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Effect of Planting Date on Yield and Yield Components of Grain Sorghum Hybrids

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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 and yield components compared with late June planting. The objectives of this research were to investigate the influence of planting dates yield and yield components 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 dry matter production, 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, 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 yield and yield components of grain sorghum hybrids were found to be variable among hybrid maturity groups and locations.

Keywords

Sorghum [*Sorghum bicolor* (L.) Moench], Grain Yield, Yield Components

1. Introduction

Grain sorghum is one of the major cereal crops grown in the United States and throughout the world. Sorghum is the fourth most important cereal crop grown in the United States, and the fifth most important cereal crop grown in the world [1]. 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 [2]. Globally the total area cropped with sorghum was 43.8 million hectares in 2007 [3].

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. [4] 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 [4] [5] stated that sorghum plays double role in farmers' life in Africa by providing income and insuring food security.

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 [3]. 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 [6].

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 [2].

Under non-irrigated conditions, grain sorghum yields are highly variable, ranging from as much as 6 $Mg \cdot ha^{-1}$ 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 [7]. 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. [8] 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. [9] 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 [10].

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. [11] reported that planting date had no consistent effect on grain sorghum yield in a study conducted in Kansas. [12] found an optimal planting period in Kansas for consistent grain sorghum yield of 25 May to 5 June. [13] 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.

2. Materials and Methods

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.

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 **Figure 1** and **Figure 2**. 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 1**). Maximum temperature was greater for all months except May

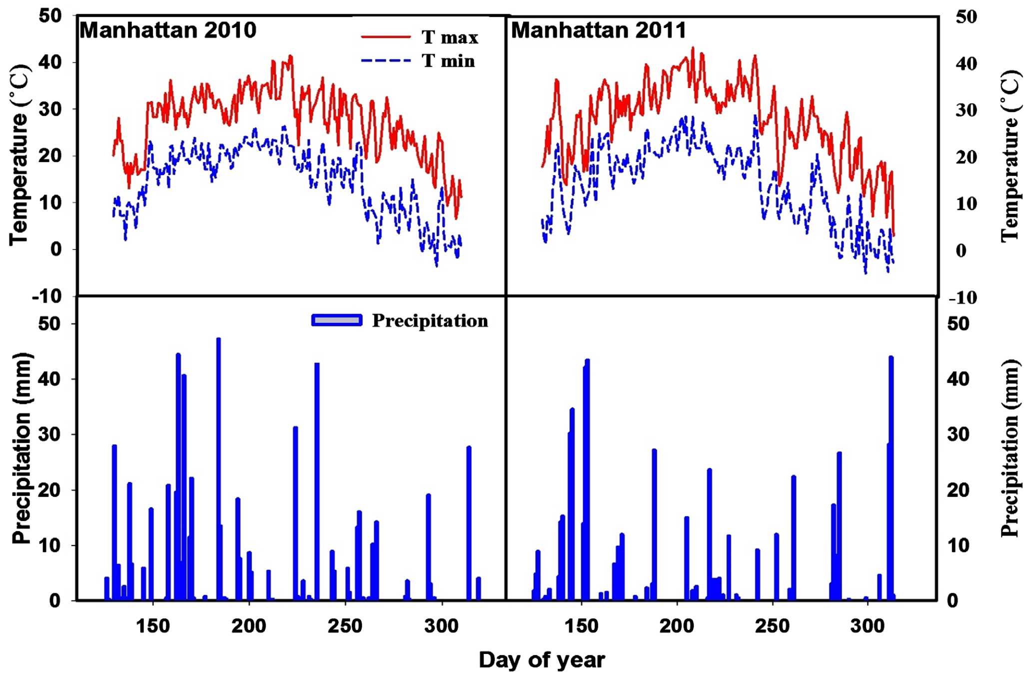

Figure 1. Daily maximum and minimum temperature, and rainfall during sorghum growing period at Manhattan 2010 and 2011.

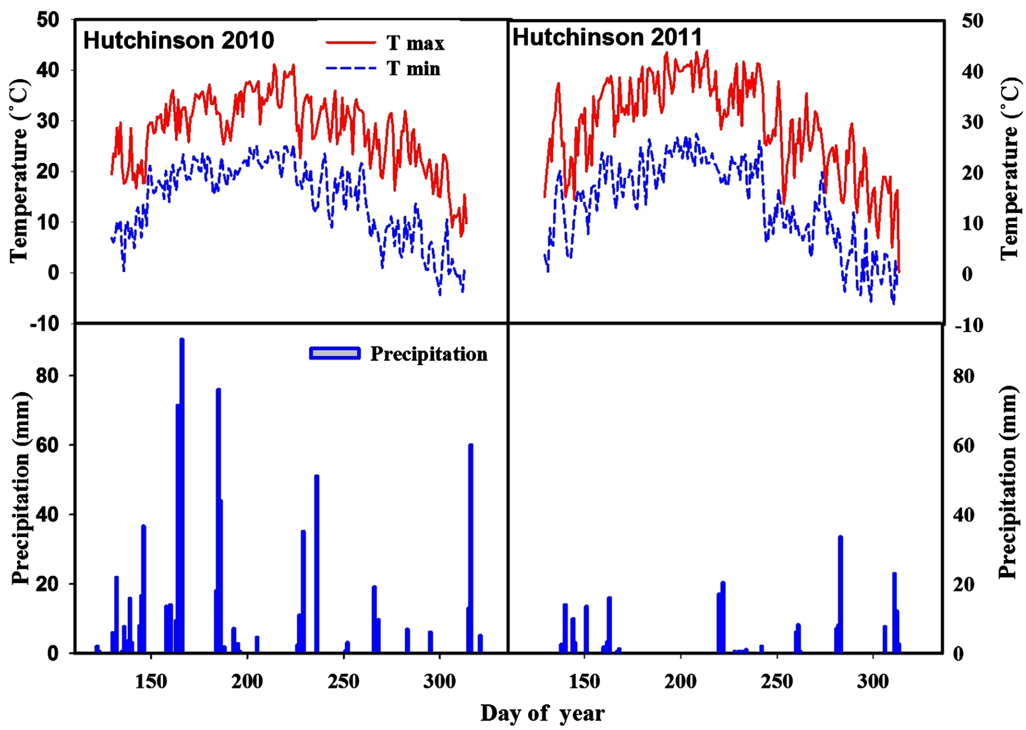

Figure 2. Daily maximum and minimum temperature, and rainfall during sorghum growing period at Hutchinson 2010 and 2011.

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 1**).

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 2**). Daily maximum, minimum temperatures and rainfall are presented in **Figure 2**. 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

Table 1. Growing season monthly average temperature and precipitation at Manhattan, KS.

Month	Temperature (˚C)						Precipitation (mm)		
	2010		2011		30-year average				
	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 2. Growing season monthly average temperature and precipitation Hutchinson, KS.

Month	Temperature (˚C)						Precipitation (mm)		
	2010		2011		30-year average				
	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

about 36% greater than the long-term average in 2010, but about 43% less than the long-term average in 2011 (**Table 2**).

The amount of precipitation received from day of year 164 to 219 was low, about 2.794 mm (**Figure 2**). 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.

2.2. Treatments

The treatments included combinations of planting dates and hybrids. Three sorghum hybrids were selected based on 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 across both years.

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.

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 324 $g·L^{-1}$ of active ingredient acetochlor and 161 $g·L^{-1}$ 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 $N·ha^{-1}$.

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.

2.5.1. Plant Population

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.

2.5.2. Total Dry Matter Production

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˚C 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.

2.5.3. Grain Yield

At maturity, sorghum panicles from 5 m 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.

2.5.4. Growing Degree Days Calculation

The Growing Degree Days was calculated using the following formula

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

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.

2.6. Statistical Analyses

Statistical analyses were performed using PROC MIXED procedure of SAS 9.1

[14]. 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. Results

3.1. Plant Population

Since significant interaction between environment, planting date, and hybrid was observed for plant density (Table 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 4).

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 5).

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

Table 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	***	***
L × PD	***	***	*	NS	***	***
Hybrid (H)	*	NS	NS	*	***	***
L × H	*	*	NS	*	***	***
H × PD	*	NS	NS	*	***	***
L × H × PD	*	*	NS	NS	***	***

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

Table 4. 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 5. 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.

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 6).

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 7.

3.2.1. Grain Yield

A significant interaction between hybrid and planting date was found for grain yield (Table 7). The late maturing hybrid, P84G62, produced yield that was approximately 26% greater compared with DKS 28-05 when planted in late-May.

Table 6. 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 $\alpha = 0.05$.

Table 7. 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.

But its yield declined by approximately 17% when planting was delayed from late-May to late June (Table 8). 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 7). 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 9. 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.

Table 8. 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 9. 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}	779e	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.

3.2.2. Yield Components

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 7**). 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 9**). 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 10).

2) Number of Kernel·panicle^{-1}

A significant interaction was observed between location and planting date for kernel·panicle^{-1} (Table 7). At Manhattan both years, average kernel·panicle^{-1} was greater in the late-June planting compared with the late-May planting (Table 9). 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 10).

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 4).

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 5).

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 6).

3.4. Total Biomass

The interaction between location and planting date and the hybrid main effect

Table 10. 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.

were significant on total biomass production (**Table 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 9**). 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 9**). 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 10**).

3.5. Correlations

There was a positive significant correlation between kernels·panicle^{-1} (**Figure 3(a)**), total biomass produced (**Figure 3(b)**), number of days from planting to maturity (**Figure 3(c)**), 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 ($r = 0.49$).

4. Discussion

Yield, Yield Components, Total Dry Mass

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 [15], 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.

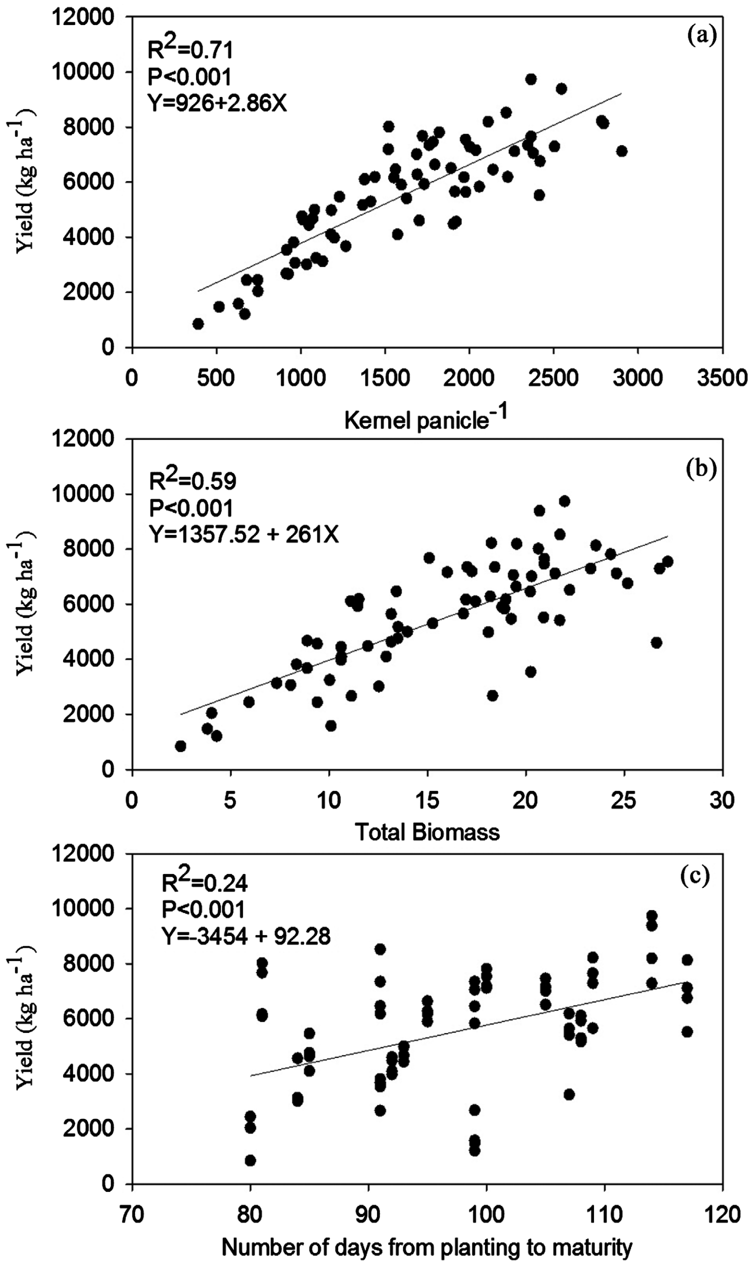

Figure 3. Regression analyses between kernel·panicle^{-1}, total biomass, number of days from planting to maturity and grain yield.

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. 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 [16] 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).

5. Conclusion

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, grain yield and growth of the full season hybrid significantly increased. 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 limits 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.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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