soil environment, which may affect emergence rate, and result on poor stand establishment and possibly replanting. Delaying the planting date until soil conditions are nearer the optimum for early plant growth and development may be a management strategy useful in overcoming these problems (Herbek et al., 1986). In a three year field experiment (1989-1991) at the USDA Conservation and Production Research Laboratory, Bushland Texas, early planting (1 to 5 May) required from 13 to 16 days for emergence compared with 7 to 10 days for late planting (20 to 25 May) with some differences between hybrids, whereas June plantings required only 5 to 7 days (Allen and Musik, 1993).

Hybrid selection also can contribute to better stand establishment. If early planting is adopted, the selected genotypes must be tolerant to low temperatures during seed germination, seedling emergence, and early plant growth (Keim and Garden, 1984). Krieg (1994) reported that the minimum temperature requirement for seed germination depends on hybrid types, with temperate hybrids having higher minimum than tropically adapted hybrids. However, Lawlor et al. (1990) found only minor genetic variation in minimum temperature requirements for germination, but their study revealed genotypic differences for rate of germination.

2.2.2 Effect of Planting Date on Grain Sorghum Tillering:

The development of tillers is an essential plant characteristic affecting accumulation of biomass and thus grain yield in many field crops. Bruns and Horrocks (1984) stated that a wide range in tiller number exists in grain sorghum depending on genotype and growing conditions. Environmental factors, including photoperiod, light intensity, temperature, soil moisture, and fertility, are known to affect the number of tillers produced by sorghum and other grasses (Langer, 1963). Variation in tillering affects the dynamics of canopy development and hence the timing and nature of crop water limitation (Hammer, 2006). Hammer and Muchow (1994) reported that prediction of tiller fertility in relation to the environment is required for prediction of canopy leaf area development and grain yield in sorghum. Simulation studies showed significant yield advantage of high tillering types in high yielding seasons when water is not limiting, whereas tillering leads to a significant disadvantage in lower yielding, water-limited circumstances (Hammer et al., 1996). Reduced tillering hybrids could be more appropriate than freely tillering hybrids under poorer growing conditions, as the smaller canopy size reduces pre-anthesis water use (Islam and Sedgley, 1981; Hammer, 2006). In addition, the presence of non-fertile tillers reduces grain yield in water-limiting environments due to inefficient water use (Jones and Kirby, 1977). Praeger (1977) found that the length of cool temperature period during the three to five leaf stage is positively correlated to the number of tillers produced and hence the proportion of tiller contribution to yield.

Greater cumulative tiller number per plant was observed with early April planting compared to early May and early June in Texas (Gerik and Neely, 1987). Their study also pointed out that cumulative tiller number per plant and the number of productive tillers per plant decreased as plant density increased. Similarly, Stickler and Pauli (1961) and Praeger (1977) reported that earlier planting in the United States increased grain sorghum yield through increased tillering and consequently increased number of heads per unit area.

In a simulation study at Bushland, TX, Baumhardt et al. (2005) found that the tillers per plant increased from early May to late June planting with 1.4 plant tillers for early 15 May planting, 1.5 plant tillers for 5 June and 1.6 plant tillers for the late 25 June planting. They explained the variation by the longer days and more direct illumination of sorghum plants in late planting. They also found significant differences in tiller number per plant between maturity groups. The average number of tiller per plant decreased from 1.7 tillers $plant^{-1}$ for late maturing cultivars to 1.6 tillers $plant^{-1}$ for medium maturing cultivars to 1.1 tillers $plant^{-1}$ for early maturing cultivars. Their results suggest that planting early maturing cultivars will decrease tillering and allows greater control of seed head number under non-irrigated conditions. The interaction between planting date and cultivars on tillers number $plant^{-1}$ also was significant.

2.2.3 Effect of Planting Date on Leaf Number and Leaf Area of Grain Sorghum

Radiation interception and photosynthesis, are of major importance in yield determination due to their role in dry matter production. Sorghum yield response to location, time of planting and soil water storage were associated with difference in leaf area development (Muchow et al., 1994). Sankarpondian et al. (1993) found a positive correlation between sorghum grain yield and dry matter production. The number of leaves and leaf dimensions are functions of hybrids, growth stage, but also depend on the growing conditions. Youni et al. (2000) found reductions of sorghum shoot dry weight, green leaf area, specific leaf area, and new leaf expansion rate under water stress. The reduction of sunflower dry matter production is associated with a reduction in leaf area (Terbea et al., 1995). Bunck (1977) stated that as planting was delayed from early May to early July, late maturing sorghum hybrids showed a reduction in leaf number, leaf area, and yield at Manhattan and Hutchinson.

Duncan et al. (1981) described two hybrids as senescent and non-senescent types in relation to relative senescence of leaves after full leaf expansion. The non-senescent line had higher green leaf number and weight at maturity, leaf area index, leaf area duration, and leaf area ratio than the senescent line. Borrell et al. (2000) reported that stay-green hybrids produced 47% more postanthesis biomass than their senescent counterparts (920 vs. 624 g m^{-2}) under a terminal water deficit regime. The study also indicated that sorghum hybrids possessing the stay-green trait had a greater yield advantage under postanthesis drought compared with hybrids not possessing this trait. Leaf senescence has been shown to increase markedly under water stress in sorghum (Kaigama et al., 1977; Kanangara et al., 1982). Leaf senescence is in general considered as a mechanism of drought avoidance in sorghum by reducing transpiration and saving soil moisture, while others think that leaf senescence during grain filling reduces photosynthesis rate and dry matter production, thus reducing final yield (Hsiao, 1973).

These results indicate that appropriate crop management practices such as optimum planting date, row spacing, and seeding rate are necessary for optimal leaves expansion of grain sorghum.

2.2.4 Effect of Planting Date on Plant Phenology

Planting date has an impact on sorghum growth stage duration. Conley and Wiebold (2003) conducted a study to quantify the response of grain sorghum yield to planting date and hybrid maturity and to develop an optimal planting date window for Missouri growers. They found that the number of days between planting and flowering decreased as planting was delayed and explained that the effect probably resulted from slower emergence and less rapid accumulation of heat units for early planting dates.

Planting date affects not only the time from planting to flowering but time from flowering to physiological maturity of grain sorghum (Clark, 1997). Clark (1997) stated that in April plantings at Chillicothe, TX, most hybrids classified as medium or medium-late will flower in about 75-85 days, depending on the planting date and temperatures prevailing in different years. In late June plantings, this range usually will be from 50-60 days. Plant development from early plantings at Chillicothe, TX, may be delayed by low temperatures at planting time. Therefore, hybrids may mature later than maturity classifications indicate, although relative maturity among hybrids probably will hold true. According to Clark (1997), the time from flowering to physiological maturity is about 40 to 45 days after flowering depending on hybrid maturity group and planting date. In early plantings, this period may be reached in about 40 days, because high temperatures in late June and July facilitate grain development. In late June plantings, the period may be extended because of the decrease in temperatures during flowering and grain development periods and shorter day length in late August and September when sorghum grain is developing. This makes the amount of heat accumulated less than in June and July when days are longest. Clark (1997) also stated that mid-season plantings are not recommended because favorable temperature and rainfall during that May and early June contribute to excessive vegetative growth. By the time flowering and grain development periods are reached, there is a large vegetative plant that has used an excessive amount of water with little reserve left in the soil for grain development. Early plantings tend to produce a similar situation, but the results are not always so pronounced as in mid-season plantings.

Earlier planting dates tended to extend the time from planting to growing point differentiation (Chao, 1938), as well as the time from growing point differentiation to half-bloom (Kambal and Webster, 1965), but reduce the time from half-bloom to physiologic maturity of grain (Karper et al., 1957), and expand the total number of days from planting to physiological maturity of grain (Kersting et al., 1961).

Pauli et al. (1964) found that the total time from planting to physiological maturity was significantly decreased as planting time was delayed from early May to early June. In late planting, late maturing hybrids mostly failed to reach physiological maturity before the first freeze killing date (Bauhmardt and Howell, 2005). Due to these variations, Kelly (2011) suggested the use of Growing Degree Days (GDDs) to predict crop development because of variation in daily minimum and maximum temperature. He found the required Cumulative Growing Degree Days ($^{\circ}$C) to reach physiological maturity (from planting) to be 1467 for short season hybrids and 1849 for long season hybrid. The time period necessary to reach that GDD is function of variation in daily maximum and minimum temperature throughout the growing season, therefore may depend on planting date.

2.2.5 Effect of Planting Date on Grain Sorghum Yield Components

To understand yield response to planting date one needs to analyze yield components. The potential number of seeds per head is set during growth stage six (Vanderlip, 1993). Environmental stress such as high temperature and drought at this time of differentiation of spikelet components can seriously reduce number of seeds and yield (Adams and Arkin, 1978).

Saeed et al. (1986) reported that seed weight becomes critical to sorghum yields in high temperature stress environment and that rate of grainfill is more important than duration of fill to seed weight, and therefore to grain yield.

In an experiment conducted at Manhattan, KS in 1999, Klein (2000) found significant interaction between dates of planting and hybrids. Highest yields were obtained for both medium and late maturity hybrids when sorghum was planted in late May compared with early July planting. Klein (2000) stated that the yield component most affected were seed weight and number of panicles plant^{-1}. Lower seed weight was observed for all hybrids with late planting with the smallest reduction for the early maturity hybrid. The medium maturity hybrid had a larger decrease in the number of heads per plant in July planting.

In a simulation study, Baumhardt et al. (2005) observed more seeds per panicle, few panicles per plant, and smaller seed weight for early May planting compared with late May and late June planting at Bushland, TX (35^{o}11’N lat; 102^{o}5’ W long; and 1170 m above sea level). They stated that earlier planted sorghum generally reached post-anthesis growing stages during the hottest summer months and likely suffered from greater water deficit stress compared with later planted sorghum.

2.2.6 Effect of Planting Date on Grain Yield

Many studies have been conducted to describe the response of grain sorghum to planting date. Some studies reported significant effects of planting time on sorghum grain yield while others found this effect not to be significant.

Conley and Wiebold (2003) found that planting earlier or later than mid-May had small and inconsistent effects on sorghum grain yield in Missouri. Assefa and Staggenborg (2010) also found that planting date has no consistent contribution on the observed dryland sorghum yield improvement during the last decade. They stated that yield improvement has been mostly due to the use of improved hybrids and fertilizer application. Baumhardt and Howell (2005) found that planting date has no effect on simulated grain yield. However, early maturity cultivars planted on 5 June were better adapted to dryland and deficit irrigation for optimum grain yield.

Many studies reported an advantage of early planting compared with late planting. Bryant et al. (1986) reported that grain sorghum yield decreased 22% when planted on 19 March, 25% on 20 May, and 49% on 21 June compared to a 19 April planting date in Arkansas. Johnson et al. (1984) reported that grain sorghum yield decreased with early June and July planting dates by 25% and 65%, respectively, compared with early May and April planting dates at Alabama, Agricultural Experiment Station. In a study in Nebraska, Francis et al. (1986) reported that across several hybrids, grain sorghum yield in Nebraska was consistently 8% greater when planted in early- to mid-May compared with early to mid-June planting. Delaying planting until July resulted in lower yield compared to May and mid-June planting in Nebraska (Pale et al., 2003).

The effect of planting date on sorghum yield changed with locations based on environmental conditions prevailing during the crop growing period. Significant yield advantage of late plantings over early plantings was observed at Chillicothe, TX, while the opposite trend was observed at Munday, TX, with early plantings yielding more than late plantings in each of the three years of the experiment (Clark, 1997). Delaying planting to early June was advantageous in northeast Nebraska. Irrigated grain sorghum had higher yield with late June planting compared with early July planting (Moomaw and Mader, 1991). In a study conducted in Mexico, Clara et al. (1983) found no advantage to early planting for better use of precipitation or yield increase of grain sorghum. However the risk that sorghum plant would not reach physiological maturity was increased with delayed planting.

2.2.7 Interaction Between Planting Date and Hybrid

Few experiments have studied the interaction between grain sorghum yield and hybrid maturity. Kreig and Lascano (1989) reported results from a two year study with four grain sorghum planting dates at Lubbock, TX, ranging from early May to late June. Their data indicated that an early May planting reduced grain yield, with the effect being greater for shorter maturity-length hybrids. With planting in mid to late June, yield was reduced and the effect was greater for the longer maturity hybrids. Stickler and Pauli (1961) also reported significant variety by planting date interactions in grain yield and its components. Under non-irrigated conditions, Jones and Johnson (1991) demonstrated that the optimum planting date, population, variety, and row spacing for grain sorghum were interdependent by showing consistent grain yield reductions by late-maturing cultivars that were planted late and at higher populations.

In a three years study (1989-1991) at the USDA Conservation and Production Research Laboratory, Bushland, TX, Allen and Musik (1993) found that if early May planting is desired under adequate irrigation, longer season medium-late maturity hybrids have additional grain yield potential compared with medium hybrids. Both medium and medium-late maturing sorghum hybrids were most productive when planted relatively early (before June 1). However, medium-maturity hybrids were better adapted if planting is delayed until June, and are better adapted than longer season hybrids to limited irrigation. Similarly, Baumhart and Howell (2005) suggested planting early maturing cultivars for early June planting under water deficit conditions, and planting late-maturing in mid-May when plant water requirement can be met during the growing season.

Ismail and Ali (1996) found significant variety by planting date interaction for plant height, head weight, and final grain yield in Qatar. Greater plant height, head weight, and grain yields were recorded for early and mid-September planting compared with early and mid-October planting for the long maturing variety.

In the forest-Savana transition zone of Nigeria, early June planting of sorghum had greater yield compared with early or late May planting. Delaying planting to early June increased yield by 25 to 27 kg ha^{-1} compared to early or late May planting (Bello, 1999).

2.3 Conclusions

Large variability exists in sorghum growth and development in response to planting date and hybrid selection. Planting date affects grain sorghum growth, development and yield depending on environmental conditions and hybrid selection. The effect was shown through reduction in stand establishment with early planting and reduction in yield and yield components with delayed planting. However, studies also showed no effect of planting date alone on sorghum grain yield. Reduction in the number of day between different growth stages was observed with delayed planting, but few studies expressed this variability based on variation on Growth Degree Units accumulated throughout growing season.

A large variability exists also between available information indicating that additional research is necessary to develop recommendations for sorghum growers. Delaying planting might be an option for better crop establishment and yield improvement.

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Chapter 3 - Effect of Planting Date on Growth, Development and Yield of Grain Sorghum Hybrids.

3.1 Introduction

Grain sorghum is one of the major cereal crops grown in the United States and throughout the world. Under non-irrigated conditions, grain sorghum yields are highly variable, ranging from as much as 6 Mg ha^{-1} to near or complete failures; mainly due to the variation in soil water storage, rainfall amount and distribution, crop management practices, and other climatic conditions (Jones and Johnson, 1991). Grain sorghum growth and development is sensitive to environmental factors such as cold, heat and drought stress depending on the growth stage at which the stress occurs. Therefore, sorghum must be properly managed to tolerate the effect of these stresses during critical growth stages. Management practices include the selection of appropriate hybrids, plant population, row spacing, and planting dates. Vanderlip (1979) reported that planting date should be selected not only to avoid the heat during anthesis but also to avoid frost and poor drying conditions in the fall. Due to adversity and variability in climatic conditions, farmers have adopted early planting to improve crop productivity. Yu and Tuinstra (2001) stated that early planting of grain sorghum allows for a longer growing season and for more efficient use of late spring and early summer rainfall, but seedling vigor may be low due to cold temperatures. Nevertheless, due to intraseasonal weather variation, planting may be delayed and the number of growing days reduced. Therefore, the choice of early season hybrids might be advantageous (Soler et al., 2008).

Many studies have been conducted to describe the response of grain sorghum to agricultural and environmental conditions. These studies resulted in different conclusions about sorghum yield response to planting date. Moreover, few experiments have studied the possible interaction between grain sorghum planting date and hybrid maturity. M'Khaitir and Vanderlip (1992) reported that planting date had no consistent effect on grain sorghum yield in a study conducted in Kansas. Martin and Vanderlip (1997) found an optimal planting period in Kansas for consistent grain sorghum yield of 25 May to 5 June. Hatfield et al. (2008) reported that over the next two decades, climate change effects in the Central United States are predicted to result in an increase of night air temperatures and the number and severity of adverse events. These trends could influence optimal management practices.

The variability in yield response to planting date and environmental conditions, and necessity of more information about the interaction of hybrids and planting date indicate that more research is necessary.

The objectives of this research were to investigate the influence of planting dates on growth, development, yield, and yield components of different grain sorghum hybrids representing three different maturity groups; to identify the yield component(s) of grain sorghum hybrid which is most critical; to determine optimal planting date and hybrid combinations for maximum grain and biomass production. The hypothesis of the study was that late May planting improves grain sorghum yield, growth and development compared with late June planting.

3.2 Materials and Methods

3.2.1 Experimental Sites and Environmental Conditions

During 2010, field experiments were conducted under non-irrigated conditions at the K-State Agronomy Research Farm in Ashland Bottoms near Manhattan, KS and near Hutchinson, KS. The soil type was Rossville silt loam at Manhattan and Farnum and Funmar loams at Hutchinson. In 2011 the location at Hutchinson remained the same, but in Manhattan, the experiment was moved to the North Agronomy Farm in Manhattan, KS on Kahola silt loam soil (Fig. 3.1).

The two cropping cropping seasons had different weather conditions. Daily maximum temperatures, minimum temperatures, and precipitations during growing season (from May to November) are presented in Fig. 3.2 and Fig. 3.3. The period from May to June (Day of year 121 to 181) is of particular importance because weather during this period influenced soil water content at planting, early growth, pollination, and grain filling period of sorghum.

In Manhattan, during both 2010 and 2011, minimum temperatures were greater than the long-term average in all months except May and September 2011 (Table 3.12). Maximum temperature was greater for all months except May 2010 and September 2011. Monthly rainfall was significantly less than the long term average in July through August in 2011. Rainfall during the growing season was about 4% and 13% below the long-term average respectively in 2010 and 2011 (Table 3.12).

In Hutchinson, maximum and minimum temperatures during the sorghum growing season were in general greater than the long-term averages in all months during both 2010 and 2011 (Table 3.13). Daily maximum, minimum temperatures and rainfall are presented in Fig. 3.3. In 2010, the monthly rainfall was greater than long term average in all months except September and October. However, in 2011 lower monthly rainfall was recorded for all months except August and November compared with long-term average. The period from June to September 2011 was extremely dry. Rainfall during the growing season was about 36% greater than the long-term average in 2010, but about 43% less than the long-term average in 2011 (Table 3.13) . The amount of precipitation received from day of year 164 to 219 was low, about 2.794 mm (Fig 3.3). This situation was detrimental for seed germination and plant growth at both planting dates. The germination rate was very low in the late-June planting, affecting both plant population and growth rate. Plots were replanted fifteen days after the first planting, but the lack of moisture lead to failure again.

3.2.2 Treatments

The treatments included combinations of planting dates and hybrids. Three sorghum hybrids were selected based upon maturity. The hybrids were Dekalb "DKS 28-05" (early maturing), "DKS 37-07" (medium maturing), and Pioneer "84G62" (late maturing). Planting dates were late May and late June for all locations for both years (Table 3.1).

3.2.3 Experimental Layout

The experimental design was a randomized complete block design in split-plot arrangement with four replications. Planting dates were main plots and hybrids were subplots. Each treatment (combination of hybrid and planting date) was randomly assigned to an experiment unit (plot). The experimental unit was 21 m^2 (3 m wide and 7 m long) in 2010, 30 m^2 (3 m wide and 10 m long) in 2011 with 0.75 m row spacing.

3.2.4 Crop Management

The experimental plots were treated with herbicide glyphosate at 1.12 kg a.i.Ha^{-1}, applied just after the first planting performed for each location during 2010. However, during 2011 herbicide Degree Xtra was applied preplant at a rate of 7 L ha^{-1}. This herbicide contains 324g L^{-1} of active ingredient acetochlor and 161g L^{-1} of active ingredient atrazine and related triazines. Additional hand weeding was carried out when needed during the growing season.

Planting was carried out with a two-row planter under no till conditions at 5 cm planting depth and 180,000 seeds ha^{-1}. No hand thinning was needed after emergence. However, in the

2010 late May planting at Manhattan, plots were unintentionally planted at higher seeding rate and then thinned to insure uniform stands of the desired plant population. Nitrogen was applied to the plots as urea by hand broadcasting fifteen days after planting at the rate of 100 kg N ha^{-1}.

3.2.5 Data Collection

Data were collected from the two middle rows of each hybrid subplot. The outside rows of each experimental unit were used as a border to minimize the impact of adjacent treatment or factors from outside the experiment.

3.2.5.1 Plant Population, Plant Height, Dry Weight and Leaf Area

Plant populations were estimated by counting the number of seedlings emerged per plot 15 to 20 days after planting (assuming emergence was completed by this time) for each experimental unit. Then, the plant population was calculated on a hectare basis (number of plants ha^{-1}). Growth stages were observed from 10 randomly selected plants from the two middle rows. Plant height at physiological maturity (measured only in 2011 at Manhattan) was determined by measuring the distance between ground surface and the top of the panicle for each of ten plants randomly selected per plot. Dates of six- leaf stage, half bloom and physiological maturity were recorded for each plot.

Leaf Area Index (LAI) was measured from samples taken at two growth stages (six-leaf stage, and physiological maturity) in 2010 and three growth stages during 2011 (six-leaf stage, half bloom, and physiological maturity). For each measurement, the plants in 1m of each the two middle rows were harvested. Only fully expanded and green leaves were taken per plot for the leaf area measurement. Leaf area was then measured in the laboratory using a LI-COR 3100 leaf area meter (LI-COR, Lincoln, NE). Leave Area Index (LAI) was calculated based on total green leaf area divided by the harvested area per plot.

3.2.5.2 Total Dry Matter Production and Harvest Index

In 2010, dry matter production and partitioning was evaluated at physiological maturity for ten randomly selected plants from each of the two middle rows in each plot. Net above-ground biomass per unit area was obtained for each plant component after samples were oven dried to constant mass at 70^oC for at least 72 hours. Dry weight of each component was recorded per plot. The total biomass was calculated from the sum of leaf dry mass, stem dry mass, and panicle dry mass.

In 2011 total biomass was obtained from samples taken for leaf area measurement at maturity. Dry matter production was estimated using plants sampled for leaf area measurements, which were separated into leaf blades, stems, and panicles. After leaf area measurement the samples were oven dried, and panicle were threshed for grain mass estimation. Harvest index was calculated by dividing the total grain dry mass by total biomass.

3.2.5.3 Grain Yield

At maturity, sorghum panicles from 5m of each middle row were hand harvested, the number of panicles was counted and heads were dried. Harvested panicles were oven dried at 70 °C for 72 h, the dry weight recorded and panicles were threshed. Grain yield was calculated as total grain produced per ha corrected to 1.4 g kg^{-1} moisture content. The number of kernels per panicle was calculated by dividing grain yield by the product of panicle number and mass per grain, after mass per grain was determined from 200 kernels weight.

3.2.5.4 Growing Degree Days Calculation

The Growing Degree Days was calculated using the following formula

$$GDD = \sum([T_{max} + T_{min}]/2) - T_b$$

Where T_{max} represents daily maximum air temperature, T_{min} represents daily minimum air temperature, and T_b represents base temperature of sorghum. If T_{max} exceeded 38°C, it was set to 38°C. A base temperature of 10°C was used. If T_{min} was less than 10°C, T_{min} was set to 10°C . Air temperatures were measured at nearby weather stations.

3.2.6 Statistical Analyses

Statistical analyses were performed using PROC MIXED procedure of SAS 9.1 (SAS Institute 2003). Location and year were modeled as fixed effects, and replication as a random effect. Since the experiment was done in two locations in 2010 and one location in 2011, year and location effects are confounded. The combination of location effect and year effect was classified as environment. Mean separation test for significant effects were performed using Tukey's Honest Significant Test. Whenever interactions were significant, main effects were ignored and interactions effects were discussed.

Correlation (PROC CORR) and regression (PROC REG) analyses were used to test the relationship between the total dry mass, two hundred seed mass, panicle plant^{-1}, kernel panicle^{-1}, plant population, growth duration, and grain yield. Only significant correlations are presented.

3.3 Results

3.3.1 Plant Population:

Since significant interaction between environment, planting date, and hybrid was observed for plant density (Table 3.3), the interaction between planting date and hybrid on plant density are presented by location.

At Manhattan in 2010, no difference was found between plant populations of an individual hybrid in the two planting times. Within planting dates, no difference was found between hybrids for plant population (Table 3.7).

At Hutchinson in 2010, no difference was found between plant population for P84G62 and DKS 28-05 in the two planting dates. However, DKS 37-07 had about a 44% higher plant population in the 22 June planting compared with the 26 May planting. In the 26 May planting, no difference was found between plant populations for the three hybrids. However in the 26 June planting, DKS 37-07 had about 55% and 66% higher plant density compared with P84G62 and DKS 28-05, respectively (Table 3.8).

At Manhattan in 2011, no difference was found between plant populations of different hybrids within either 30 May or 28 June planting date. Plant population was higher in 30 May plantings compared with late 28 June plantings for all hybrids. Plant density was reduced respectively by 15%, 15%, and 19% for P84G62, DKS 28-05, and DKS 37-07 (Table 3.9).

3.3.2 Yield and Yield Components

Results of the three way analysis of variance for yield and yield components and their significance levels are presented in Table 3.2.

3.3.2.1 Grain Yield

A significant interaction between hybrid and planting date was found for grain yield (Table 3.2). The late maturing hybrid, P84G62, produced yield that was approximately 26% greater compared with DKS 28-05 when planted in late-May. But its yield declined by approximately 17% when planting was delayed from late-May to late June (Table 3.4). No difference was found between yields of late-May planting and late-June planting for hybrids DKS 37-07 and DKS 28-05.

A significant interaction between location (environment) and planting dates was observed on yield (Table 3.2). A late-June planting resulted in higher yields than the late-May planting at Manhattan in 2010. At Hutchinson in 2010, yield decreased when planting was delayed from late-May to late-June (Table 3.5). At Manhattan in 2011, no difference was found between yield of late-May and late June planting. In the late-May planting, the highest yield was observed at Manhattan in 2011. Grain yield in the late June planting at Manhattan both years was greater compared with Hutchinson. No difference was found between yields of two years at Manhattan in the late-June planting.

3.3.2.2 Yield Components

3.3.2.2.1 Number of Panicle Plant^{-1}

Planting date had different effect on the number of panicle plant^{-1} in different locations as indicated by a significant interaction between location and planting date (Table 3.2). At Manhattan in 2010, a higher number of panicle plant^{-1} was measured in the 26 June planting compared with the 25 May planting date. As planting was delayed from late-May to late-June, the number of panicle plant^{-1} was increased (Table 3.5). At Hutchinson in 2010 and Manhattan/North farm in 2011 no difference was found between Late-May and late-June for number of panicle plant^{-1}. In the late-May planting, no difference was found between the numbers of panicle plant^{-1} of different locations. Panicle plant^{-1} in the late-June planting at Manhattan in 2010 was significantly different those measured at Hutchinson in 2010, but had higher number of panicle plant^{-1}compared with those measured at Manhattan in 2011.

Hybrid effected the number of panicle plant^{-1}. The early maturing hybrid had about 14% and 12% higher number of panicle plant^{-1} compared respectively with the late maturing hybrid

(P84G62) and medium maturing hybrid (DKS 37-07). The mid- and full-season hybrids were not different in the number of panicles plant^{-1} measured (Table 3.6).

3.3.2.2.2 Number of Kernel Panicle^{-1}

A significant interaction was observed between location and planting date for kernel panicle^{-1} (Table 3.2). At Manhattan both years, average kernel panicle^{-1} was greater in the late-June planting compared with the late-May planting (Table 3.5). At Hutchinson, the number of kernel per panicle decreased as planting was delayed from late-May to late-June.

Hybrid differences in kernel panicle^{-1} were consistent, regardless of planting date. The fullest maturity hybrid (P84G62) and mid-season hybrid (DKS 37-07) had greater number kernels panicle^{-1} compared with the earliest maturing hybrid (DKS 28-05) (Table 3.6).

3.3.2.2.3 Seed Mass

A significant interaction between location, planting date and hybrid was observed for seed mass, thus result of interaction between planting date and hybrid on seed mass are presented by location.

At Manhattan in 2010, no difference was found within and between hybrids and planting dates for seed mass (Table 3.7).

At Hutchinson in 2010, no difference was found between hybrids seed mass in the late-May planting. However the early maturing hybrid had the greatest seed mass in the late June planting. No difference was found between P84G62 and DKS 37-07. Seed mass of DKS 37-07 decreased by about 12% when planting was delayed (Table 3.8).

At Manhattan in 2011, no difference was found between seed mass in the individual hybrids in the two planting dates. In the 30 May planting, P84G62 was not different from DKS

37-07, but had about 17% higher seed mass compared with DKS 28-05. In the 28 June planting, no difference was found between hybrids for seed mass (Table 3.9).

3.3.3 Plant Phenology and Growth

3.3.3.1 Number of Days from Planting to Maturity

There was effect of interactions between location, hybrid and planting date; location and planting date, hybrid and planting date, hybrid and location, effect of location, effect of planting date, and effect of hybrid on number of day from planting to maturity, but also on number of Growing Degree Days (GDD) (Table 3.3).

Since a significant interaction between location, hybrids, and planting dates was found for the number of days from planting to physiological maturity, and the GDD, results will be presented as the interaction between planting date and hybrid by locations. At the 2010 locations, the number of days from planting to physiological maturity decreases for all hybrids as planting was delayed (Table 3.7 and 3.8). However, at Manhattan in 2011, the number of days to physiological maturity increased with later planting for all hybrids (Table 3.9). Regardless of planting date and location the full season hybrid required more days and more GDD to reach physiological maturity.

3.3.3.2 Leaf Area Index

3.3.3.2.1 LAI at Six-Leaf Stage

A three way interaction among location (environment), planting date, and hybrids occurred for LAI at six-leaf stage and at maturity, therefore LAI results are discussed by location (Table 3.3).

At Manhattan in 2010, no difference was found between LAI at six-leaf stage for P84G62 and DKS 28-05 in the two planting dates (Table 3.7). However, DKS 37-07 had approximately 39% greater six-leaf stage LAI in the 26 June planting compared with the 25 May planting. (Table 3.7). Within either the 25 May nor the 26 June planting, no differences were found between six-leaf stage LAI for the three hybrids.

At Hutchinson in 2010, no difference was found between LAI at six-leaf stage for DKS 37-07 and DKS 28-05 in the two planting dates. However, the LAI of P84G62 was reduced by 61 % when planting was delayed from 26 May to 22 June (Table 3.8).

At Manhattan in 2011, P84G62 and DKS 28-05 had higher LAI at the six leaf stage in the 28 June planting compared with the 30 May planting. However similar LAI values at six-leaf stage were recorded for DKS 37-07 for both planting dates (Table 3.9).

3.3.3.2.2 LAI at Maturity

Planting date had different effects on leaf area at maturity in different locations (Table 3.3). At Manhattan in 2010 and at Hutchinson no difference was found in LAI at maturity between the late-May and late-June plantings (Table 3.5). The late May planting resulted in higher LAI at maturity at Manhattan in 2010 compared with Hutchinson in 2010 and Manhattan in 2011. No difference in LAI was found Hutchinson in 2010 and Manhattan in 2011 in the late May planting. The late June planting resulted in higher LAIs at maturity for Manhattan in 2010 compared with Hutchinson in 2010. No value for LAI at maturity was recorded for Manhattan in 2011, since maturity of hybrid P84G62 coincided with the first freeze killing day.

3.3.3.2.3 Comparison of LAI at Three Growth Stages in Two Planting Dates at Manhattan in 2011

Comparison between observed leaf-area at three growth stages at Manhattan in 2011 found that LAI increased from six-leaf stage to half bloom then decrease to physiological maturity for all hybrids. In the 30 May planting (Fig. 3.4.a), all hybrids had similar LAI at six leaf-stage; however, at half bloom they separated by maturity group. The late maturing hybrid had the most leaf area and the earliest maturing hybrid the least. The same general trend was observed in the 28 June planting date (Fig. 3.4 b) but no difference was observed between P84G62 and DKS 37-07 at half bloom. Measurements of leaf area at physiological maturity in late June planting was not possible for the full season hybrid (P84G62) because its maturity coincided with a killing freeze event.

3.3.3.3 Plant Height at Maturity

This variable was measured only in Manhattan in 2011. There was a significant interaction between planting date and hybrid on plant height at maturity (Table 3.10).

In the 30 May planting, the full season hybrid (P84G62) was taller than the other two hybrids. In the late-June planting no differences in plant height were found between the late maturing and mid-late maturing hybrids. However, both were taller than the early maturing hybrid. As planting was delayed from 30 May to 28 June, average plant height increased by 10.6 cm for DKS37-07, and 12.5cm for DKS 28-05 and did not change for P84G62 (Table 3.10).

3.3.4 Total Biomass and Harvest Index (HI)

3.3.4.1 Total Biomass

The interaction between location and planting date and the hybrid main effect were significant on total biomass production (Table 3.3).

At Manhattan in 2010, 19% more total biomass was produced in the 25 June planting compared with 25 May planting, while at Hutchinson in 2010 the total biomass produced decreased by 36% when planting was delayed from the 26 May to the 22 June (Table 3.5). At Manhattan in 2011, no difference was found between total biomass produced by planting date

In the late-May plantings no differences were found between total biomass produced at the three locations (Table 3.5). However, in the late-June plantings, lower total biomass was produced at Hutchinson in 2010 compared with Manhattan in 2011.

Differences between hybrids in total biomass produced were consistent. The late maturing hybrid (P84G62) and medium maturing hybrid (DKS 37-07) were not different. The early maturing hybrid (DKS 28-05) produced about 21%, and 13% less biomass compared with the other two hybrids (Table 3.6).

3.3.4.2 Harvest Index

Harvest index was influenced interactions between hybrid and planting date, and location and hybrid (Table 3.3).

In the late-May plantings, no consistent difference was found between HI of the different hybrids. But in the late June planting, P84G62 had a lower HI compared with the two other hybrids, which were not different from each other (Table 3.4). Hybrid P84G62 had lower HI in the late-June planting compared with the late May-planting. As planting was delayed, its HI decreased by about 9%.

At Manhattan in 2010 and 2011, no differences were found between hybrids for HI. At Hutchison in 2010, the short season hybrid had 11% higher HI compared with the full season one (Table 3.11).

3.3.5 Correlations

There was a positive significant correlation between kernels panicle^{-1} (Fig. 3.5a), total biomass produced (Fig. 3.5b), number of days from planting to maturity (Fig. 3.5c), and grain yield. The correlation was higher for number of kernel panicle^{-1} ($r = 0.84$) as compared with total biomass produced ($r=0.77$) and number of days from planting to maturity ($r = 0.49$).

3.4 Discussion

3.4.1 Yield, Yield Components, Total Dry Mass and Harvest Index

In this study, the planting date by hybrid interaction for grain yield was consistently significant. In the late-May planting, yield of the late maturing hybrid was 17% greater than of the medium maturing hybrid and 26% greater than of the early maturing hybrid. As planting was delayed from late May to late June grain yield of the late maturing hybrid declined by about 17% while no difference was found as planting was delayed for the early maturing and medium maturing hybrids. These results agree with the findings of Bunck (1977), who stated that as planting was delayed from early May to early July, late maturing sorghum hybrids showed a reduction in leaf number, leaf area, and thus in yield at Manhattan and Hutchinson. However, analysis of yield components found that the interaction between location (environment) and planting date, and the hybrid main effect were more significant for grain yield and yield components than planting date. Planting date effect on sorghum grain yield, and total biomass produced varied by location. These yield differences may be explained by differences in environmental conditions in the different growing seasons and locations. Among yield components, only plant density was reduced for P84G62 at Manhattan (2010) when planting was delayed. Reductions in LAI also were recorded for this hybrid when planting was delayed. This leaf-area reduction might have affected yield through a reduction in light interception.

The effect of planting date on grain yield varied by location (environment). Lower yields were recorded in 25 May planting compared to the 26 June planting at Manhattan in 2010. This situation may be mainly due to high plant populations in the first planting date that affected plant growth and development, and thus yield. High plant population results in competition between individual plant for light and nutrients. At Hutchinson in 2010 the late-June planting out yielded the late-May planting. The late May plantings resulted in lower panicle plant^{-1}, lower kernel panicle^{-1}, and greater seed mass compared with late June planting.

At Hutchinson in 2010, yield and total biomass decreased for all hybrids when planting was delayed from 26 May to 22 June. This situation might be due to environmental conditions (high temperature and lower precipitation in late-June compared to late-May) prevailing during the growing period (Fig. 3.3). With delayed planting, there were reductions in seed mass for DKS 37-07, and reductions in kernel weight for all hybrids. Rainfall distribution and variation in temperature associated with above critical temperature during vegetative growth and grain filling period may have affected plant growth, yield components, and yield potential in the late planting. This result is consistent with Mutava's (2010) finding that high temperature during the last part of panicle development may reduce yield by causing floret abortion.

Total biomass production and grain yield followed similar trends, with the late-June planting favorable to total biomass production at Manhattan in 2010, late May planting favorable at Hutchinson, and no difference at Manhattan in 2011. These variations might be due to differences in environmental conditions between Manhattan and Hutchinson (temperature and precipitation), and differences between the two growing seasons (2010 and 2011).

Harvest index (HI) was reduced for P84G62 in the late-June planting compared with the late-May planting. Low temperatures prevailing later in the season during the vegetative growth period of late June planting might have affected development of the full season hybrids compared to the late-May planting. In the late-June planting, the full season hybrid reached bloom around day 230 when temperatures started to decline and heat accumulation was slowed. This situation may have contributed to a decrease in both vegetation dry matter production and grain yield, with higher decrease in grain yield, as result harvest index declined.

3.4.2 Plant Phenology

At Manhattan and Hutchinson in 2010, the number of days from planting to physiological maturity decreased for all hybrids as planting date was delayed. This agrees with result found by Kersting (1961) who reported that earlier planting dates tended to expand the total number of days from planting to physiological maturity of grain. However, at Manhattan in 2011, the number of days from planting to maturity was expanded when planting was delayed from 30 May to 28 June. This particular situation may be caused by unusual variation in rainfall distribution and temperatures. The late rain and high temperatures might have delayed crop growth and development. As a result, maturity of the late maturing hybrid coincided with the first killing freeze day. This agrees with Bauhmardt et al. (2005) who stated that in late planting, late maturing hybrids generally failed to reach physiological maturity before the first killing freeze.

No difference in LAI, was detected between hybrids at six leaf stage for late-June planting at Manhattan in 2010 and late-May planting at Hutchinson. But at half bloom, greater leaf area was observed with late maturing hybrid in the late-May planting at Manhattan in 2011. In the late-June planting, this difference at half bloom was not measured between P84G62 and DKS37-07. This agrees results found by Klein (2000). He found similar leaf area for all hybrids of three maturing groups until growing point differentiation in both May and June plantings. However, he found differences between hybrids for LAI based on maturity group at growing point differentiation. The greatest leaf area was observed with late maturing hybrid and the earliest maturing hybrid had the lowest leaf area. The observed differences between LAI values might be genetic, but also influenced by differences in growing and environmental conditions such as plant population, rainfall quantity and distribution, air and soil temperatures. These leaf area differences are important for determining final yield due the role of leaves in light interception thus in the photosynthesis process.

3.5 Conclusions

The results of this study pointed out that the effect of planting date on grain sorghum yield, yield components, and growth was highly dependent on environmental conditions. Planting date alone had no consistent effect on sorghum grain yield. Planting in late-May under relatively longer day lengths when the plant experienced warmer temperatures significantly increased grain yield and growth of the full season hybrid. When planting was delayed from late-May to late-June, better yields were obtained from early maturing hybrid (DKS 28-05) and medium maturing hybrid (DKS 37-07). Investigation of yield components found that seed mass, kernel panicle^{-1}, and plant population were affected by planting date depending on location. Significant positive correlation was found between grain yield and kernels panicle^{-1}, total dry mass produced, and number of days from planting to maturity. The results of this study suggest that variability exists in the effect of planting date on yield depending environmental conditions. A late maturing hybrid can be planted up to late May in environments similar to those observed in this study. The choice of early or medium maturing hybrids would be preferable when planting is delayed. The limited number of year data from each experiment site coupled with the large variability in weather conditions limit the scope of inference for this study. Continuation of the research is necessary to confirm the results and for more investigation on the effect of planting date on yield components for more description of decrease in yield for full season hybrid due to delayed planting in wider range of environment and planting dates.

3.6 Figures and Tables

Figure 3.1 Experiment sites map and average annual rainfall.

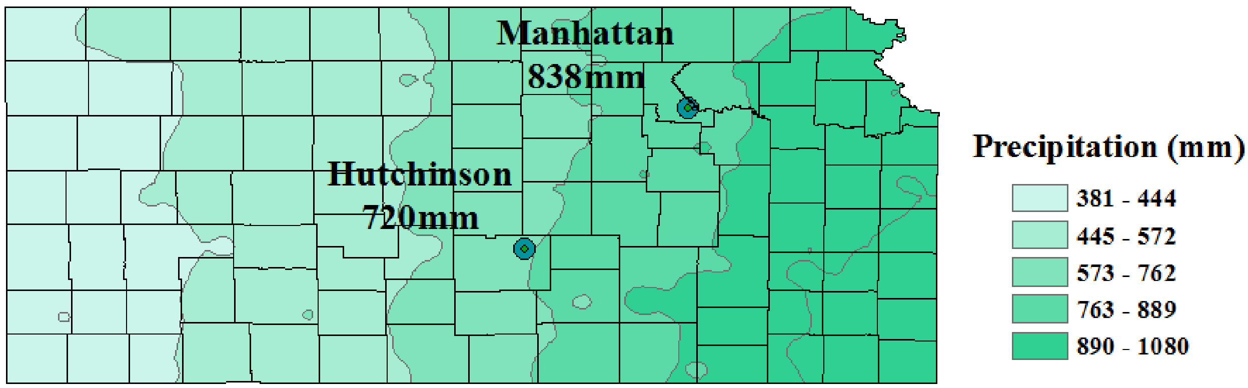


Figure 3.2 Daily maximum and mimimum temperature, and rainfall during sorghum growing period at Manhattan 2010 and 2011.

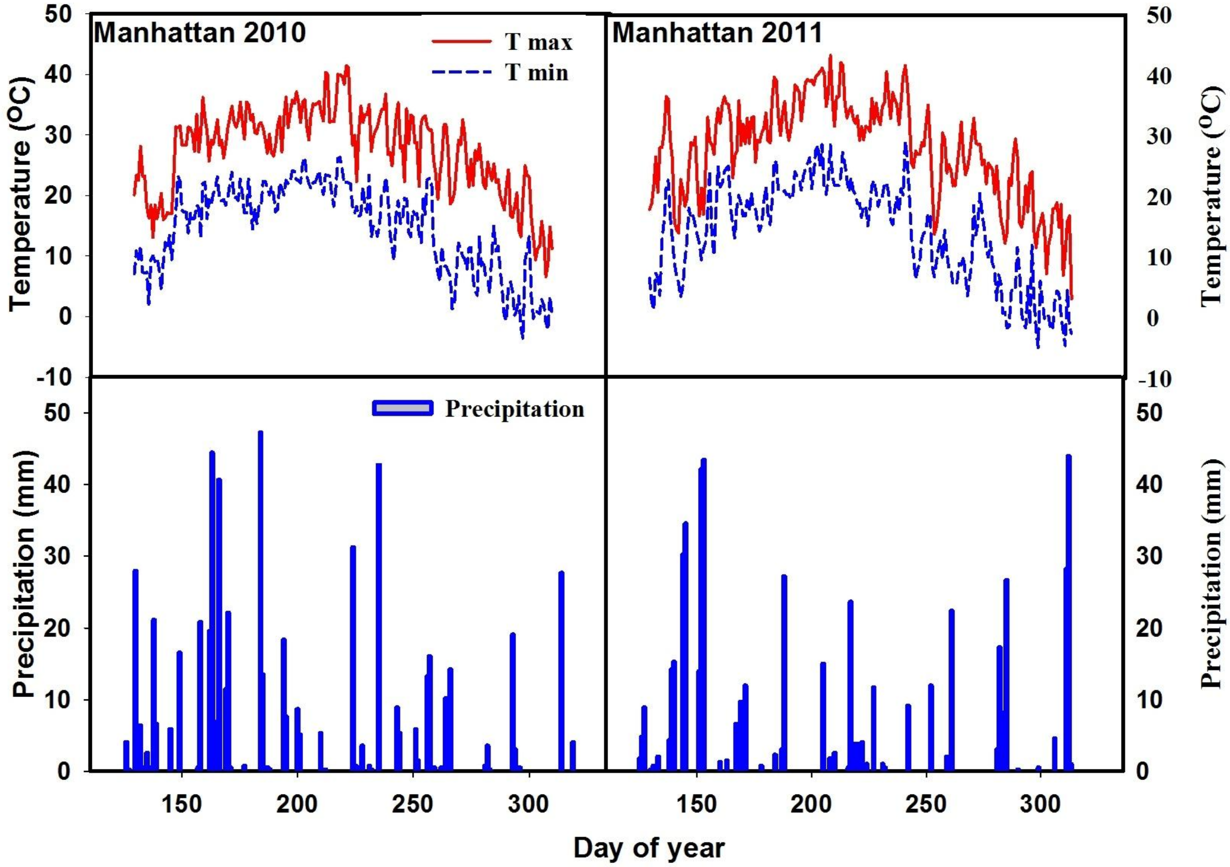


Figure 3.3 Daily maximum and mimimum temperature, and rainfall during sorghum growing period at Hutchinson 2010 and 2011.

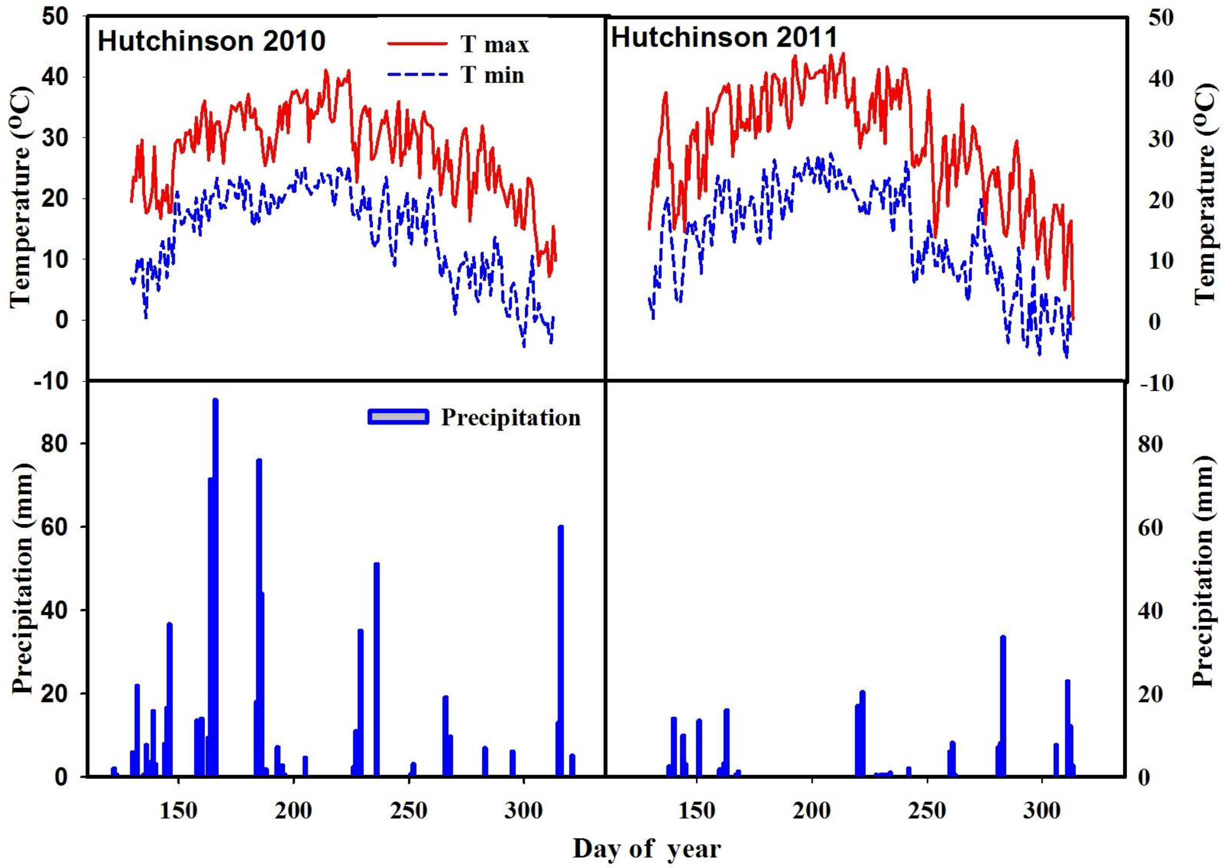
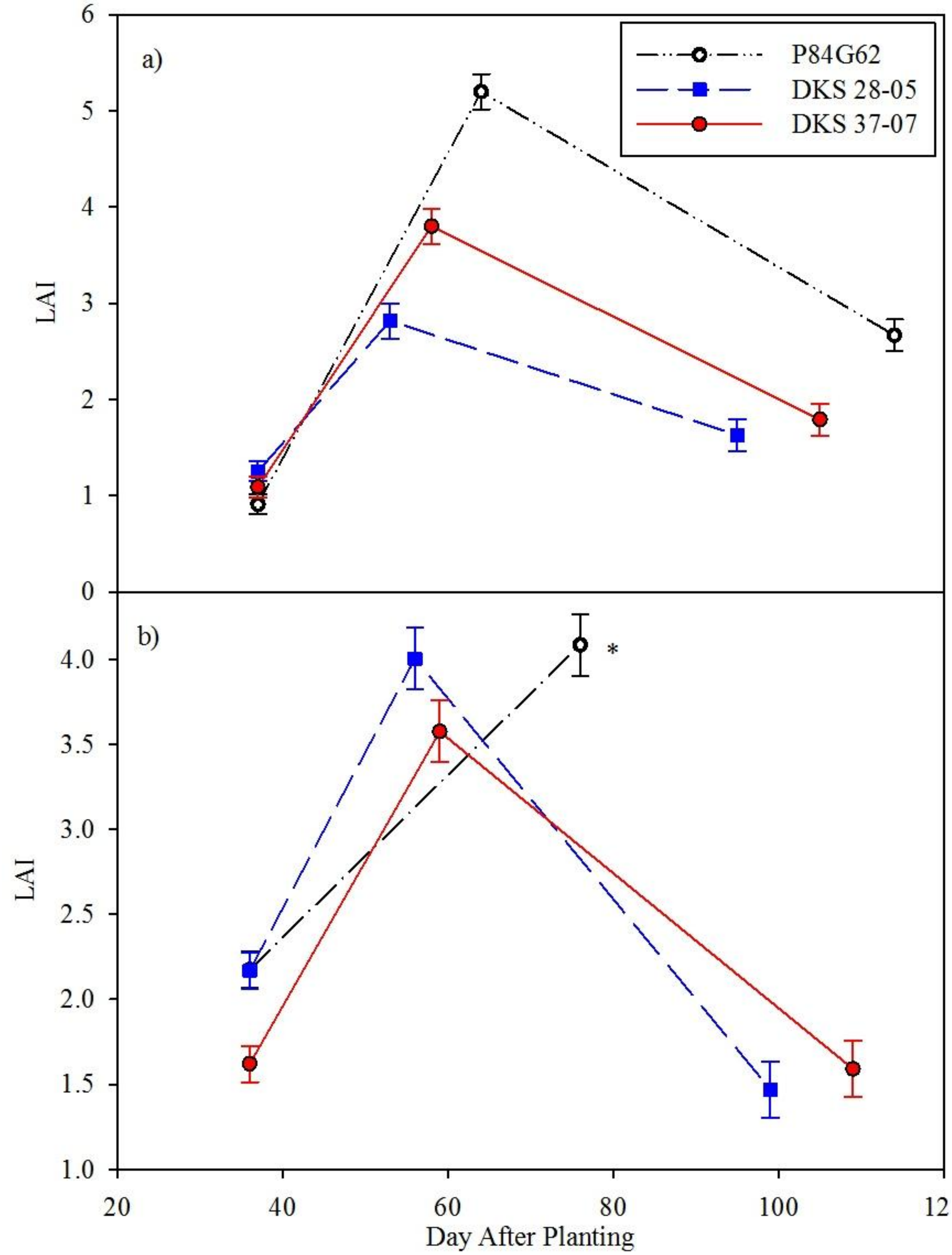


Figure 3.4 Leaf area index (LAI) at six-leaf stage, half bloom, and physiological maturity for three hybrids at Manhattan in 2011 for a late-May planting (a) and late-June planting (b).



(*) = Data not available.

Figure 3.5 Regression analyses between kernel panicle^{-1}, total biomass, number of days from planting to maturity and grain yield.

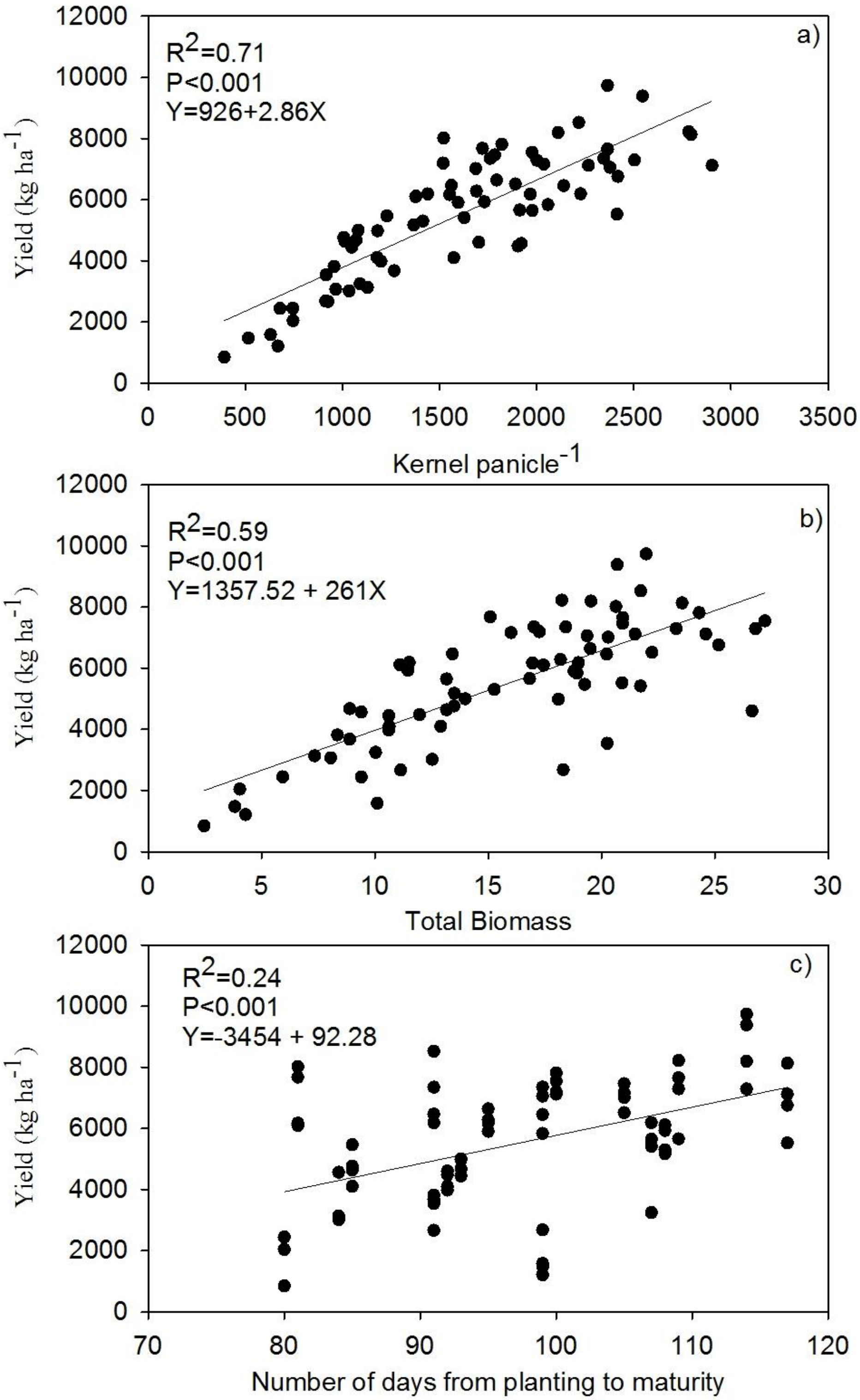


Table 3.1 Planting dates of sorghum in our experiment in 2010 and 2011 at Manhattan and Hutchinson.

Location (year)	Planting dates			
	May	Day of year	June	Day of year
Manhattan in 2010	25	145	26	177
Hutchinson in 2010	26	146	22	173
Manhattan in 2011	30	150	28	179
Hutchinson in 2011	21	141	24	175

Table 3.2 Analysis of variance for sorghum yield and yield components by location, planting date and hybrids in Kansas during 2010 and 2011.

Source	Grain yield (kg ha^{-1})	TBM† (kg ha^{-1})	kernels panicle^{-1}	panicle plant^{-1}	200 kernels weight (g)
Location (L)	***	***	**	***	***
Planting Date (PD)	NS††	NS	NS	NS	NS
L x PD	***	***	***	***	*
Hybrid (H)	***	**	**	**	***
L x H	NS	NS	NS	NS	**
H x PD	***	NS	NS	NS	NS
L x H x PD	NS	NS	NS	NS	***

TBM†=Total Biomass; NS††= Non Significant, *=<0.005; **=<0.001; ***=<0.0001;

Table 3.3 Analysis of variance for sorghum growth parameters by location, planting date and hybrids in Kansas during 2010 and 2011.

Source	Plant Pop. ha^{-1}	LAI at six-leaf stage	LAI at maturity	Harvest index	Day to maturity	GDD
Location (L)	***	NS	***	***	***	***
Planting Date (PD)	***	***	NS	NS	***	***
LxPD	***	***	*	NS	***	***
Hybrid (H)	*	NS	NS	*	***	***
L x H	*	*	NS	*	***	***
H x PD	*	NS	NS	*	***	***
L x H x PD	*	*	NS	NS	***	***

Plant pop= Plant population ha^{-1}; GDD=Growing Degree Days for maturity.

Table 3.4 Effect of interaction between planting date and hybrid on yield and harvest index (HI) at all locations.

Planting Date	Hybrid	Yield (kg ha^{-1})	HI
Late-May	P84G62	6466 a†	0.38 a
Late-June	P84G62	5343 bc	0.29 b
Late-May	DKS 28-05	4811 c	0.39 a
Late-June	DKS 28-05	5201 bc	0.41 a
Late-May	DKS 37-07	5366 bc	0.37 a
Late-June	DKS 37-07	5918 ab	0.41 a

† means followed by the same letter within the same column are not different at a 0.05 alpha level.

Table 3.5 Effect of interaction between location and planting date on grain yield, total biomass, panicle plant^{-1}, kernels panicle^{-1}and LAI at maturity.

Location	**Planting date**	**Yield (kg ha^{-1})**	**Total Biomass (t ha^{-1})**	**Panicle plant^{-1}**	**Kernels panicle^{-1}**	**LAI at maturity**
Manhattan (2010)	25 May	5047 b†	13.30 bc	1.31 c	1225 d	2.86 a
Manhattan (2010)	26 June	7177 a	19.04 a	1.86 a	1727 bc	3.45 a
Hutchinson (2010)	26 May	4284 b	13.82 ab	1.49 abc	1529 cd	1.87 b
Hutchinson (2010)	22 June	2367 c	8.91 c	1.83 ab	779 e	1.38 b
Manhattan (2011)	30 May	7311 a	20.33 ab	1.47 abc	1955 b	2.03 b
Manhattan (2011)	28 June	6918 a	20.50 ab	1.14 bc	2417 a	N.A

N.A = data not available.

† Means followed by the same letter within the same column are not different at a 0.05 alpha level.

Table 3.6 Effect of hybrid on total biomass, number of panicles plant^{-1} and number of kernels panicle^{-1} (all locations and planting dates)

Hybrid	**Total biomass ($t\ ha^{-1}$)**	**Number of panicle plant^{-1}**	**Number of kernels panicle^{-1}**
P84G62	17.83 a†	1.47 b	1778 a
DKS 28-05	14.03 b	1.71 a	1424 b
DKS 37-07	16.08 ab	1.50 b	1614 ab

† Means followed by the same letter within the same column are not different at a 0.05 alpha level.

Table 3.7 Effect of interaction between planting date and sorghum hybrid on plant population, phenology, seed mass, GDD and LAI (six-leaf growth stage) at Manhattan in 2010.

Planting Date	Hybrid	Plant population (1000 plant ha^{-1})	200 seeds mass (g)	Number of days from Planting to maturity	GDD for maturity	LAI at six-leaf stage
25 May	P84G62	149.5 ab†	6.52 a	108 a	1653.2 a	0.19 ab
26 June	P84G62	106.8 b	6.26 a	100 b	1437.7 bc	0.25 a
25 May	DKS 28-05	166.0 a	5.92 a	85 d	1344.4 e	0.15 b
26 June	DKS 28-05	109.3 ab	5.75 a	81 e	1258.3 f	0.20 ab
25 May	DKS 37-07	150.3 ab	5.34 a	93 c	1458.7 b	0.14 b
26 June	DKS 37-07	109.8 ab	6.23 a	91 c	1374 d	0.23 a

GDD= Growing Degree Days.

† Means followed by the same letter within the same column are not different at a 0.05 alpha level.

Table 3.8 Effect of interaction between planting date and sorghum hybrid on plant population, phenology, seed mass, GDD and LAI (six-leaf growth stage) at Hutchinson in 2010.

Planting Date	**Hybrid**	**Plant Population (1000 plant ha^{-1})**	**200 seeds mass (g)**	**Number of days from planting to maturity**	**GDD for maturity**	**LAI six-leaf stage**
26 May	P84G62	78.8 b†	6.65 ab	107 a	1767.2 a	0.23 a
22 June	P84G62	63.5 b	6.19 ab	99 b	1593.5 b	0.09 b
26 May	DKS 28-05	89.8 ab	6.46 ab	84 d	1440.5 e	0.17 ab
22 June	DKS 28-05	48.5 b	6.84 a	80 e	1349.7 f	0.08 b
26 May	DKS 37-07	79.5 b	6.69 a	92 c	1559.2 c	0.21 a
22 June	DKS 37-07	142.25 a	5.88 b	91 c	1503.1 d	0.13 ab

GDD= Growing Degree Days.

† Means followed by the same letter within the same column are not different at a 0.05 alpha level.

Table 3.9 Effect of interaction between planting date and sorghum hybrid on plant population, phenology, seed mass, GDD and LAI (six-leaf growth stage) at Manhattan in 2011.

Planting Date	**Hybrid**	**Plant Population (1000 plant ha^{-1})**	**200 seeds mass (g)**	**Number of days from planting to maturity**	**GDD for Maturity**	**LAI six-leaf stage**
30 May	P84G62	97.8 a†	5.70 a	114 b	1806.4 a	2.18 a
28 June	P84G62	83.2 bc	5.38 ab	117 a	1630.1 c	0.91 c
30 May	DKS 28-05	95.8 ab	4.75 b	95 d	1615.1 cd	1.25 bc
28 June	DKS 28-05	81.5 c	4.78 b	99 c	1496.3 f	2.17 a
30 May	DKS 37-07	98.5 a	5.30 ab	105 f	1732.4 b	1.09 bc
28 June	DKS 37-07	79.6 c	4.98 b	109 e	1599.7 d	1.62 b

GDD= Growing Degree Days.

† Means followed by the same letter within the same column are not different at α= 0.05.

Table 3.10 Effect of interaction between planting date and sorghum hybrid on plant height at maturity at Manhattan in 2011.

Planting Date	**Hybrid**	**Plant height (cm)**
30 May	P84G62	135.8 ab†
28 June	P84G62	136.5 a
30 May	DKS 28-05	117.0 d
28 June	DKS 28-05	129.5 bc
30 May	DKS 37-07	126.4 c
28 June	DKS 37-07	137.1 a

† Means followed by the same letter within the same column are not different at $\alpha = 0.05$.

Table 3.11 Effect of interaction between location and sorghum hybrid on harvest index (HI) for all planting dates.

Location	**Hybrid**	**HI**
Manhattan (2010)	P84G62	0.39 ab†
Manhattan (2010)	DKS 28-05	0.37 ab
Manhattan (2010)	DKS 37-07	0.43 ab
Hutchinson (2011)	P84G62	0.27 b
Hutchinson (2011)	DKS 28-05	0.38 a
Hutchinson (2011)	DKS 37-07	0.31 ab
Manhattan (2011)	P84G62	0.35 ab
Manhattan (2011)	DKS 28-05	0.44 ab
Manhattan (2011)	DKS 37-07	0.43 ab

† Means followed by the same letter within the same column are not different at α= 0.05.

Table 3.12 Growing season monthly average temperature and precipitation at Manhattan, KS.

	Temperature (°C)						Precipitation (mm)		
	2010		2011		30-year average				
Month	Low	High	Low	High	Low	High	2010	2011	30-year average
May	12.2	23.2	11.7	24.3	12.0	24.8	92	131	129
June	19.3	31.2	18.9	31.5	17.2	30.0	168	121	145
July	21.8	32.4	23.2	36.5	20.1	33.0	107	53	112
August	19.9	34.1	20.2	34.5	18.8	32.3	81	59	105
September	14.4	28.4	11.6	26.7	13.2	27.6	76	37	87
October	7.1	23.3	7.1	22.9	6.2	20.9	27	56	68
November	0.2	13.0	1.0	14.4	-0.7	13.0	32	78	44
Total							583	535	690

Table 3.13 Growing season monthly average temperature and precipitation Hutchinson, KS.

	Temperature (°C)						Precipitation (mm)		
	2010		2011		30-year average				
Month	Low	High	Low	High	Low	High	2010	2011	30-year average
May	11.4	24.0	11.4	25.7	11.5	24.2	122	44	113
June	19.9	32.6	19.3	35.0	16.8	30.1	199	23	123
July	21.2	33.1	23.3	39.3	19.5	33.2	155	01	96
August	20.0	33.8	20.6	36.2	18.6	32.7	100	43	80
September	14.8	29.1	11.2	27.6	13.2	28.0	33	15	68
October	6.9	24.0	6.6	22.6	6.2	20.8	13	49	59
November	-0.7	13.5	0.2	14.0	-0.6	13.2	78	46	34
Total							700	220	573

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