EFFECT OF PLANTING GEOMETRY, HYBRID MATURITY, AND POPULATION DENSITY ON YIELD AND YIELD COMPONENTS IN SORGHUM

by

KALAIYARASI PIDARAN

B.Sc., Tamil Nadu Agriculture University, 2003
M.Sc., Tamil Nadu Agriculture University, 2006

A THESIS

submitted in partial fulfillment of the requirements for the degree

MASTER OF SCIENCE

Department of Agronomy
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2012

Approved by:

Co-Major Professor
Rob M. Aiken

Approved by:

Co-Major Professor
Mary Beth Kirkham

Abstract

Prior studies indicate clumped planting can increase grain sorghum yield up to 45% under water deficit conditions by reducing tiller number, increasing radiation use efficiency, and preserving soil water for grain fill. The objective of this study was to evaluate effects of planting geometry on sorghum grain yield. The field study was conducted in seven environments with two sorghum hybrids, four populations, and two planting geometries. Crop responses included leaf area index, yield, and components of yield. Delayed planting decreased yield by 39%, and a later maturing hybrid increased yield, relative to an early hybrid, by 11% under water sufficiency. Clumped planting increased the fraction of fertile culms (culms which formed panicles) from 5-14%. It reduced the number of culms m^{-2} by 12% under water limiting conditions (at one of two locations) but increased culms m^{-2} 16% under water sufficiency. Seeds per panicle and seed weight generally compensated for differences in panicles m^{-2}, which were related to different planting population densities.

Although agronomic characteristics of hybrids varying in maturity have been widely studied, little information exists concerning their physiological differences. Therefore, the objective of the greenhouse study was to determine if stomatal resistance, leaf temperature, and leaf chlorophyll content differed between two DeKalb grain sorghum [*Sorghum bicolor* (L.) Moench] hybrids. They were DKS 36-16 and DKS 44-20, of medium-early and medium maturity, respectively, when grown under field conditions in Kansas. Seeds were planted in a greenhouse. Stomatal resistance and leaf temperature were measured 55 days after planting with a Decagon Devices (Pullman, WA) diffusion porometer, and chlorophyll content was measured 119 days after planting with a Konica Minolta (Osaka, Japan) SPAD chlorophyll meter. The two hybrids did not differ in stomatal resistance, leaf temperature, chlorophyll content, height, and dry weight. Their difference in maturity was not evident under the greenhouse conditions. Future work needs to show if hybrids of different maturities vary in physiological characteristics

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Acknowledgements

I effusively express my inestimable gratitude to my major advisor Dr. Robert M. Aiken for his learned counsel, incisive comments, patience and untiring help evinced through out the tenure of this study. I whole heartedly thank my Co-major advisor Dr. Mary Beth Kirkham for her constant encouragement and meticulous care throughout my study period.

I am having immense pleasure to record thank to my committee member Dr. Tesfaye Tesso, for timely help, concrete suggestions and constructive criticism. I would like to thank Dr. Kraig L. Roozeboom, Dr. Brian Olson, Dr. Alan Schlegel and Dr. John Holman to coordinate the field trails at different locations. I would like to thank the funding source for this study through Center for Sorghum Improvement and Hatch project from Kansas State University.

I would like to thank Alicia Oien, Ralph Wolf, Ray Duffey, Vickie Brown and high school students for their help to take timely measurements and made my stay as a wonderful time. I would like to Thank Ann Miner who give a moral support throughout my stay at Colby. I thank Terri L. Branden, Facilities Maintenance Supervisor, Kansas State University, for mounting the black plastic and treating the plants with the insecticides.

I am grateful to my husband Dr. Sivakumar Sukumaran who is caring, guiding and supporting throughout the way of life. I would like to Thank Lakshmi, Nivas and Asha & family for their whole hearted support.

Chapter 1- Effect of planting geometry, hybrid maturity and population density on yield and yield components of sorghum

Abstract

Prior studies indicate clumped planting can increase grain sorghum yield up to 45% under water deficit conditions by reducing tiller number, increasing radiation use efficiency, and preserving soil water for grain fill. The objective of this study was to evaluate effects of planting geometry on sorghum grain yield. The field study was conducted in seven environments with two sorghum hybrids, four populations, and two planting geometries and two planting dates. Crop responses included leaf area index, yield, and components of yield. Delayed planting decreased yield by 39%, and a later maturing hybrid increased yield, relative to an early hybrid, by 11% under water sufficiency. Clumped planting increased the fraction of fertile culms (culms which formed panicles) from 5-14%. It reduced the number of culms m^{-2} by 12% under water limiting conditions (at one of two locations) but increased culms m^{-2} 16% under water sufficiency. Seeds per panicle and seed weight generally compensated for differences in panicles m^{-2}, which were related to different planting population densities. Planting geometry altered components of yield for growing environments differing in planting date and available water.

Introduction

Grain sorghum [*Sorghum bicolor* (L.) Moench] is the fifth most important crop grown in the world. It will become increasingly important in the central high plains of the USA, as irrigated land reverts to dryland. In the semi-arid Great Plains of the USA, water is the major factor affecting growth. The most important choice a producer of rainfed crops must make is crop selection based on the amount of water availability (Unger et al., 2010, p. 29). Therefore, grain sorghum [*Sorghum bicolor* (L.) Moench] is widely grown in the region, because it is classified as a drought-resistant species.

Dryland sorghum is generally rain-fed and the success of the crop depends on seeding during high precipitation periods. Therefore, early growth of dryland sorghum plants often occurs under favorable conditions so individual plants normally tiller extensively. But tillers use a high amount of water and nutrients, very often not cases all of the tillers bear panicles with good grains due to post flowering water stress (Bandaru, Stewart, et al., 2006, Steiner, 1986, Steiner, 1987). The success of dryland grain sorghum production mainly depends on the efficient use of precipitation and soil water that can be managed by planting date and planting geometry. In an earlier study, soil water content at sorghum planting time was the dominant factor contributing to sorghum yield increase (Unger and Baumhardt, 1999). Apart from the rainfall and available soil water, other agronomic practices, such as population density and planting geometry, have a great influence on grain sorghum yield. Planting geometry is defined as shape, size, and orientation of leaves and stems in relation with spatial distribution (Godin, Costes, et al., 1999). Yield stability was greater in skip row planting than the conventional planting method where the annual rainfall was less than 675 mm (Abunyewa, Ferguson, et al., 2010).

Dryland grain sorghum accounts for much of the crop production in the Great Plains region and planting practices must ensure crop yield rather than crop failure. In different semi-arid to arid regions, planting geometry was studied as one of the management aspects for maize (Kapanigowda, Stewart, et al., 2010) and sorghum (Bandaru, Stewart, et al., 2006, Kapanigowda, Schneider, et al., 2010). It was reported that clumped planting had a definite advantage over a uniform planting geometry in water limiting condition. In a simulated study done under water limiting conditions, sorghum yield was greater than maize yield (Sinclair and Muchow, 2001). But no two growing seasons are similar in semi–arid regions, so to confirm the effect of clumped planting geometry the study was carried out in the central great plains region.

To reduce the pressure on irrigation and water use, we need to exploit the potential of dryland cultivation (Rosegrant M.W. et al., 2002). Several dryland planting strategies have been used to conserve water. These include using different planting geometries such as wider row spacing or planting in clumps; planting early-maturing hybrids, which use less water than later-maturing hybrids; and reducing plant population (Stewart et al., 2010). Little information exists concerning the combined effects of these three factors on sorghum grown in the Great Plains.

The first chapter of the thesis reports results of field studies using three different planting geometries (clumped, uniform, and paired rows); two different hybrids (medium-early and medium maturities); and four seeding rates (24,700; 98,800; 172,900; and 247,000 seeds/ha). The studies were done in seven environments in 2009 and 2010 at three locations in western Kansas (Colby, Garden City, and Tribune). The second chapter of the thesis reports an experiment in which two grain sorghum hybrids varying in maturity were grown in a greenhouse, and physiological measurements were taken. The two hybrids were the same as those grown in the field. One was a hybrid with medium-early maturity, and one was a hybrid of medium maturity. Stomatal resistance, leaf temperature, and chlorophyll content were measured to see if they differed between the two hybrids. The main objective of this thesis was to evaluate the effects of planting geometry, hybrid maturity, and plant population density on yield and yield components of sorghum grown in western Kansas.

Materials and methods

The experiment employed different planting geometries (clumped, uniform, and paired row), hybrids (early-medium and medium maturity), and seeding rate (24,700; 98,800; 172,900; and 247,000 seeds/ha) over 7 environments in 2009 and 2010. The hybrids used were Pioneer 87G57 (medium early maturing) and Pioneer 85G46 (medium maturing) in Colby, KS. DKS36-16 (early-medium maturity) and DKS44-20 (medium maturity) in Garden City, Kansas, and Tribune, Kansas. Plant traits measured were leaf area index (LAI), light transmittance, biomass at mid-season and harvest, and yield components (number of culms and panicles, grain weight, and 200 seed mass).

Colby 2009 and 2010

The experimental site was located at the Northwest Research-Extension Center in Colby, Kansas (39° 23' 45" N /101° 3' 9" W). It was conducted in a factorial split plot treatment design, with planting date (5/21/2009 and 6/24/2009) as a main effect in 2009; split plot treatments consisted of hybrid, planting geometry, and seeding rate, in factorial arrangement. Four replicates of experimental treatments were arranged in a randomized complete block experimental design. The hybrids used in this experiment were Pioneer 87G57 (early maturity) and Pioneer 85G46 (medium maturity), which were selected based on their maturity and local adaptability.

The three planting geometries were standard uniform spacing, clumped planting, and paired row spacing. Four different seeding rates were employed: 24,700; 98,800; 172,900; and 247,000 seeds/ha. The treatment combinations were assigned randomly to the sub-plots. Each experimental plot had an area of 10 m × 3 m per plot. In 2010, except for early planting, all other treatments were similar to those of 2009. The early planting was not possible due to heavy precipitation, so planting was done on June 21, 2010. Measurements taken at this study site included leaf area index (LAI), light transmittance (172,900 seeds/ha seeding rate only), above-ground biomass at mid-season and physiological maturity (172,900 seeds/ha seeding rate only), and yield components (number of culms and panicles, grain weight, and 200 seed mass).

Garden City and Tribune (2009 and 2010)

The field studies conducted in 2009 and 2010 at Garden City (37° 58' 18" N / 100° 52' 20" W) and Tribune (38° 28' 11" N / 101° 45' 10") consisted of a factorial treatment design with hybrid, planting geometry, and seeding rate. In Garden City, the study was planted on May 29, 2009 and on June 9, 2010. In Tribune, seeds were planted on June 6, 2009 and on June 2, 2010. Measurements included above-ground biomass at mid-season and physiological maturity (172,900 seeds/ha seeding rate only), and yield components (number of culms, number of panicles, grain weight, and 200 seed weight). The hybrids used were DKS36-16 (early-medium maturity) and DKS44-20 (medium maturity), which were adapted to these locations.

Biomass and Harvest index

For biomass, the plant samples were harvested from 1 m of row which was representative of the treatment combinations. The plants were harvested at ground level, weighed, and sub-samples were taken and dried in the oven at 60^{o} C to constant dry weight, which was determined by repeated measurements and moisture content determinations. Biomass was calculated on a dry mass per unit area basis. Harvest index was calculated as the ratio of grain mass to above ground biomass.

Leaf area index (LAI)

Leaf area index is the ratio of total one-sided area of photosynthetic tissue to ground surface area (Watson, 1947). LAI was measured using an LAI-2000 plant canopy analyzer (LI-COR, Lincoln, Nebraska, USA). Measurements were taken 50 days after planting (DAP) and 64 DAP on early and late planting experiments at Colby, KS, in 2009, and at 44 DAP at Colby, KS, in 2010. Measurements were taken when the sun was near the horizon, *i.e.*, within two hours after sunrise or before sunset, to get the low angle diffused radiation as per the manufacturer's specifications. Leaf area index was calculated from the ratio of below-canopy to reference measurements using software provided by the manufacturer. Data were screened to eliminate below-canopy readings which exceeded reference above-canopy readings of irradiance.

Light Transmittance

Light transmittance (τ) of photosynthetically active radiation (PAR) was measured using a line quantum sensor (LI−191SA, LI−COR, Lincoln, Nebraska, USA). Measurements were taken at 66 DAP at Colby, 2009 and consisted of a single reference measurement, of incident (horizontal surface) PAR, above-canopy PAR and five measurements of transmitted (horizontal surface) PAR, taken below the canopy. For each below-canopy reading, the line quantum sensor was placed perpendicularly to rows. Canopy PAR τ was calculated as the ratio of the average of five below-canopy readings to the reference above-canopy reading, expressed as a fraction. The extinction coefficient (corresponding to that of Beers' Law) was computed as the slope of the regression of ln-transformed τ on LAI.

Harvest procedure

Plants were harvested from one meter of row which was representative of the treatment combination for the plot. Individual culms and panicles were counted and harvested in two different categories: Culm heights were recorded for culms in representative 1m row samples (both hybrids and all planting geometries, 172,000 seed/ha seeding rate) plots in Colby 2009. A frequency distribution was prepared from culm height observations, indicating a bi-modal distribution. Based on this analysis, a culm was classified as short if it's height was less than two thirds of the height of culms in the upper height distribution. Based on this relative height tall and short culms were categorized. Panicles were dried, weighed, and threshed by using a machine thresher. Number of seeds per panicle was also categorized based on the category of tall and short panicles. Grain weight and two-hundred seed weight were recorded using a seed counter and seed analyzer, was used for testing seed mass and moisture content (GAC 2100 Agri; DICKEY-John Corporation)

Harvesting was done on September 28 and 29, 2009, for the early planting date experiment and on October 7, 2009, for the late planting experiment at Colby. The total crop period was 131 days and 105 days for early and late planting dates, respectively. During 2009, the first fall freeze occurred on October 3, 2009. In 2010, harvest was done at Colby on October 18. At Tribune, harvesting was done on October 27 and October 15 in 2009 and 2010, respectively. Harvesting was done on October 26, 2009, and October 12, 2010, at Garden City.

Statistical analysis

The data were analyzed in SAS (SAS-Statistical Analysis Systems version 9.1.3, Cary, North Carolina) using Proc GLM. An ANOVA was calculated for each environment and reported separately. Experimental design was RCBD; treatment design was factorial (two hybrids x two or three planting geometries x four seeding rates). To test main effects interaction mean sum of squares (geometry*hybrid* population) were used as error term and to test the interaction terms residual error mean sum of squares were used. Mean separation were done using DMRT with probability of greater F value less than 0.05. Yield advantage of clumped planting geometry was determined by plotting the difference between the yield of clumped planting geometry and uniform planting geometry vs. yield of uniform planting geometry. Differences in extinction coefficients for canopy PAR τ were evaluated by analysis of covariance, testing for homogeneity of slopes using paired t tests.

Results

Analysis of variance for each environment is reported in Tables 1-7. In Colby for the early planting in 2009, hybrid maturity affected yield. Seeding rate had no significant effect on any of the yield and yield component traits (**Table 1.1.**). In Colby for the late planting in 2009, planting geometry affected yield and panicles/culm. Hybrid maturity affected culms/m2 and seeds/panicle for panicles of tall culms; the late maturing hybrid had more seeds/panicle for panicles of tall culms and greater seed weight. Seeding rates affected all traits, except yield (**Table 1.2**). In Tribune in 2009, planting geometry affected panicles/culm. Hybrid maturity affected culms/m2 and seeds/panicle on panicles of tall culms. Seeding rates affected culms/m^2, panicles/culm, and seeds/panicle on panicles of tall culms (**Table 1.3**). In Garden City in 2009, planting geometry affected panicles/culm. Hybrid maturity affected culms/m2, and seeds/panicle for panicles of tall culm (**Table 1.4**).

In Colby in 2010, planting geometry had a significant effect on culms/m^2, seeds/panicle on tall culms, and seed weight. Hybrid maturity affected culms/m^2 and seeds/panicle on tall and short culms. Seeding rates affected culms/m^2 and seeds/panicle on panicles of tall culms (**Table 1.5**). In Tribune in 2010, seeding rates affected culms/m^2 and seeds/panicle on panicles of tall culms (**Table 1.6**). In Garden City in 2010, planting geometry affected seeds/panicle on panicles of tall culms. Hybrid maturity had significant effects on seeds/panicle in panicles of tall culms and seed weight, and the effects of seeding rates were on yield, culms/m^2, and seeds/panicle on tall culms (**Table 1.7**).

Planting geometry and yield components

In Colby for the late planting date experiment, clumped planting geometry had 24% more yield than the uniform planting geometry, but the total crop period was 104 days due to the early frost during October that killed the crop before maturation in 2009. Other locations did not show variation for grain yield. Numbers of culms in a meter were similar for the clumped and uniform planting geometries in all locations. Panicles/culm was significantly higher for the clumped planting geometry than for the other geometries

(**Fig. 1.16**). Seeds/panicle on panicles of tall culms were not different in all locations. Seeds/panicle on panicles of short culms were not significantly different for planting geometries among locations (**Table 1.8**).

In 2010, at Colby, planting geometry affected culms/m2, seeds/panicle for tall culms and seed weight. For clumped planting geometry at Colby, culms/m^2 was higher seeds/panicle (tall culms and seed weight was lower. At Garden City, seeds/panicle (tall culms) was also greater for clumped planting geometry (**Table 1.9**). Uniform planting geometry tended to increase yield (19% greater, relative to clumped planting geometry) when yield potential exceeded 1000g/m^2 (**Fig. 1.15**).

Hybrid maturity and yield components

In 2009 at Colby, the later maturing hybrid Pioneer 85G46 had higher yield (early planting), 7 % more culms/m^2 (late planting) and 17 % more seeds/panicle for tall culms (late planting) than the earlier maturing Pioneer 87G57 hybrid. In other environments, significant variation was not observed for grain yield. In Tribune and Garden City (2009), the earlier hybrid DKS36-16 had more culms/m^2 than the later hybrid DKS44-20. Seeds/panicle on panicles of tall culms was higher for the later maturing hybrid in all environments. Seeds/panicle on panicles of short culms was higher for DKS36-16 in Tribune 2009, and seed weight was higher for the early hybrid in Colby for the late planting experiment (**Table 1.10**).

In the Colby experiment in 2010, culms/m^2 and seeds/panicle of short culms was higher for the early hybrid; the late maturity hybrid had a higher number of seeds/panicle on tall culms. In Garden City (2010) the early maturity hybrid had a higher number of seeds/panicle on panicles of tall culms. Yield and panicles/culm were not significantly different among the hybrids across all locations (**Table 1.11**).

Seeding rates and yield components

In Colby (2009), panicles/culm was greater for both the 24,700 seeds/ha and 247,000 seeds/ha seeding rates (late planting). Seeds/panicle for tall culms was greater for the three lower seeding rates than for 247,000 seeds/ha. Seeds/panicle for short culms was highest for 247,000 seeds/ha in Colby (late planting); seed weight was greater for 172,900 seeds/ha and 247,000 seeds/ha. In Colby (late planting) and Tribune (2009), culms/m^2 were greater for 172,900 seeds/ha and 247,000 seeds/ha. Panicles/culm was highest for the low and high population densities in Colby (late planting) and Tribune (2009). Seeds/panicle for tall panicles was highest for 24,700 seeds/ha in Colby (late planting) and Tribune (**Table 1.12**).

In Garden City (2010), grain yield was greatest for 98,800 seeds/ha seeding rate. Culms/m^2 were greatest for 247,000 seeds/ha and least for 24,700 seeds/ha seeding rates at Colby, Tribune and Garden City (2010). Seeds/panicle for tall culms were greater for 24,700 seeds/ha than other three seeding rate in all locations in 2010 (**Table 1.13**). Seed weight and number of seeds per panicle were compensatory with effects of seeding rate (**Fig.1.17**).

Leaf area index and light transmittance

The planting geometries altered LAI (**Fig. 1.13**) and PAR transmittance **(Table 1.14)**. Canopy transmittance of PAR decreased with increasing LAI for all three planting geometries; however, the extinction coefficient was least for clumped planting and similar for uniform and paired-row planting geometries. The coefficient of determination,

R^2 values, were 0.96, 0.90, and 0.98 for uniform, clumped, and paired row planting geometries, respectively (**Fig. 1.14**). The clumped planting geometry showed a higher amount of PAR transmittance than the uniform and paired row spacing planting geometry.

Discussion

Little or no water during reproduction and grain filling stage results in yield loss in the US Great Plain regions (Craufurd and Peacock, 1993). Effect of skip-row planting showed yield reduction up to 10.9 per cent (Larson and Vanderlip, 1994). Yields were generally less in a skipped row configuration in high yield potential regions (Unger and Baumhardt, 1999).

Clumped planting geometry had a higher yield advantage at low yield potential, such as under semi-arid, non-irrigated conditions, compared with a uniform, standard planting geometry. Uniform planting geometry had around 19% more yield than clumped planting geometry at Colby for the early planting experiment during 2009, but the yield in 2009 was higher than the average yield of Kansas, due to high precipitation in the crop growth season. In other studies, the clumped planting geometry showed an inverse relationship with yield in high yielding environments (Kapanigowda, Schneider, et al., 2010, Kapanigowda, Stewart, et al., 2010). The results suggest that clumped planting geometry can result in equivalent or greater grain yield for semi-arid, dry environments, when grain yield potential is less than 8,500 kg ha^{-1}.

The clumped planting geometry had a greater fraction of fertile culms, which can result in greater harvest index, relative to uniform planting geometry (Lafarge, Broad, et al., 2002). The medium maturing hybrid had more seeds than the early maturing hybrid in all the environments except Garden City during 2010, which showed the advantage of yield components in increasing the yield. The increase in seed weight could also be due to the long maturity period.

At maximum LAI, the clumped planting geometry showed a higher light transmittance than uniform planting geometry, which indirectly showed that the clumped planting geometry used less water when compared with the uniform, standard planting geometry.

For a given leaf area, more light is transmitted (less intercepted) for sorghum with clumped planting than for sorghum planted in uniform or paired-row method. Since water use is linked to light interception, clumped planting could have corresponding reduction in water use; this could be favorable for yield formation under water-limiting conditions.

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Figures and Tables

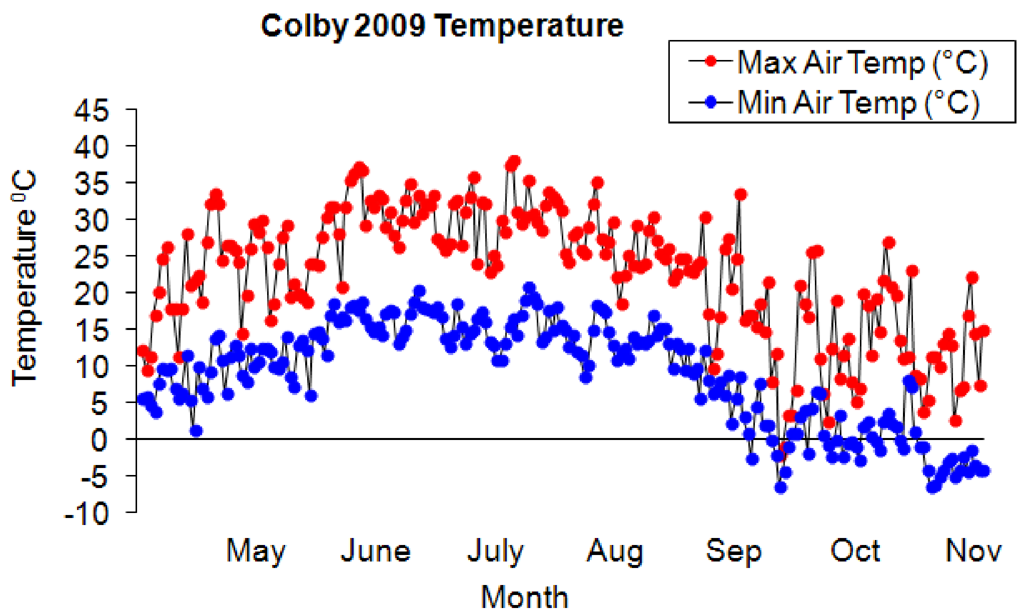

Figure 1.1. Daily maximum and minimum temperature (^{0} C) at Colby, KS 2009.

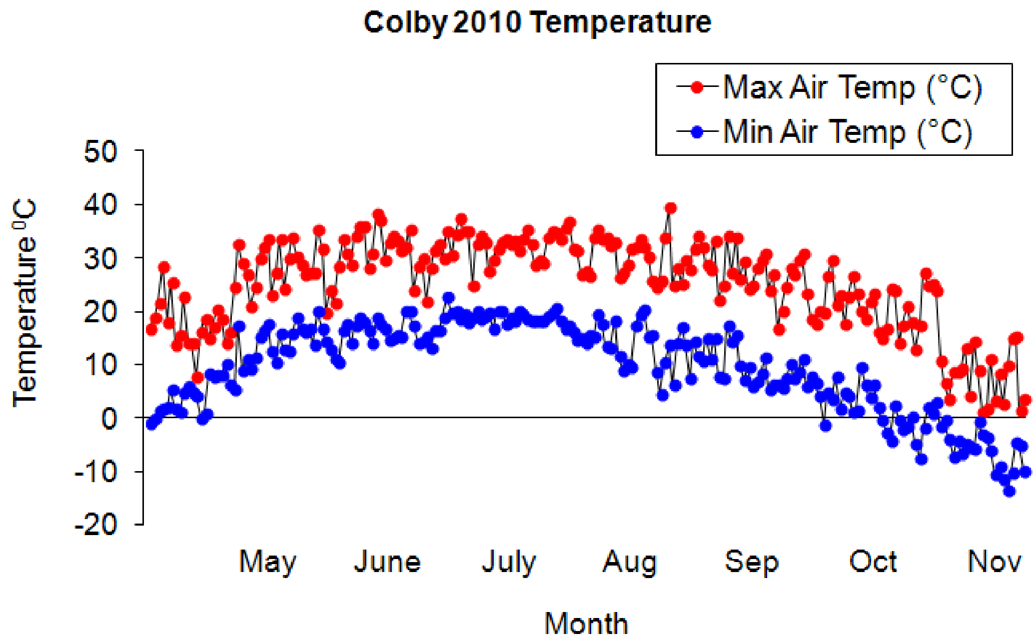

Figure 1.2. Daily maximum and minimum temperature (^{0} C) at Colby, KS 2010.

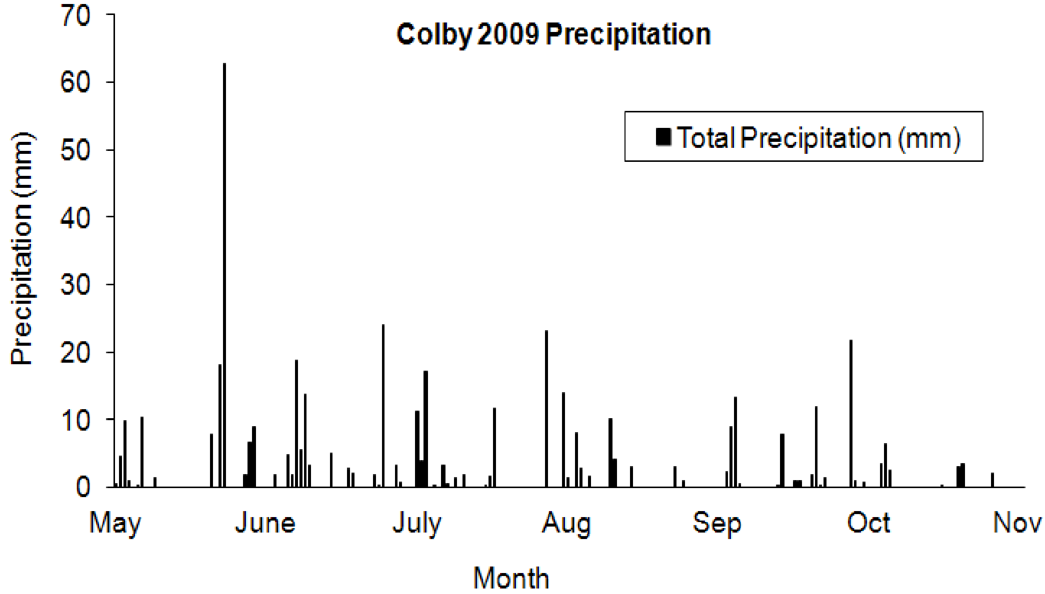

Figure 1.3. Total precipitation (mm) at Colby, KS 2009.

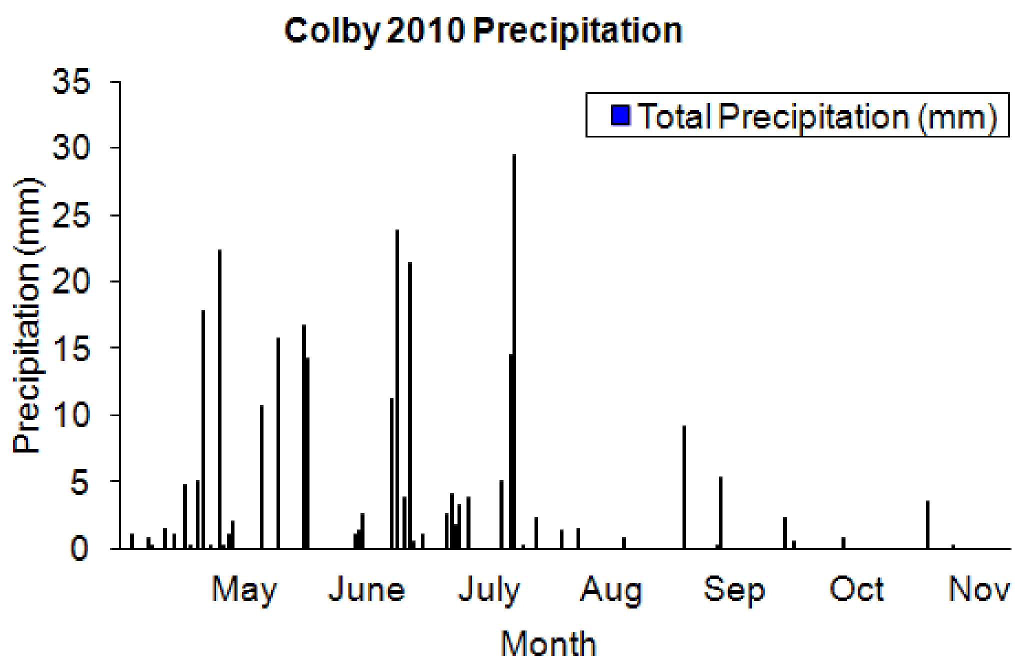

Figure 1.4. Total precipitation (mm) at Colby, KS 2010.

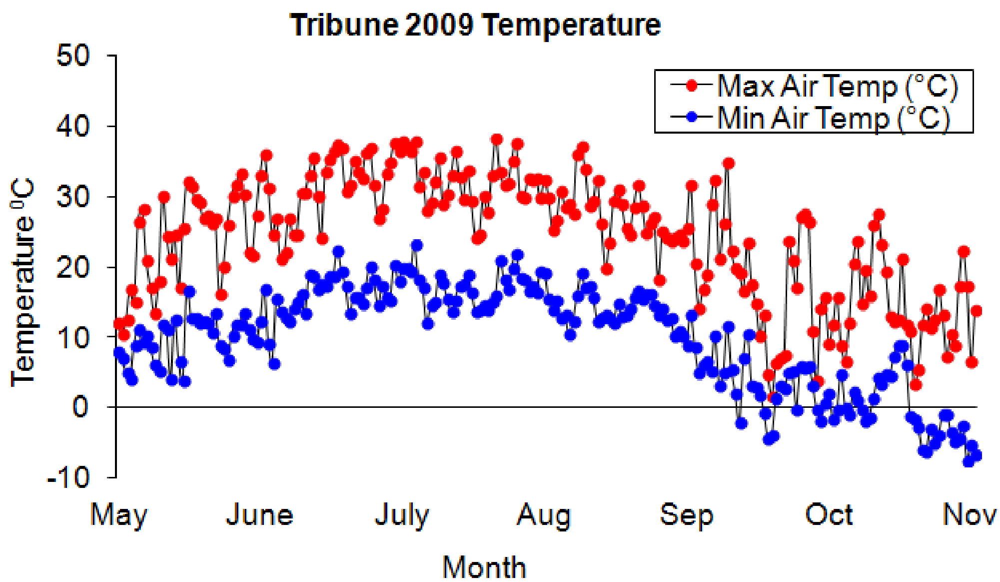

Figure 1.5. Daily maximum and minimum temperature (^{0} C) at Tribune, KS 2009.

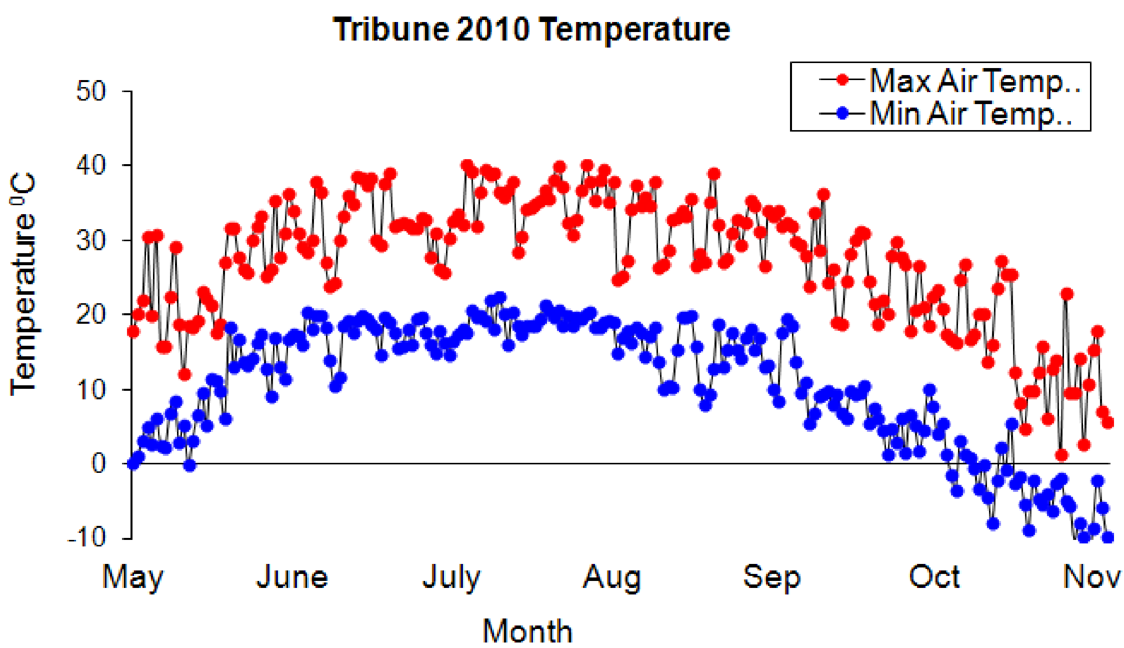

Figure 1.6. Daily maximum and minimum temperature (^{0} C) at Tribune, KS 2010.

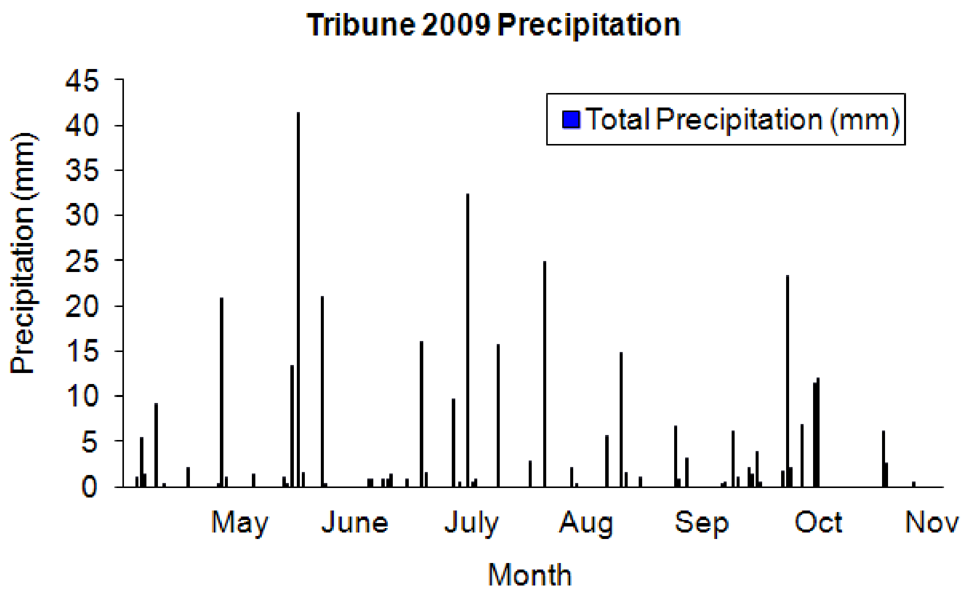

Figure 1.7. Total precipitation (mm) at Tribune, KS 2009.

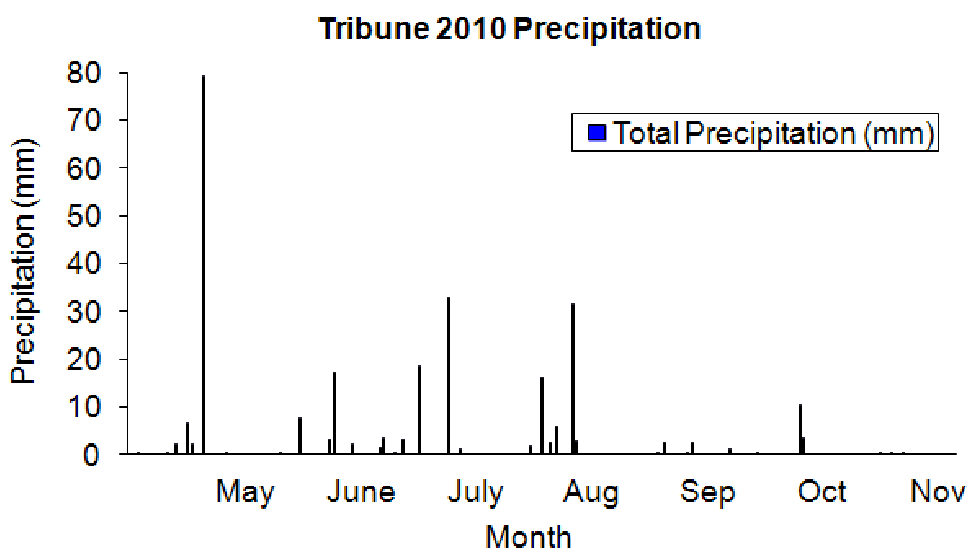

Figure 1.8. Total precipitation (mm) at Tribune KS 2010.

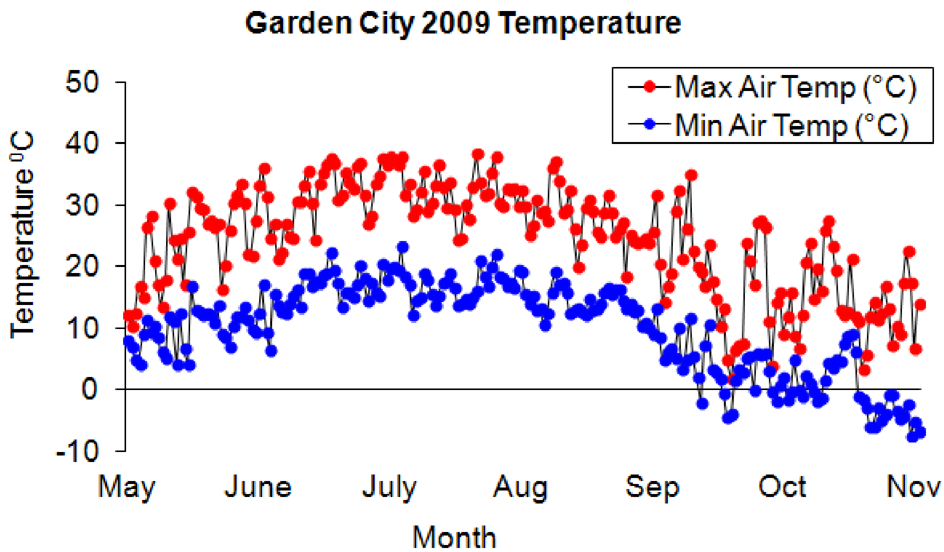

Figure 1.9. Daily maximum and minimum temperature (^{0} C) at Garden City, KS 2009.

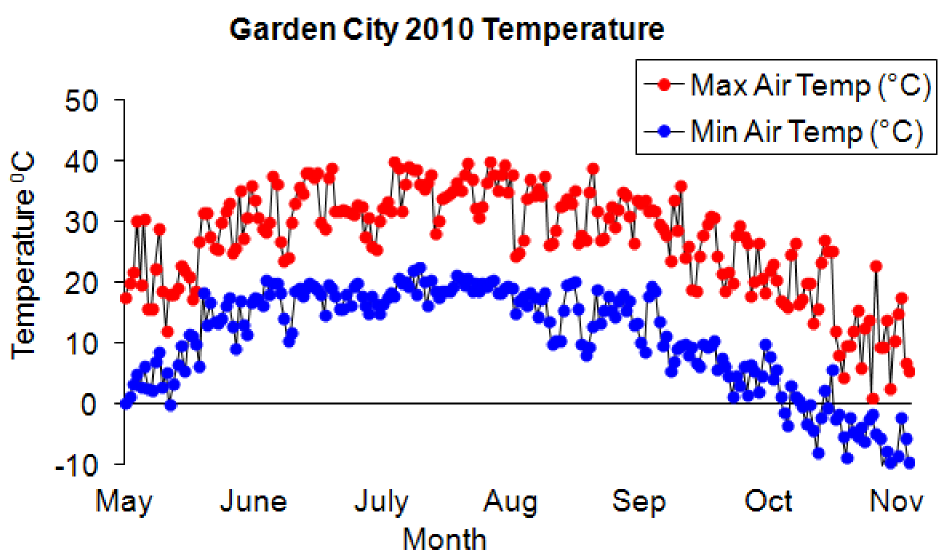

Figure 1.10. Daily maximum and minimum temperature (^{0} C) at Garden City, KS 2010.

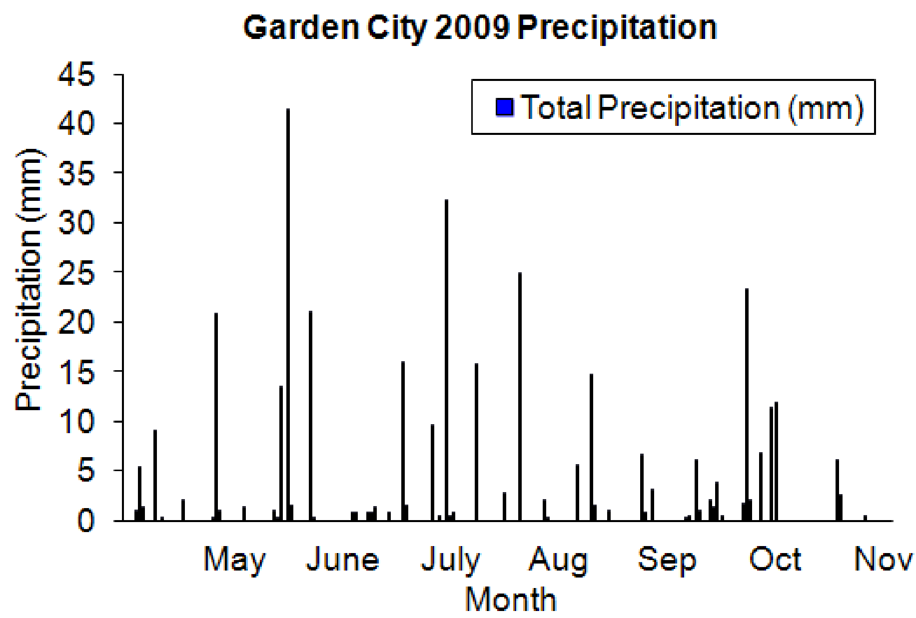

Figure 1.11. Total precipitation (mm) at Garden City, KS 2009.

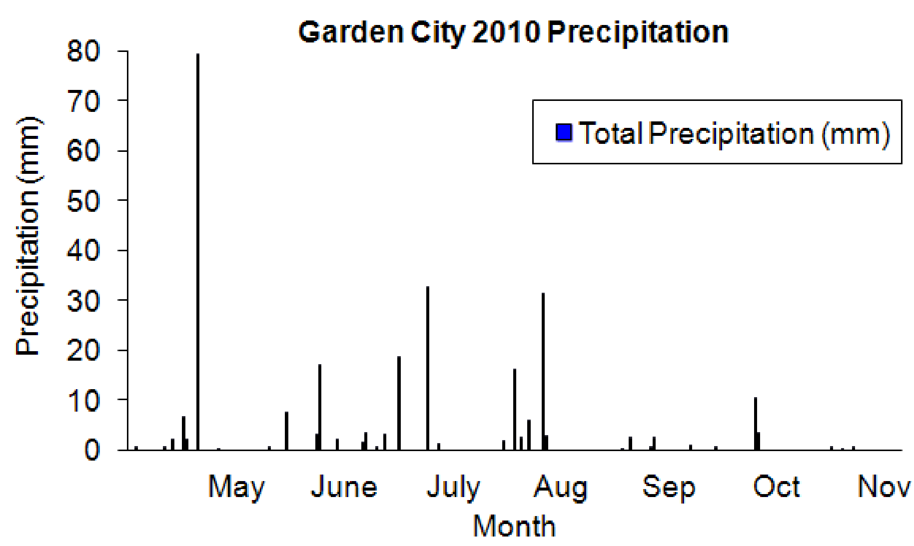

Figure 1.12. Total precipitation (mm) at Garden City KS 2010.

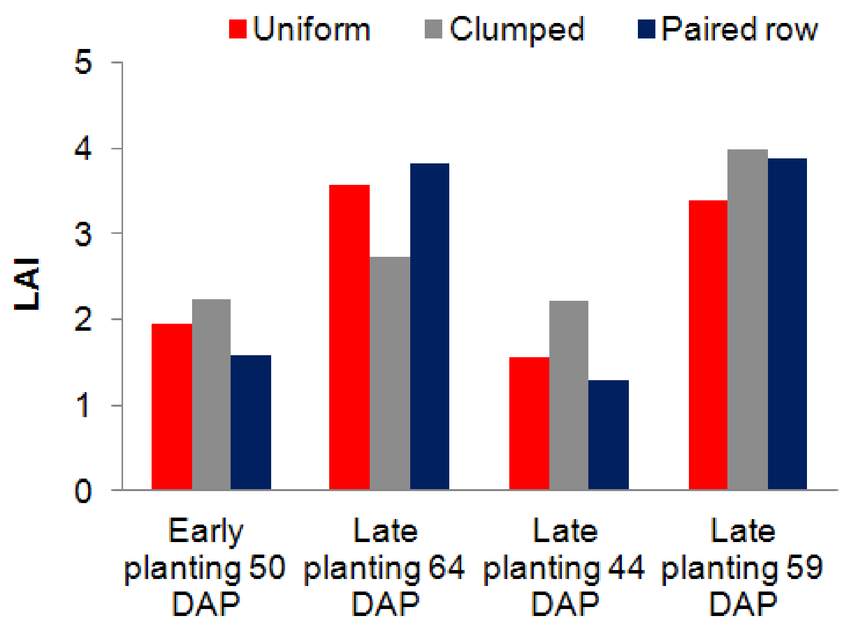

Figure 1.13. Effect of planting geometry on LAI at Colby, KS 2009 & 2010

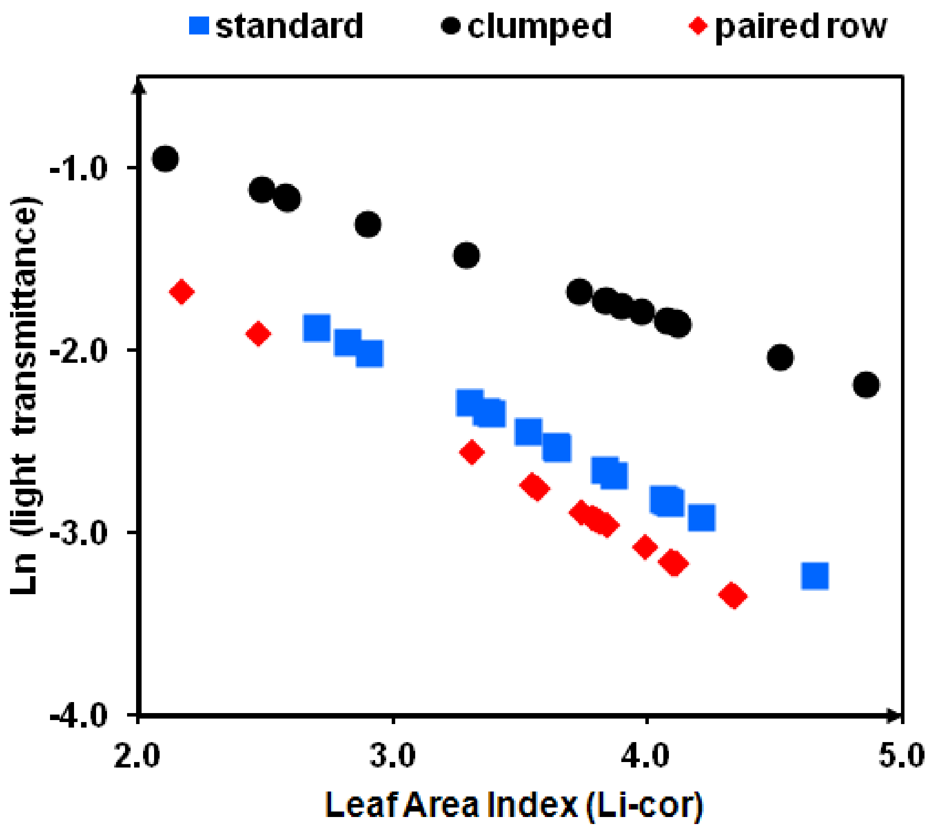

Figure 1.14. Effect of planting geometry and leaf area index (LAI) on light transmittance (ln-transformed)

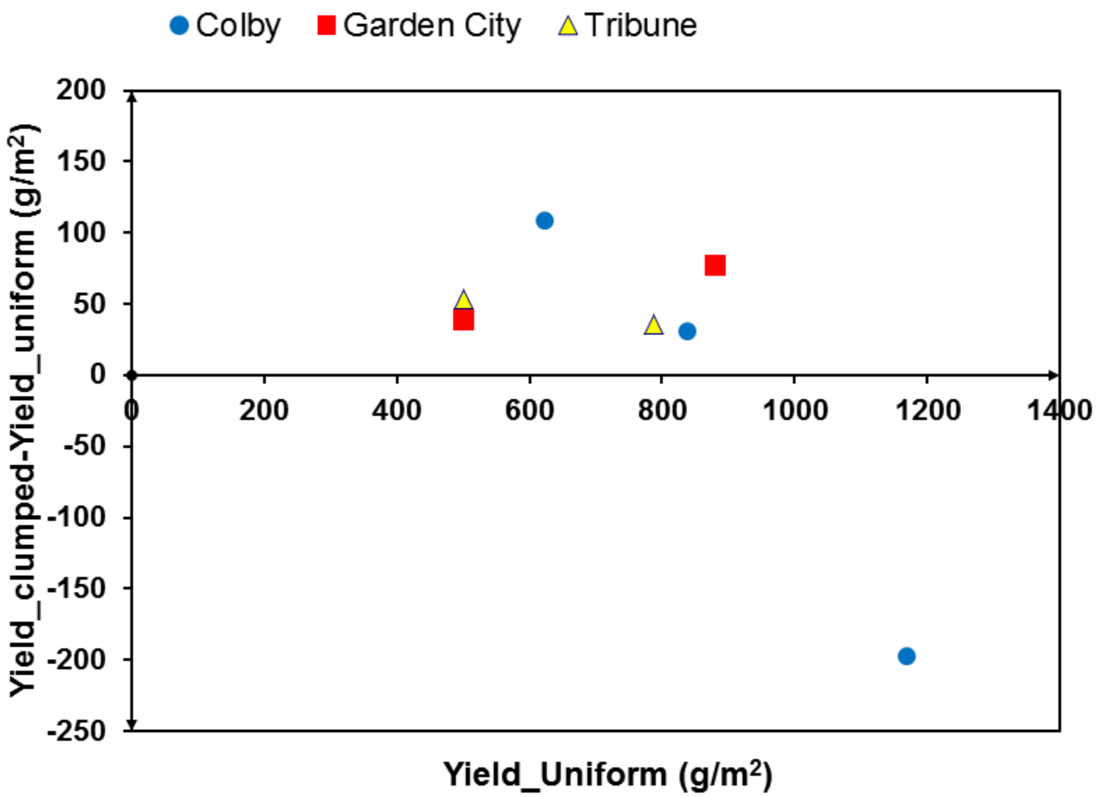

Figure 1.15. Yield advantage of clumped planting geometry over uniform planting geometry from all the three locations

┼Locations shown in this plot are not statistically compared.

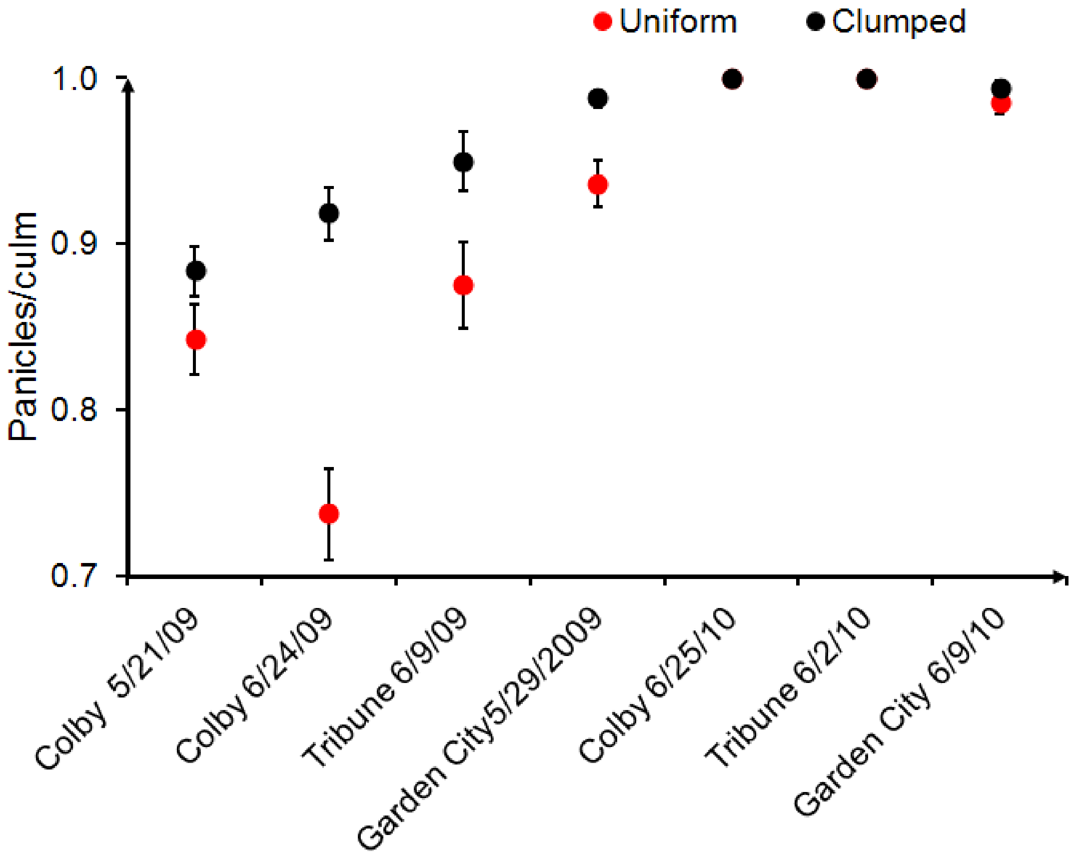

Figure 1.16. Effects of clumped and uniform planting geometries on fraction of fertile culms for seven growing environments.

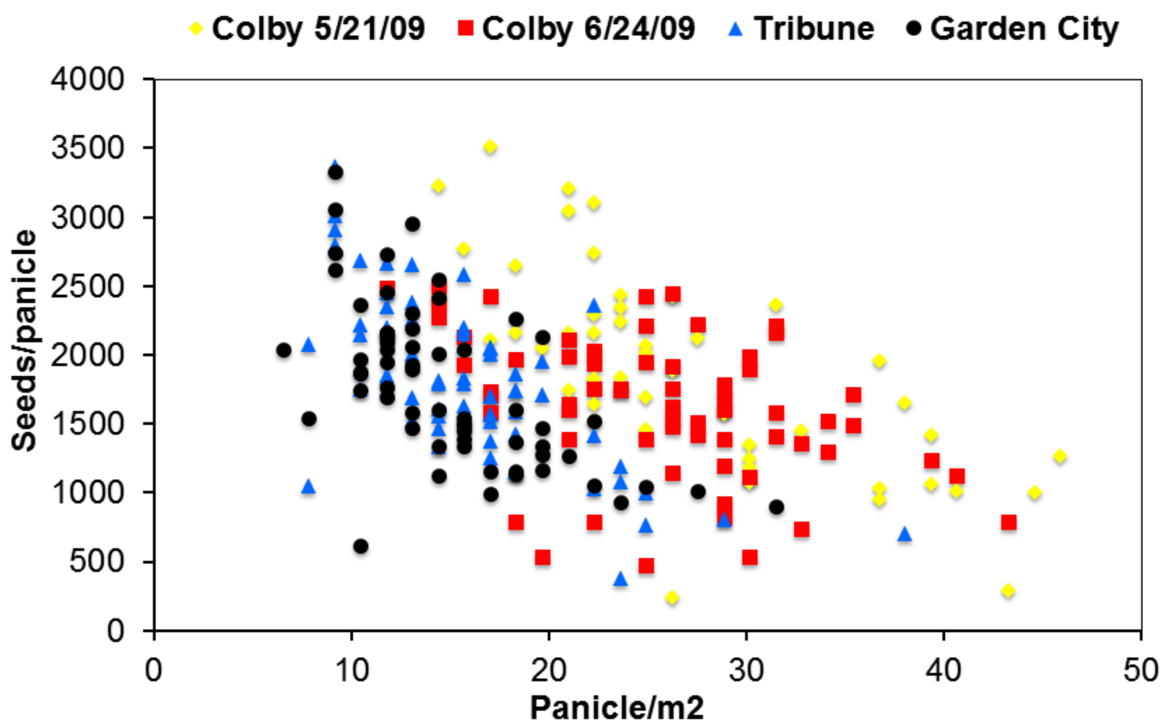

Figure 1.17. Effects of number of panicles on number of seeds per panicles

Table 1.1. Yield and yield components as affected by planting geometry (g), hybrid (h) and seeding rate (pp) at Colby early planting date, Kansas, 2009

		Type III mean squares					
Sources of variation	df	Yield	Culms/m^2	Panicles /culm	Seeds/panicle Tall culms	Seeds/panicle Short culms	200 seed weight
Replication	3	225541	20	0.014	306342	137513	0.023
Geometry	2	302915	211	0.015	2309270	562563	0.432
Hybrid	1	906511*	299	0.076	1643222	27714	0.043
Seeding rate	3	143074	114	0.019	453900	347556	0.160
Geometry×Hybrid	2	51853	23	0.022	432744	188014	0.369*
Hybrid ×Seeding rate	3	64901	15	0.010	1047708*	260472	0.279*
Geometry ×Seeding rate	6	31119	83*	0.034*	449571	147617	0.097
Geometry×Hybrid×Seeding rate	6	137669	61	0.020*	574659	325698	0.154
┼MSE	55	73218	29	0.005	251885	222425	0.058

* Probability of greater F value at this effect <0.05,
┼ Main effects were tested using g*h*pp as error term; interaction effects were tested using MSE as error term

Table 1.2. Yield and yield components as affected by planting geometry (g), hybrid (h) and seeding rate (pp) at Colby late planting date, Kansas, 2009

		Type III mean squares					
Sources of variation	**df**	**Yield g/m^2**	**Culms/m^2**	**Panicles /culm**	**Seeds/panicle Tall culms**	**Seeds/panicle Short culms**	**200 seed weight**
Replication	3	135281	97	0.018	97828	353146	0.227
Geometry	2	183709*	33	0.407*	53840	16487	0.106
Hybrid	1	8260	152*	0.047	1900515*	82122	2.317*
Seeding rate	3	86946	93*	0.070*	1374970*	333297*	0.944*
Geometry×Hybrid	2	62215	149*	0.047	30269	10158	0.192*
Hybrid ×Seeding rate	3	234971*	116	0.038	167090	396037*	0.018
Geometry ×Seeding rate	6	52879	47	0.010	232623	239305*	0.139*
Geometry×Hybrid×Seeding rate	6	38577	17	0.011	138588	50762	0.031
†MSE	67	28385	49	0.012	130989	110194	0.044

* Probability of greater F value at this effect <0.05,
† Main effects were tested using g*h*pp as error term; interaction effects were tested using MSE as error term

Table 1.3. Yield and yield components as affected by planting geometry (g), hybrid (h) and seeding rate (pp) at Tribune, Kansas, 2009

		Type III mean squares					
Sources of variation	**df**	**Yield g/m^2**	**Culms $/m^2$**	**Panicles /culm**	**Seeds/panicle Tall culms**	**Seeds/panicle Short culms**	**200 seed weight**
Replication	3	5307	7	0.01	253553	1122	1.17
Geometry	1	45975	2	0.09*	315470	45280	0.41
Hybrid	1	6950	308*	0.01	2827308*	62385	0.01
Seeding rate	3	7780	299*	0.12*	3364091*	18912	0.38
Geometry×Hybrid	1	11610	10	0.00	6156	8526	0.55
Hybrid ×Seeding rate	3	37891	77*	0.00	277727	1524	0.49
Geometry ×Seeding rate	3	31107	5	0.01260	289913	14000	0.33
Geometry×Hybrid×Seeding rate	3	23904	25	0.00120	137269	7076	0.56
†MSE	45	15714	10	0.01	115809	13007	0.43

* Probability of greater F value at this effect <0.05,
† Main effects were tested using g*h*pp as error term; interaction were effects tested using MSE as error term

Table 1.4. Yield and yield components as affected by planting geometry (g), hybrid (h) and seeding rate (pp) at Garden City, Kansas, 2009

		Type III mean squares					
Sources of variation	**df**	**Yield g/m^2**	**Culms $/m^2$**	**Panicles /culm**	**Seeds/panicle Tall culms**	**Seeds/ panicle Short culms**	**200 seed weight**
Replication	3	60674	34.6	0.004	295663	19509	0.248
Geometry	1	23532	67.3	0.043*	249960	4247	0.148
Hybrid	1	82927	337.6*	0.001	6515828*	8342	0.175
Seeding rate	3	26829	59.6	0.005	595811	29641	0.217
Geometry×Hybrid	1	4178	84.4	0.002	1204889*	41481	0.601*
Hybrid ×Seeding rate	3	17329	14.6	0.004	70334	20072	0.122
Geometry ×Seeding rate	3	7374	7.8	0.001	134906	57382*	0.051
Geometry×Hybrid× Seeding rate	3	18706	8.7	0.003	129286	43710	0.043
┼MSE	43	20554	15.66	0.004	139328	19123	0.080

* Probability of greater F value at this effect <0.05,
┼ Main effects tested using g*h*pp as error term; interacting effects tested using MSE as error term

Table 1.5. Yield and yield components as affected by planting geometry (g), hybrid (h) and seeding rate (pp) at Colby, Kansas, 2010

		Type III mean squares					
Sources of variation	df	Yield g/m^2	Culms/m^2	Panicles/culm	Seeds/panicle Tall culms	Seeds/panicle Short culms	200 seed weight
Replication	3	33980	29.9	0	367199	27417	0.530
Geometry	2	9924	1217.5*	0	1406961*	63372	0.653*
Hybrid	1	47198	271.4*	0	4394808*	103820*	0.000
Seeding rate	3	18247	350.1*	0	1402237*	67434	0.082
Geometry×Hybrid	2	11705	43.8	0	19427	7788	0.103
Hybrid ×Seeding rate	3	11292	29.1	0	111504	13250	0.069
Geometry ×Seeding rate	6	21482	28.5	0	258632	24972	0.056
Geometry×Hybrid×Seeding rate	6	17425	48.5	0	283664	24534	0.175*
┼MSE	69	19068	29.8	0	147063	26205	0.041

* Probability of greater F value at this effect <0.05,
┼ Main effects were tested using g*h*pp as error term; interaction effects were tested using MSE as error term

Table 1.6. Yield and yield components as affected by planting geometry (g), hybrid (h) and seeding rate (pp) at Tribune, Kansas, 2010

		Type III mean squares					
Sources of variation	df	Yield g/m^2	Culms/m^2	Panicles/culm	Seeds/panicle Tall culms	Seeds/panicle Short culms	200 seed weight
Replication	3	298212	33.22	0	53127	22486	2.8574
Geometry	1	23532	0.43	0	20850	28105	0.8372
Hybrid	1	82927	6.89	0	96353	36978	0.1208
Seeding rate	3	26829	172.01*	0	2128344*	29947	0.4880
Geometry×Hybrid	1	2662	6.89	0	69104	17881	0.0086
Hybrid ×Seeding rate	3	84190	22.32	0	203944*	28865	0.2356
Geometry ×Seeding rate	3	3905	8.83	0	72981	41090	0.4512
Geometry×Hybrid×Seeding rate	3	26881	7.82	0	48788	35785	0.2439
┼MSE	45	32883	9.27	0	73519	20820	0.2518

* Probability of greater F value at this effect <0.05,
┼ Main effects were tested using g*h*pp as error term; interaction effects were tested using MSE as error term

Table 1.7. Yield and yield components as affected by planting geometry (g), hybrid (h) and seeding rate (pp) at Garden City, Kansas, 2010

		Type III mean squares					
Sources of variation	df	Yield g/m^2	Culms/m^2	Panicles/culm	Seeds/panicle Tall culms	Seeds/panicle Short culms	200 seed weight
Replication	3	103229	27.941	0.004	12426	40.55	0.07
Geometry	1	99749	25.860	0.001	1906706*	42.85	0.30
Hybrid	1	144	16.819	0.001	3387352*	41.95	5.91*
Seeding rate	3	130325*	76.451*	0.000	2182947*	39.27	0.20
Geometry×Hybrid	1	25001	29.305	0.002	877501*	41.91	0.02
Hybrid ×Seeding rate	3	39928	12.082	0.001	136338	37.72	0.03
Geometry ×Seeding rate	3	133120*	24.282*	0.001	180541	40.73	0.12
Geometry×Hybrid×Seeding rate	3	14818	8.782	0.001	67209	37.84	0.07
┼MSE	45	18831	7.906	0.001	92708	38.69	0.05

* Probability of greater F value at this effect <0.05,
┼ Main effects were tested using g*h*pp as error term; interaction effects were tested using MSE as error term

Table 1.8. Mean values of yield and yield components as affected by planting geometries in 2009

		Yield (g/m^2)	Culms/m^2	Panicles/culm	Seeds/panicle Tall culms	Seeds/panicle Short culms	200 seed weight
Colby early planting	Uniform	1171.88a	27.78a	0.84a	2490.85a	665.87a	4.20a
	Clumped	973.67a	35.85a	0.88a	1655.55a	628.87a	4.40a
	Paired row	1126.59a	27.61a	0.79a	2369.26a	443.49a	4.31a
		(371)	(8)	(0.14)	(758)	(571)	(0.392)
Colby late planting	Uniform	625.09b	30.47a	0.74b	1921.7a	278.06a	3.03a
	Clumped	772.94a	32.4a	0.92a	1897.5a	322.19a	3.13a
	Paired row	631.51b	31.95a	0.71b	1972a	307.1a	2.99a
		(196)	(4.08)	(0.104)	(372)	(225)	(0.176)
Tribune	Uniform	500.37a	17.96a	0.87b	1850.4a	88.82a	3.45a
	Clumped	553.97a	17.59a	0.95a	1990.8a	31.35a	3.61a
		(155)	(5)	(0.035)	(370)	(84)	(0.75)
Garden City	Uniform	501.16a	16.65a	0.94b	1827.6a	46.64a	3.65a
	Clumped	540.08a	14.60a	0.99a	1941.6a	61.15a	3.75a
		(137)	(2.95)	(0.055)	(360)	(209)	(0.21)

┼ Comparisons were done within locations. Mean separation was done by using DMRT. Numbers followed by same letters were not significantly different at $P<0.05$. ± Numbers in parentheses are RMS of (g*h*pp) interaction

Table 1.9. Mean values of yield and yield components as affected by planting geometries in 2010

		Yield (g/m^2)	Culms/m^2	Panicles /culm	Seeds/panicle Tall culms	Seeds/panicle Short culms	200 seed weight
Colby	Uniform	840.4a	20.55b	1a	1851.51a	372.6a	4.21a
	Clumped	869.7a	31.17a	1a	1556.40b	294.1a	3.98b
	Paired raw	872.1a	20.42b	1a	1961.99b	353.7a	4.25a
		(132)	(6.96)	(0)	(533)	(157)	(0.148)
Tribune	Uniform	786.05a	17.55a	1a	2102.1a	20.06a	3.93a
	Clumped	829.5a	17.39a	1a	2138.2a	52.89a	4.16a
		(164)	(2.8)	(0)	(221)	(189)	(0.49)
Garden city	Uniform	876.81a	16.32a	0.99a	2102.44b	1.68a	4.85a
	Clumped	955.77a	15.05a	0.99a	2447.65a	0.05a	4.99a
		(69)	(2.96)	(0.032)	(259)	(6.15)	(0.26)

┼ Comparisons were done within locations. Mean separation was done by using DMRT. Numbers followed by same letters were not significantly different at $P<0.05$. ± Numbers in parentheses are RMS of g*h*pp interaction

Table 1.10. Mean values of yield and yield components as affected by hybrid maturity in 2009

		Yield (g/m^2)	Culms/m^2	Panicles /culm	Seeds/panicle Tall culms	Seeds/panicle Short culms	200 seed weight
Colby early planting	Pioneer 87G57	985.30b	28.53a	0.87a	1993.79a	613.27a	4.3a
	Pioneer 85G46	1196.87a	31.88a	0.81a	2380.19a	557.75a	4.31a
		(371)	(8)	(0.14)	(758)	(571)	(0.392)
Colby late planting	Pioneer 87G57	682.91a	30.35a	0.81a	1780.97b	274.73a	3.21a
	Pioneer 85G46	669.01a	32.86b	0.77a	2079.65a	329.65a	2.89b
		(196)	(4.08)	(0.104)	(372)	(225)	(0.176)
Tribune	DKS36-16	516.75a	19.97a	0.92a	1710.43b	93.14a	3.52a
	DKS-44-20	537.59a	15.58b	0.9a	2130.80a	29.10b	3.55a
		(155)	(5)	(0.035)	(370)	(84)	(0.75)
Garden city	DKS36-16	483.44a	17.92a	0.97a	1557.24b	0.02a	3.64a
	DKS-44-20	557.80a	13.33b	0.96a	2211.94a	0.02a	3.75a
		(137)	(2.95)	(0.055)	(360)	(209)	(0.21)

┼ Comparisons were done within locations. Mean separation was done by using DMRT. Numbers followed by same letters were not significant different ($P<0.05$). ± Numbers in parentheses are RMS of (g*h*pp) interaction

Table 1.11. Mean values of yield and yield components as affected by hybrid maturity in 2010.

		Yield (g/m^2)	Culms/ m^2	Panicles /culm	Seeds/panicle Tall culms	Seeds/panicle Short culms	200 seed weight
Colby	Pioneer 87G57	838.6a	25.72a	1a	1576.01b	350.1b	4.1a
	Pioneer 85G46	882.9a	22.36b	1a	2003.93a	310.3a	4.1a
		(132)	(6.96)	(0)	(533)	(157)	(0.148)
Tribune	DKS36-16	786.53a	17.14a	1a	2081.38a	16.94a	4.09a
	DKS-44-20	829.01a	17.8a	1a	2158.99a	56.1a	4a
		(164)	(2.8)	(0)	(221)	(189)	(0.49)
Garden City	DKS36-16	917.78a	15.17a	0.99a	2505.11a	0.05a	4.61b
	DKS-44-20	914.79a	16.2a	0.99a	2044.99b	1.67a	5.22a
		(69)	(2.96)	(0.032)	(259)	(6.15)	(0.26)

┼ Comparisons were done within locations only. Mean separation was done by using DMRT. Numbers followed by same letters were not significant different ($P<0.05$). ± Numbers in parentheses are RMS of (g*h*pp) interaction

Table 1.12. Mean values of yield and yield components as affected by seeding rate in 2009

	Seeds/ha	Yield (g/m^2)	Culms/m^2	Panicles/culm	Seeds/panicle Tall culms	Seeds/panicle Short culms	200 seed weight
Colby early planting	24700	1,189a	23.91a	0.94a	2724.86a	424.9a	4.33a
	98800	1,176a	29.09a	0.85a	2217.95a	474.05a	4.25a
	172,900	1,070a	30.70a	0.81a	2212.47a	671.68a	4.25a
	247000	986a	33.36a	0.81a	1946.01a	672.3a	4.39a
		(371)	(8)	(0.14)	(758)	(571)	(0.392)
Colby late planting	24700	612.49a	28.87c	0.82a	2044.10a	188.21b	2.76c
	98800	645.20a	31.5b	0.73b	2134.80a	207.89b	3.01b
	172,900	751.19a	32.75ab	0.76ab	1966.90a	367.68ab	3.20a
	247000	689.68a	33.3a	0.84a	1584.92b	435.48a	3.21a
		(196)	(4.08)	(0.104)	(372)	(225)	(0.176)
Tribune	24700	525a	11.73c	1.00a	2487.77a	27.94a	3.43a
	98800	556a	18.78b	0.85b	1938.62b	45.05a	3.47a
	172,900	525a	18.62b	0.83b	1890.30b	107.84a	3.46a
	247000	502a	21.98a	0.97a	1365.77c	59.44a	3.76a
		(155)	(5)	(0.035)	(370)	(84)	(0.75)

Garden City	24700	473.75a	13.04a	0.98a	2067.00a	0.01a	3.56a
	98800	557.53a	15.26a	0.97a	2012.75a	0.03a	3.84a
	172,900	555.29a	17.06a	0.94a	1775.94a	0.01a	3.66 a
	247000	500.25a	17.14a	0.96a	1669.10a	0.02a	3.73 aa
		(137)	(2.95)	(0.055)	(360)	(209)	(0.21)

┼ Comparisons were done within locations only. Mean separation was done by using DMRT. Numbers followed by same letters were not significant different ($P<0.05$). ± Numbers in parentheses are RMS of (g*h*pp) interaction

Table 1.13. Mean values of yield and yield components as affected by seeding rate in 2010

	Seeds/ha	Yield (g/m^2)	Culms/m^2	Panicles/culm	Seeds/panicle Tall culms	Seeds/panicle Short culms	200 seed weight
Colby	24700	879a	20c	1a	2112a	361.8a	4.22a
	98800	845a	22bc	1a	1825b	337.8a	4.16a
	172,900	830a	26ab	1a	1668b	371.4a	4.09a
	247000	889a	28a	1a	1555b	252.6a	4.12a
		(132)	(6.96)	(0)	(533)	(157)	(0.148)
Tribune	24700	810a	13.21c	1a	2560.85a	2.91a	4.28a
	98800	843a	17.39b	1a	2208.09b	82.35a	3.91a
	172,900	810a	18.13b	1a	2025.40b	51.53a	4.08a
	247000	769a	21.16a	1a	1686.40c	10.94a	3.92a
		(164)	(2.8)	(0)	(221)	(189)	(0.49)
Garden City	24700	909b	12.80c	0.99a	2715.06a	0.01a	5.07a
	98800	1046a	16.32ab	0.99a	2408.63ab	3.21a	4.92a
	172,900	852b	15.58b	1a	2117.35bc	0.05a	4.82a
	247000	858b	18.04a	0.99a	1859.14c	0.18a	4.87a
		(69)	(2.96)	(0.032)	(259)	(6.15)	(0.26)

† Comparisons were done within locations only. Mean separation was done by using DMRT. Numbers followed by same letters were not significant different (P<0.05). ± Numbers in parentheses are RMS of (g*h*pp) interaction.

Table 1.14. Effect of planting geometry (g), hybrid (h), and seeding rate (pp) on light transmittance (T) and Leaf area Index (LAI) at Colby, KS, 2009.

Sources of variation		Light transmittance (T)	Leaf area Index (LAI)
Hybrid	Pioneer 87G57	0.160a	3.29a
	Pioneer 85G46	0.132a	3.47a
Geometry	Uniform	0.117b	3.25a
	Clumped	0.212a	3.41a
	Paired raw	0.110b	3.48a
Seeding rate	24700 seeds/ha	0.264a	2.84b
	98800 seeds/ha	0.156b	3.65a
	172,900 seeds/ha	0.099c	3.61a
	247000 seeds/ha	0.076c	3.40a

┼Mean separation was done using DMRT, Numbers followed by same letters were not significant different (P<0.05).

Chapter 2- Physiological Characteristics and Growth of Two Grain Sorghum Hybrids Varying in Maturity

Abstract

Although agronomic characteristics of hybrids varying in maturity have been widely studied, little information exists concerning their physiological differences. Therefore, the objective of the greenhouse study was to determine if stomatal resistance, leaf temperature, and leaf chlorophyll content differed between two DeKalb grain sorghum [*Sorghum bicolor* (L.) Moench] hybrids. They were DKS 36-16 and DKS 44-20, of medium-early and medium maturity, respectively, when grown under field conditions in Kansas. Seeds were planted in a greenhouse in pots (23 cm diam.; 21.5 cm tall) of soil (33% sand; 51% silt; 16% clay). Stomatal resistance and leaf temperature were measured 55 days after planting with a Decagon Devices (Pullman, WA) diffusion porometer, and chlorophyll content was measured 119 days after planting with a Konica Minolta (Osaka, Japan) SPAD chlorophyll meter. Height was measured 46 and 60 days after planting. Dry weight was determined at harvest, 152 days after planting. Average stomatal resistances (and standard error; n = 24) of DKS 36-16 and DKS 44-20 were 929±118 and 936±127 s/m, respectively. Average leaf temperatures of DKS 36-16 and DKS 44-20 were 24.8±0.3 and 25.0±0.2 ^{o}C. Average SPAD units of DKS 36-16 and DKS 44-20 were 42.6±1.5 and 43.0±2.2. Average plant height 46 days after planting for DKS 36-16 and DKS 44-20 was 28.7±0.7 and 29.4±0.7 cm. Average height 60 days after planting for DKS 36-16 and DKS 44-20 was 47.0±1.9 and 46.0±2.1 cm. At harvest, dry weight per plant of DKS 36-16 and DKS 44-20 was 5.8±0.6 and 6.3±0.8 g. The two hybrids did

not differ in stomatal resistance, leaf temperature, chlorophyll content, height, and dry weight. Their difference in maturity was not evident under the greenhouse conditions. Future work needs to show if hybrids of different maturities vary in physiological characteristics.

Introduction

It is well known that hybrids of the same crop have different maturities. Early-maturing hybrids take a shorter time to reach maturity than late-maturing hybrids. We here define maturity as "readiness for harvest" (Barnes and Beard, 1992). Breeders select for earliness or lateness, and, thus, the time to maturity is genetically determined. However, the reasons for varying maturity are poorly understood. Plant physiologists have known for centuries how crops grow (Day, 1969). Plants depend upon carbon dioxide and water for photosynthesis and nutrients for growth. Even though we know much about how plants grow, we know little of why (Steward, 1969, p. 27). This is particularly true for maturity. Why is one hybrid earlier than another?

Because essentially no experiments have been done comparing the physiological characteristics of hybrids varying in maturity, we grew two sorghum hybrids, one medium-early and one medium in maturity, in a greenhouse and measured stomatal resistance, leaf temperature and chlorophyll content. In addition, we measured growth (height, number of tillers, and weight at harvest). The hypothesis was that early-maturing hybrids might grow faster, and, because of their faster, earlier growth, they may have a lower stomatal resistance than later-maturing hybrids. Stomatal resistance is the reciprocal of stomatal conductance, and stomatal conductance and growth are directly related. In general, the more open the stomata (i.e., the higher the stomatal conductance), the faster can be the rate of growth. Open stomata take up more carbon dioxide for photosynthesis and subsequent growth than closed stomata. Also, leaf temperature is an indication of stomatal opening. If stomata are open, transpirational cooling occurs, and leaf temperature is cool. Conversely, when stomata are closed, transpiration is reduced, and leaf temperature increases (Kirkham, 2011, p. 119). We measured chlorophyll content with a chlorophyll meter to document any differences in leaf color between the two hybrids.

Materials and Methods

The experimental plants were two DeKalb hybrids of grain sorghum [*Sorghum bicolor* (L.) Moench], DKS 36-16 and DKS 44-20, which were grown under greenhouse conditions in Manhattan, Kansas, USA (39^{o}08' N; 96^{o}37' W; 314 m ASL). When grown under field conditions in western Kansas, DKS 36-16 is of medium-early maturity and DKS 44-20 is of medium maturity.

On 17 January 2011, 48 black plastic pots (23 cm diameter; 21.5 cm tall; 5 drainage holes per pot) were filled with a silt-loam soil obtained from Britt's Garden Acres, 1400 S. Scenic Drive, Manhattan, Kansas, which is located near the Manhattan Regional Airport, southwest of Manhattan. (As described later, this soil turned out to be a poor medium for growth. It crusted and cracked, causing water to flow through the cracks. The surface dried out, and the soil in the bottom of the pots remained wet.) On 18 January 2011, the soil in each pot was watered with 230 mL of a fertilizer solution (Miracle-Gro, Marysville, OH) (15% total nitrogen; 30% P_2O_5; 15% K_2O; 0.05% Cu; 0.10% Fe as chelated iron; 0.05% Mn; and 0.05% Zn), mixed at a concentration of 14 grams fertilizer per 3.8 L of tap water. On the same day (18 Jan. 2011), six samples of the soil were submitted to the Soil Testing Laboratory at Kansas State University for analysis. Three of the samples were the unfertilized soil, and three of the samples were the soil after fertilization.

Pots were watered to pot capacity before planting. On 3 Feb. 2011, about 6 seeds were planted in each pot. DKS 36-16 was planted in 24 pots, and DKS 44-20 was planted in 24 pots. None of the plants emerged due to the poor soil. Seeds then were pre-germinated in Petri dishes. After radicle emergence, which took two days, about 20 pre-germinated seeds were transplanted on 15 Feb. into each pot at the 2-cm depth. By 20 Feb. 2011, 3 to 17 plants per pot had emerged. On 4 March 2011, plants were in the three-leaf stage. On 7 March 2011, plants were thinned to 2 plants per pot. On 22 March 2011, a second thinning was done, leaving one plant per pot. In this paper, the first planting date, 3 Feb. 2011, is used to calculate days after planting.

On 8 February 2011, the north and south walls of the greenhouse, which were glass, were covered with black plastic to prevent light from coming into the greenhouse from the adjacent greenhouse rooms. These rooms had lights on 24 hours a day.

The experiment was originally designed to see the effect of a pre-flowering and a post-flowering drought on the plants, and there were going to be four replications per treatment. Consequently, on 15 and 22 March 2011, 1000 mL water was added to each pot that was designated for the post-flowering drought treatment. No water was added to pots designated for the pre-flowering drought treatment. However, after 22 March 2011, differential watering of the pots stopped. This was because the plants developed slowly in the soil, which, as noted, was a poor medium for growth. The soil crusted and cracked on the surface of the pots, while the soil below the surface did not dry out, as determined by regular measurements of soil water content using a 20-cm long probe that monitored moisture (Hold All Moisture Meter, made in China and supplied to Wal-Mart Stores, Inc. by American Tack and Hardware Co., Inc., Monsey, NY). The soil in the bottom half of the pots remained wet. After 22 March 2011, all pots were watered the same until the end of the experiment. On 4 and 12 April 2011, 500 mL water was added to all pots. On 26 May and 6 June, 1000 mL was added to all pots.

Throughout the experiment, temperature and relative humidity were recorded every hour by a data logger (Model HOBO RH/Temp, Part Number H08-003-02, Onset Computer Corporation, Bourne, MA). Temperature in the greenhouse was set at 27 ^{o}C during the day and 18 ^{o}C during the night. Relative humidity was not controlled and varied between about 25 and 60 %.

On 8 March 2011, Marathon insecticide (imidaclopridwas applied to the soil to control thrips. On 31 March 2011, Pylon miticide-insecticide (chlorfenapyr) [4-bromo-2-(4-chlorophenyl)-1-ethoxymethyl-5-trifluoromethytl-*1H*-pyrrole-3-carbonitrile] was sprayed on the leaves, again to control thrips.

Plant height was measured from the soil surface to the tip of the youngest fully expanded leaf. The plant was extended along a ruler to make the measurement. Plant height of both plants in each pot was taken on two consecutive days in March: 21 March (replication three; 46 days after planting) and 22 March (replications one, two, and four; 47 days after planting). On 4 April 2011 (60 days after planting and 13 days after the second thinning), height was taken of each plant in each pot. On 30 March 2011 (55 days after planting), stomatal resistance was measured on the abaxial (bottom) surface of one recently matured leaf in each pot using a steady-state diffusion porometer (Model SC-1;

Decagon Devices, Pullman, WA). The instrument also measures leaf temperature, and it was recorded along with stomatal resistance. Chlorophyll content was measured 119 days after planting with a Konica Minolta (Osaka, Japan) SPAD chlorophyll meter. (SPAD stands for Special Products Analysis Division, a division of Minolta.) Tillers were counted on 27 May 2011 (113 days after planting) and at harvest on 5 July 2012 (152 days after planting). Plants were harvested over two consecutive days: 5 July (replications two and three) and 6 July (replications one and four). Dry weight was determined by drying the plants to constant weight in a plant-drying oven for one week. Dry weight was measured on 14 July 2012.

The experiment was set up as a randomized complete block with four blocks. Because no differential watering regime was established due to the soil that remained wet in the bottom half of the pots, there were 24 plants of each hybrid for each measurement (n = 24). Means and standard errors are shown in the tables.

Results and Discussion

The analyses of the soil samples are given in Table 1. In the six samples analyzed (three from the unfertilized soil and three from the fertilized soil), percent sand varied from 20 to 66%, percent silt from 24 to 64%, and percent clay from 10 to 18%. The high variability in the analyses of sand, silt, and clay showed that the soil was poorly mixed and probably a mixture of different types of soils, so that it could not be categorized taxonomically (M.D. Ransom, personal communication, 26 March 2012). As expected, the fertilized soil had higher amounts of N, P, K, and essential trace elements (Cu, Fe, Mn, and Zn) than the unfertilized soil.

Height of the two hybrids did not differ significantly (Table 2). Also, tillers, fresh weight, and dry weight at harvest did not differ significantly between the two hybrids (Table 3). The tiller count on 27 May (113 days after planting) showed only two plants of each hybrid had tillers. DKS 36-16 had one plant with one tiller and another plant with three tillers. DKS 44-20 had two plants, each with one tiller. But, by harvest, although not significant, there was a tendency for the medium-maturing hybrid (DKS 44-20) to produce more tillers and to have more tillers per plant, when tillers appeared, than the medium-early maturing hybrid (DKS 36-16). The minimum number of tillers per plant at harvest on the medium maturing hybrid was three, and the minimum number of tillers per plant at harvest on the medium-early maturing hybrid was one (Table 3). The medium maturing hybrid, therefore, appeared to be more prolific.

On 27 May, a plant of DKS 44-20 (medium-maturing hybrid) was in the boot stage, while all other plants were still in the vegetative stage. At harvest, one plant of DKS 36-16 had a panicle and three plants of DKS 44-20 had panicles. Because growth was poor in the soil, the plants did not reach maturity and no grain could be harvested. When the two hybrids were grown in the field under dryland conditions in western Kansas in 2009 and 2010, the medium-maturing hybrid (DKS 44-20) yielded more seeds per panicle than the medium-early maturing hybrid (DKS 36-16) (Pidaran, 2012). These two years had higher-than-average rainfall, and the 2010 planting date was delayed due to fields that were too wet to plant.

Under dryland conditions in western Kansas over a three-year period (2005, 2006, and 2007), Frank et al. (2012) found a linear, inverse relationship between ear population and dry stover yield of 18 hybrids of corn (*Zea mays* L.) varying in relative maturity from 98 to 118 days. The later maturing corn hybrids produced more vegetative matter, and less grain, than the early maturing hybrids. They did not measure dry stover yield under irrigated conditions. Under irrigated conditions, hybrid maturity did not affect grain yield. Frank et al. (2012) cite other research for corn that shows, under favorable conditions, there is no detectable association of yield with hybrid maturity. Frank et al. (2012) found under irrigated conditions that tiller population was not significantly different among hybrids. However, under dryland conditions, they found a linear, inverse relation between ear population and tiller population. Late-maturing hybrids produced more tillers than early-maturing hybrids, and many of the tillers on the late-maturing hybrids were barren. The tendency for a higher number of tillers to appear on the medium-maturing sorghum hybrid compared to the medium-early hybrid agrees with the data of Frank et al. (2012) for corn hybrids varying in maturity and grown under dryland conditions. Sorghum is usually grown under dryland conditions, so the results of Frank et al. for dryland corn would be relevant for dryland sorghum, too.

Stomatal resistance, leaf temperature, and chlorophyll content did not differ between the two hybrids (Table 4). There was only a tendency for the medium-maturing hybrid to have slightly higher stomatal resistances than the medium-early maturing hybrid. Also, the medium-maturing hybrid tended to have warmer leaf temperatures compared to the medium-early maturing hybrid, which agreed with the slightly higher stomatal resistances of the medium-maturing hybrid. The measurements made with the chlorophyll meter showed that the leaves were green. The SPAD units measured in this experiment agreed with those of Frank et al. (2012), who found that for dryland corn hybrids grown in the field in western Kansas, the mean SPAD units and standard error were 46.2 ± 0.6.

Conclusion

In conclusion, the hypothesis of the experiment could not be validated, because the plants did not grow well in the poor soil. Future research will need to be done to determine if hybrids varying in maturity have different physiological characteristics. Experiments need to be done under well-watered and dry conditions. The physiological characteristics might not vary under well-watered conditions, but they may be evident under drought. These studies should focus on stomatal resistance. While it appears desirable to have an early-maturing hybrid with a low stomatal resistance so it grows fast, this same hybrid, after establishment, should be able to switch its stomatal resistance so that it is high. If conditions become dry, as often happens during hot, summer months in Kansas, these hybrids, then, would conserve water for later in the growing season, when water is needed for flowering and grain filling.

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Tables

Table 2.1. Chemical and textural analysis of the soil without and with fertilizer. Each value is the mean and standard deviation of three samples.

Property	No fertilizer	Fertilizer
pH	7.7±0.1	7.7±0.0
Mehlich-3 available P, mg kg^{-1}	87.6±2.0	340.0±36.7
Exchangeable K, mg kg^{-1}	362±4.5	1025±130
Ca, mg kg^{-1}	2978±71	2418±40
Mg, mg kg^{-1}	182±8	167±10
Na, mg kg^{-1}	22±1	54±14
Cation exch. cap., $cmol_c$ kg^{-1}	17.4±0.4	16.3±0.6
Total N, g kg^{-1} †	0.11±0.01	0.14±0.01
Total C, g kg^{-1}	0.61±0.16	0.49±0.05
Total N, mg kg^{-1} ‡	886±40	1189±17
Total P, g kg^{-1}	617±36	929±24
Elec. conductivity, mS cm^{-1}	1.6±0.2	2.0±0.1
NH_4-N, mg kg^{-1}	1.6±0.2	335.5±60.0
NO_3-N, mg kg^{-1}	48.2±1.1	54.6±15.8
Organic matter, g kg^{-1}	1.5±0.1	1.5±0.1
Cu, mg kg^{-1}	0.7±0.1	1.5±0.2
Fe, mg kg^{-1}	10.5±0.6	17.2±0.4
Mn, mg kg^{-1}	2.7±0.3	16.3±3.1
Zn, mg kg^{-1}	1.5±0.1	2.6±0.4
Sand, g kg^{-1}	28±14	38±25
Silt, g kg^{-1}	55±13	47±20
Clay, g kg^{-1}	17±1	15±5

† Total N determined using a combustion technique (Model No. CNS 2000, Leco Corp., St. Joseph, Michigan) ‡ Total N determined using a salicylic acid technique

Table 2.2. Height and standard error of two greenhouse-grown DeKalb grain sorghum hybrids varying in maturity. Planting date was 3 Feb. 2011.

	DKS 36-16	DKS 44-20
planting[†]	Medium-early (cm)	Medium (cm)
46-47	28.5±0.7	29.4±0.7
60	47.0±1.9	46.0±2.1

[†] n = 48 for 46-47 days after planting and n = 24 for 60 days after planting

Table 2.3. Tillers, fresh weight, and dry weight at harvest of two greenhouse-grown DeKalb grain sorghum hybrids varying in maturity. Harvest was 5 July and 6 July 2011, 152 and153 days after planting.

Growth Characteristic	DKS 36-16 Medium-early	DKS 44-20 Medium
Tillers, no.[†]	27 (tillers on 10 plants)	29 (tillers on 8 plants)
	Range in tillers/plant: 1-5	Range in tillers/plant: 3-5
Fresh weight/plant, g[‡]	9.8$\pm$1.2	11.5$\pm$1.7
Dry weight/plant, g[‡]	5.8$\pm$0.6	6.3$\pm$0.8

[†] Total number of tillers on 24 plants of each hybrid; 14 DKS 36-16 plants did not have tillers; 16 DKS 44-20 plants did not have tillers

[‡] Mean $\pm$ standard error; n = 24

Table 2.4. Physiological characteristics (stomatal resistance, leaf temperature, and chlorophyll content) of two greenhouse-grown DeKalb grain sorghum hybrids varying in maturity

Physiological characteristic	DKS 36-16 Medium-early	DKS 44-20 Medium
Stomatal resistance, s/m†	929±118	936±127
Leaf temperature, °C †	24.8±0.3	25.0±0.2
Chlorophyll content, SPAD units‡	42.6±1.5	43.0±2.2

† Stomatal resistance and leaf temperature were taken on 30 March 2011, 55 days after planting. Mean ± standard error are given; for stomatal resistance, n = 23 for DKS 36-16 and n = 24 for DKS 44-20, and, for leaf temperature, n = 24 for both hybrids. ‡ Chlorophyll content was determined 2 June 2011, 119 days after planting. Mean ± standard error are given; n = 23 for DKS 36-16 and n = 22 for DKS 44-20.