Skip-Row and Plant Population Effects on Sorghum Grain Yield

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ABSTRACT

In environments with limited rainfall, skip-row configuration (planting one or a group of rows alternated with rows not planted) under rainfed conditions may increase yield of grain sorghum [*Sorghum bicolor (*L.) Moench] due to conservation of soil water between widely-spaced crop rows that is not accessed until late in the growing season. A field study was conducted over 10 site-years in Nebraska from 2005 through 2007 to evaluate effects of row configuration and plant population on grain yield and yield stability. Three row configurations including all rows planted with a 76-cm row spacing (s0), alternate rows planted (s1), and two rows planted alternated with two rows skipped (s2) were evaluated with two plant populations. At the site with the greatest precipitation of 496 mm skip-row configuration reduced grain yield by 20 to 30% compared with s0. At low precipitation sites of 319 mm with larger soil water deficits, grain yield increased 5 and 123% with s1 and s2 compared to s0. The s0 treatment outperformed skip-row configurations when mean yield was above 4.5 Mg ha^{-1}. Skip-row configurations also had greater yield stability than conventional planting. Skip-row configuration will be advantageous to a producer if the total in-season available water (initial total profile water + growing season precipitation) is <675 mm.

Grain sorghum is a major crop produced in the drier cropping areas of the central and southern Great Plains of the United States with <600 mm annual precipitation (Unger and Baumhardt, 1999). This crop can delay development under water stress during vegetative growth stages and can resume growth when water conditions improve (Bennett et al., 1990). This drought avoidance mechanism works well under tropical and subtropical conditions with a long growing season. However, this mechanism of drought resistance may result in poor yield and sometimes total crop failure under prolonged drought, insufficient season length, or severe soil water deficits at critical growth stages (Fukai and Foale, 1988).

Skip-row planting is one strategy suggested for efficient soil water use, improved yield stability, and reduced risk with rainfed grain sorghum production in marginal rainfall regions (McLean et al., 2003; Routley et al., 2003). This strategy is based on the rationale that suppression of early crop growth and the delay in using stored soil water by changing the arrangement of plants in the field may improve grain sorghum water use when relying primarily on stored soil water for production (Blum and Naveh, 1976). Early plant competition can be increased by maintaining plant density but increasing the width between rows. It is theorized that this will reduce early season vegetative dry matter and water use, thereby conserving water in the skipped area for use by plants during flowering and grain fill.

Under conventional spacing and in seasons or locations with low rainfall, soil water reserves are often depleted before anthesis, resulting in low yield or total crop failure (Fukai and Foale, 1988). With skip-row planting, the soil water conserved in the interrow area during the early stages of crop growth can be used during reproductive stages to reduce risk of crop failure (McLean et al., 2003; Routley et al., 2003). Routley et al. (2003) has shown that sorghum roots grow in all directions at rates of 15 to 40 mm d^{-1}, depending on the growth stage. If the mean rate of root growth is 25 mm d^{-1}, crops planted in uniformly spaced 76 cm rows will exploit available soil water before flowering in the absence of adequate in-season precipitation. Skip-row planting is expected to be most effective where soil has high water-holding capacity and can therefore conserve significant amounts of water for use during flowering and grain fill. When terminal water deficit stress is not a concern, grain sorghum yields with skip-row planting are likely to be less than yields with conventional planting, since solar radiation, nutrients, and water may not be fully used (Steiner, 1986, 1987).

Studies report various optimum sorghum plant populations ranging between 50,000 and 100,000 plants ha^{-1} under rainfed conditions (Wade and Douglas, 1990). Staggenborg et al. (1999) suggested 123,500 to 185,250 plants ha^{-1} for early- to mid-season grain sorghum hybrids in Kansas when soil water is adequate. In crops with a large capacity to produce tillers, the optimum plant population for grain yield is wide and should be guided by soil water status and hybrid maturity (Staggenborg et al., 1999).

The objectives of the study were to evaluate the interactions of skip-row planting configuration and plant population on sorghum grain yield and yield stability across different climatic environments in the central Great Plains. The study evaluated soil water availability in each row configuration during the growing season

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Abbreviations: DAP, days after planting; SWC, soil water content.

and estimated the relationship between grain yield and the sum of total profile soil water plus growing season precipitation.

MATERIALS AND METHODS

Field studies were conducted at seven sites over a 3-yr period (10 site-years) across Nebraska from 2005 through 2007 to evaluate the effect of skip-row configuration and plant population on sorghum grain yield and yield stability. All fields were nonirrigated and under no-till management. Soil series, taxonomic classes, and cultural practices for each site-year are listed in Table 1. Three planting configurations and two plant populations were evaluated in a complete factorial arrangement in a randomized complete block experimental design with four replications at all sites. The row configurations included: (i) conventional planting 76-cm row spacing (s0); (ii) alternate rows planted, or single skip configuration, (s1); and (iii) two rows planted alternated with two skipped rows, or double skip configuration, (s2). Plot size of each treatment was 6.1 by 8.97 m.

At Clay County, a relatively high rainfall site with 50-yr mean annual precipitation of 734 mm, plants were thinned 21 d after emergence to obtain 75,000 and 150,000 plants ha^{-1}. At the remaining six counties (Gosper, Frontier, Hayes Center, Lincoln, Red Willow, and Cheyenne) sites where annual precipitation was low to moderate, plant population was thinned 21 d after emergence to 50,000 and 100,000 plants ha^{-1}. Plant population remained constant across all treatments, resulting in a higher within-row plant density in skip-row treatments. Medium (110 d) maturing grain sorghum cultivar Dekalb 42–20 was planted at the Clay County site and early (105 d) maturing Dekalb 29–28 (Monsanto Company, St. Louis, MO) was planted at the remaining sites. Fertilizer application at each site was based on University of Nebraska recommendations for grain sorghum and soil nutrient content (Ferguson, 2000). At the Clay County site N rates (0, 50, 100, and 150 kg ha^{-1}) were imposed but this analysis uses yield at only one N rate (100 kg ha^{-1}). The Gosper, Frontier, Hayes, and Red Willow County sites were located within cooperating producer's fields, while the Clay, Lincoln, and Cheyenne County sites were located on university research stations. At all sites weeds were controlled using pre-emergence herbicides.

At each site, neutron probe access tubes were installed in the center of the skipped area of s1 and s2 configurations and midway between two rows of the s0 configuration. Volumetric soil water content was measured beginning 3 wk after planting at 2- or 3-wk intervals until physiological maturity using a Troxler 4301 neutron probe (Troxler Electronic Labs Research Triangle Park, NC) at depths of 300, 600, 900, and 1200 mm. The neutron probe was calibrated using soil samples within the access tube hole at the time of tube installation. Volumetric water contents of the soil samples were calculated by multiplying gravimetric water content by bulk density. A linear regression relationship was established between probe count ratio and soil water content (SWC) for each site-year:

$$\mathrm{SWC} = mx + c$$

where m and c are regression slope and intercept values of the calibration equation at each site, respectively, and x is the count ratio (count/standard count) at each depth.

Total soil profile water was estimated as cumulative soil water content across depths. Total growing season water was estimated by adding total growing season precipitation (May through October) and initial total profile water. In-season precipitation and long term (50-yr) average in-season precipitation data were collected from nearby automated weather data network sites (www.hprcc.unl.edu/services/). The automated weather data network sites were located 0.05 to 0.2 km from the study site at the Clay, Lincoln, and Cheyenne County sites, and 0.1 to 2 km from the study in the remaining county sites.

Plots were machine harvested and grain yield determined from 18.2 m^2 (3.04 by 6 m) in the center of plots of the s0 and from 9.1 m^2 (1.52 by 6 m) in the center of plots of the skip-row configurations at all sites. Yields were adjusted to 135 g kg^{-1} moisture concentration by drying a grain subsample at 65°C over 72 h.

All data were analyzed using the MIXED procedure of SAS (SAS Institute, 2007). Fisher's protected LSD test was used to separate treatment means at $P \leq 0.05$. Regression analysis was conducted using SigmaPlot v.10 (Systat Software, 2006) to determine the relationship between grain yield means and total in-season plant-available water across site-years. Regression was also used to

Table 1. Soil series, taxonomic classes, and agronomic information for seven sites in Nebraska.

Site, soil, and agronomic data	County						
	Clay	Gosper	Frontier	Red Willow	Lincoln	Hayes	Cheyenne
Location and elevation	40°34′ N, 98°08′ W; 543 m asl	40°28′ N, 99°53′ W; 732 m asl	40°40′ N, 100°29′ W; 829 m asl	40°23 N, 100°58′ W; 792 m asl	41°05 N, 100°75′ W; 922 m asl	40°30′N, 101°01′ W; 922 m asl	41°12′N, 103°01′ W; 1317 m asl
Soil series	Crete silt loam	Holdrege silt loam	Hall silt loam	Holdrege and Keith silt loam	Holdrege silt loam	Kuma silt loam	Duroc loam
Taxonomic class	fine, smectitic, mesic Pachic Arguistolls	fine-silty, mixed, superactive, mesic Typic Argiustolls	fine-silty, mixed, superactive, mesic Pachic Arguistolls	fine-silty, mixed, superactive, mesic Typic/Aridic Argiustolls	fine-silty, mixed, superactive, mesic Typic/Aridic Argiustolls	fine-silty, mixed, superactive, mesic Pachic Arguistolls	fine-silty, mixed, superactive, mesic Pachic Haplustolls
†Total PPT, mm	591	489	469	462	445	441	379
Previous crop	corn	corn	corn	corn	corn	corn	wheat
Plant date	24 May 2005 7 June 2006 6 June 2007	16 May 2006	23 May 2006	24 May 2006	1 June 2007	24 May 2006	1 June 2006 5 June 2007
Harvest date	14 Oct. 2005 25 Oct. 2006 10 Oct. 2007	31 Oct. 2006	31 Oct. 2006	2 Oct. 2007	2 Oct. 2007	1 Nov. 2006	17 Oct. 2006 3 Oct. 2007

† Growing-season precipitation.

determine the linear relationship between mean grain yield with skip-row configuration and conventional planting across environments. The stability of grain yield for the various row configurations was estimated across environments according to the procedure outlined in Eberhart and Russell (1966). This was done by regressing grain yield on the environmental index (site mean), and comparing standard errors (SE) and slope of the regression equations. The *t* test was used to test for equality of slopes of the regressions. A stable practice will have a low slope and little deviation from the slope (Eberhart and Russell, 1966; Braun et al., 1992).

RESULTS AND DISCUSSION

Precipitation

Monthly in-season precipitation at the Clay County site in 2005 followed the general pattern of distribution as the 50-yr mean of 591 mm but was 71% of the total mean in-season precipitation. Total in-season precipitation in 2006 and 2007 was 82 and 120%, respectively, of the 50-yr average precipitation over the growing season (Fig. 1A, B, and C). The total in-season precipitation in 2006 was 496, 390, 376, and 261 mm at the Gosper, Frontier, Hayes, and Cheyenne County sites, respectively, representing 119, 87, 100, and 82% of the 50-yr average (Fig. 1D, F, H, and J). Most of the 2006 in-season precipitation at the Gosper County site occurred more than 70 d after planting (DAP). In 2007, growing season precipitation was 121, 109, and 77% of the 50-yr mean at the Red Willow, Lincoln, and Cheyenne County sites, respectively, with 388, 377, and 261 mm, respectively (Fig. 1E, G, and I).

Soil Water Content

Since soil water content was measured at a single location midway between rows, this may only partially represent total profile soil water of each row configuration. However, at 30, 75, and 120 DAP in 2005 at the Clay County site, profile soil water content measured at the center of the skipped area of s2 was significantly higher than profile soil water content measured between the two rows of s0 (Table 2). In 2006, soil water content was significantly influenced by row configuration at the Clay County site at 30 DAP, Frontier, and Cheyenne County sites at 75 DAP, and at the Frontier and Cheyenne County sites at 120 DAP. At 75 DAP soil water content was significantly higher with skip-row treatments than with s0 at the Clay, Frontier, and Cheyenne County sites. These three sites had higher soil water content than that of Gosper and Hayes County sites at 75 DAP. In 2007, there were significant effects of row configuration on profile soil water content only at the Red Willow County site at 120 DAP (Table 2). In all cases, interrow profile water content was in the order s0 < s1 < s2.

Grain Yield

Site × row configuration and site × row configuration × population interactions significantly affected grain yield (Table 3). At the Clay County site (high rainfall), low plant population produced grain yield equal to high plant population with s0, while the plant population effect on yield with skip-row planting was inconsistent (Fig. 2). At medium and low rainfall sites, low plant population produced equal or greater yield than high plant population with s0. Plant population effects on yield were inconsistent with skip row configuration.

In all 3 yr, s0 produced greater grain yield than skip-row planting at the Clay County site (Fig. 3). This agrees with other findings that yield potential can be reduced in high yielding environments when using wider rows due to the inability of plants to efficiently use available resources (Holland and McNamara, 1982). Steiner (1986) reported that a grain sorghum canopy with a 38-cm row spacing intercepted about 80% of the daily incoming photosynthetically active radiation compared with about 70% with a 76-cm row spacing. With adequate soil water, grain yield is typically greater with narrow spacing compared with wide spacing (Maman et al., 2003; Mason et al., 2008).

At the Gosper, Frontier, Lincoln, and Red Willow County sites, which had moderate growing-season rainfall (350– 490 mm), grain yield with skip-row (s1 and s2) planting was equal to or greater than s0 (Fig. 3). In 2007, s0 grain yield was greater than skip-row configurations at all sites except the Lincoln County site (Fig. 3). Though the Gosper County site in 2006 had total in-season precipitation higher than the 50-yr average of 496 mm, 84% of the in-season rainfall occurred after the flower stage (60 DAP). This delayed s0 panicle development and reduced grain yield. Water deficits after flowering and grain-fill stages can severely affect grain sorghum yield (Maman et al., 2003, 2004; Lafarge et al., 2002). In 2006, the Frontier and Cheyenne County sites had greater soil water availability with s1 and s2 from anthesis to physiological maturity as well as higher yield compared with the Hayes and Gosper County sites (Table 2). With high in-season precipitation in 2007 at all sites except Cheyenne County, grain yield with s0 was higher than with s2. At sites with moderate precipitation, grain yield was reduced by 18% (0.3–0.6 Mg ha^{-1}) with s2 and not affected by s1 compared with s0 in 2006 and 2007. At the Clay County site, where precipitation was relatively high, grain yield was reduced by 20 to 30% (2.8–3.6 Mg ha^{-1}) with s1 and s2 compared with s0 across years.

At the Hayes and Frontier County sites in 2006, where rainfall from June to September was only 229 to 264 mm, skip-row planting configurations produced significantly higher grain yield than s0 (Fig. 3), with a trend for higher yield with skip row configuration at Cheyenne County in 2006. Greater yield with skip row configurations in Frontier County in 2006, and a trend for higher yield in Cheyenne County, may be associated with greater stored soil water in the interrow area at 75 DAP (Table 2). There was no difference in grain yield between s1 and s2 at the Cheyenne County site in 2006, but there was higher yield with s1 than s2 at the Hayes County site in 2006.

Increase in grain yield with skip-row over conventional planting ranged between 5 and 123% (0.3–1.4 Mg ha^{-1}) in the driest years where rainfall from June through September ranged from 229 to 264 mm. These results confirm findings of other studies that show a grain yield advantage of skip-row planting of grain sorghum and corn over conventional planting under water deficit conditions (Holland and McNamara, 1982; Routley et al., 2003; Collins et al., 2006, Lyon et al., 2009).

There was a linear relationship between sorghum grain yield and growing season water (initial profile stored soil water plus growing season precipitation) with all row configurations (Fig. 4). If growing season water for a site was higher than 675 mm (SE = 13.5), s0 planting had higher grain yield than skip-row configurations. Thus skip-row configurations can be expected to result in lower yields than conventional planting if the total growing season water is more than 675 mm. However, actual distribution of in-season precipitation, as well as vapor pressure deficit,

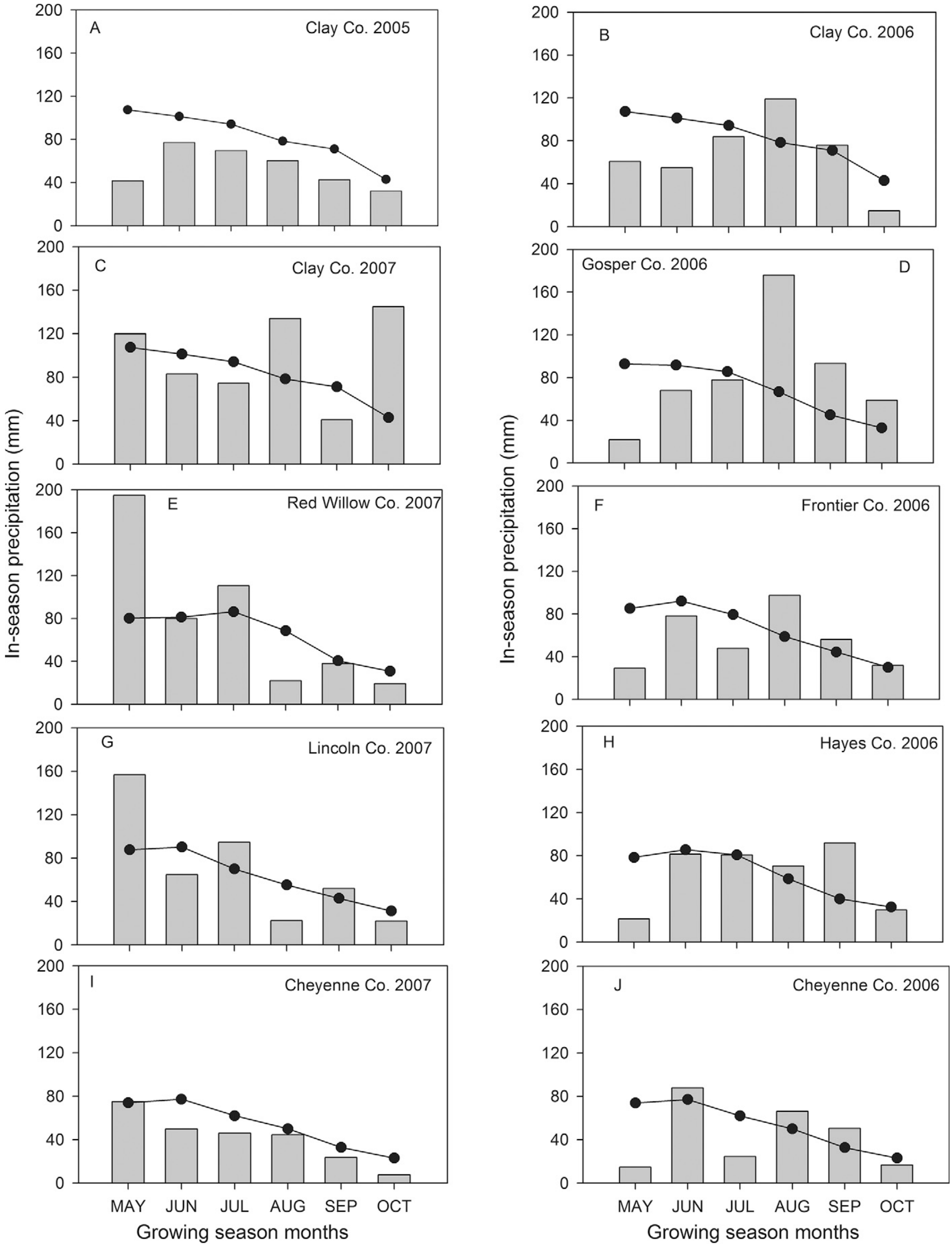

Fig. 1. Growing season monthly precipitation (bars) and 50-yr growing season mean (line) at Nebraska skip row study sites in 2005, 2006, and 2007.

Table 2. Total soil profile (0–120 cm) water content at 30, 75, and 120 d after planting (DAP) grain sorghum.

DAP	Row configuration	Clay 2005	Clay 2006	Gosper 2006	Frontier 2006	Hayes 2006	Cheyenne 2006	Clay 2007	Red Willow 2007	Lincoln 2007	Cheyenne 2007
		mm									
30	s0	234	369	242	296	225	348	397	513	368	615
	s1	–	–	251	313	227	348	405	508	364	587
	s2	253	381	231	295	245	344	406	517	367	623
	LSD	8.33	7.14	ns†	ns	ns	ns	ns	ns	ns	ns
75	s0	231	328	199	226	190	281	342	440	264	428
	s1	–	–	211	249	185	293	359	457	274	423
	s2	308	370	203	265	189	333	370	458	282	437
	LSD	12.5	12.5	ns	16.6	ns	10.9	ns	ns	ns	ns
120	s0	234	313	215	235	193	237	380	336	204	306
	s1	–	–	209	259	196	245	383	371	202	308
	s2	253	325	204	260	192	263	390	378	202	358
	LSD	7.42	ns	ns	14.8	ns	8.77	ns	21.6	ns	ns

† ns = not significant.

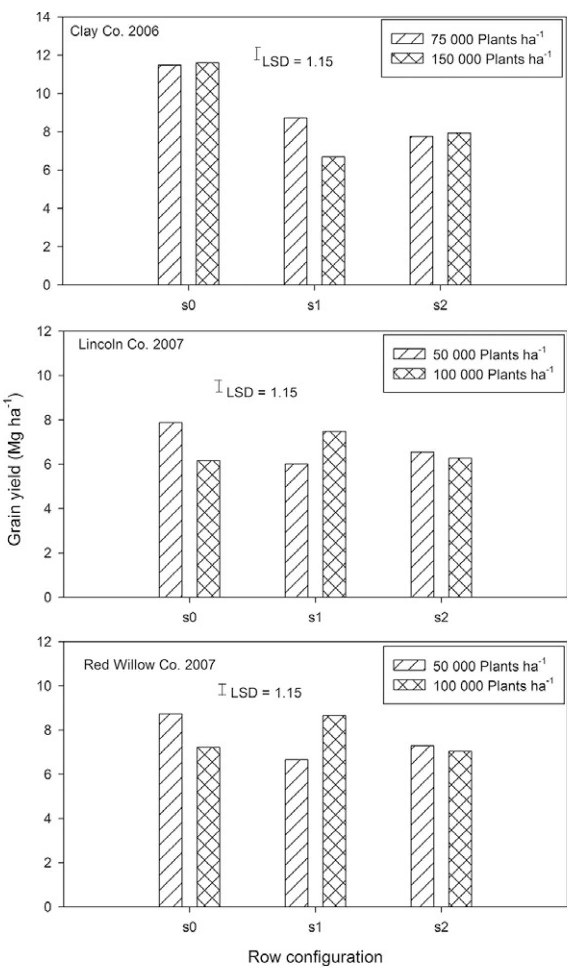

Fig. 2. Response of sorghum grain yield to row configuration and plant population at the Clay, Lincoln, and Red Willow county sites in Nebraska. Y-bars = LSD (0.05).

Table 3. Summary of analysis of variance of grain sorghum yield (Mg ha^{-1}) with three row configurations (s) and two plant populations (p) across 10 site-years in Nebraska.

Source of variation	DF	F	$P > F$
Site-year (S-yr)	9	67.41	< 0.0001
Skip-row (s)	2	7.47	0.2504
Plant pop. (p)	1	0.05	0.8297
S-yr × p	9	0.27	0.9543
S-yr × s	18	12.50	< 0.0001
S-yr × p × s	20	2.33	0.0210

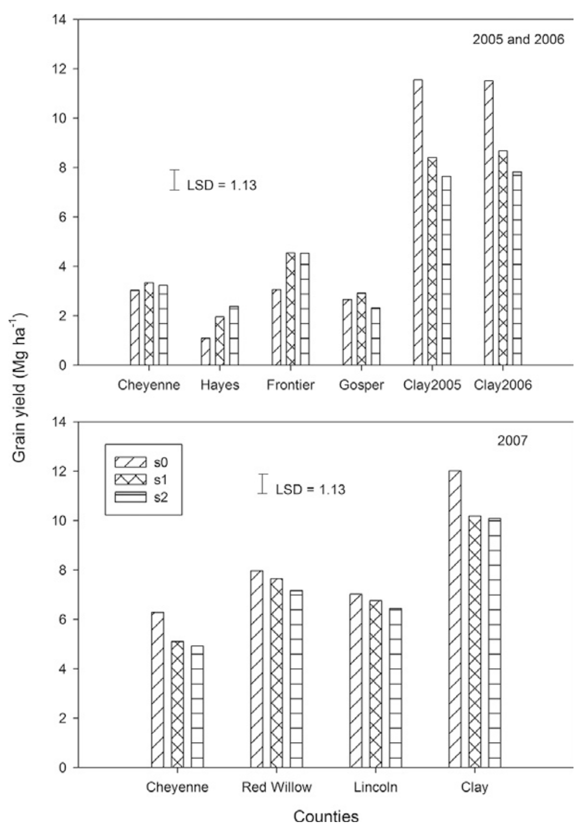

Fig. 3. Response of sorghum grain yield to row configuration from 2005 to 2007 in Nebraska. s0 = conventional planted; s1 = alternate rows planted; s2 = two rows planted alternated with two rows skipped. Y-bars = LSD (0.05).

solar radiation, and wind speed will have significant influences on grain yield (Maman et al., 2003; Olufayo et al., 1996).

Grain yield with both s1 and s2 showed a positive linear relationship to s0 grain yield (Fig. 5). The significantly greater slope of s0 compared with s1 and s2 suggests that s0 will have higher grain yield than s1 and s2 at higher yield potential sites, while at lower yield potential sites s1 and s2 will have significantly greater grain yield than s0 planting. The difference between the slopes of s1 and s2 was not significant. Conventional planting produced significantly greater yield than skip-row planting when the average yield was above 4.5 Mg ha^{-1}, below which skip-row had greater yield than s0. Similar trends with grain sorghum were observed in Australia, but with a crossover value of 2.5 Mg ha^{-1} (Routley et al.*,* 2003; Collins et al., 2006). Our results support those from a recent multi-locational corn study in the central Great Plains where skip-row planting gave higher grain yield than conventional planting when conventionally planted yields were < 4.7 Mg ha^{-1} (Lyon et al., 2009).

There was a positive linear relationship between grain yield and the mean site yield (Fig. 6). The skip-row configurations had a slope of 0.84 with s1 and 0.78 with s2 compared with 1.22 with s0. A stable practice will have a low slope and little deviation from the slope (Eberhart and Russell, 1966; Braun et al., 1992). Grain yield with s0 was least in the lower-yield environments and greatest in the high yield environments indicating that s0 is more responsive to changes in growing conditions compared with s1 and s2 (Heinrich et al., 1985). With the lowest slope of 0.78, s2 is the least responsive row configuration across environments. The SE of the s0 slope was 2.5 times greater than s1 and s2 indicating less stability, or greater reaction to positive or negative influences particular to an environment with skip configurations.

CONCLUSIONS

This study was conducted over 10 site-years in Nebraska to evaluate the effect of row configuration and plant population on soil water availability and grain sorghum yield and yield stability across different environments. In general, the effect of plant population on sorghum grain yield was not consistent nor significant across sites. At sites with higher growing season precipitation (385–597 mm), skip-row configuration was 20 and 30% (2.8–3.6 Mg ha^{-1}) less than that with s0. At the lowest rainfall sites (< 300 mm in-season precipitation), grain yield was 5 to 123% (0.3–1.4 Mg ha^{-1}) higher with s1 and s2 than with s0 in dry years. In 2007, however, where greater and more uniformly distributed precipitation occurred throughout the growing season at all sites except Cheyenne County, grain yield was reduced with skip-row planting at all sites. Skip-row planting is expected to produce higher yields than planting every row when mean site yields are < 4.5 Mg ha^{-1} or if growing season water (initial profile stored soil water and growing season precipitation) is < 675 mm. Conventional planting, however, will likely produce higher yield when growing season water is more than 675 mm. Overall, skip-row planting was less responsive to environmental changes, and thus less risky in environments with low and variable in-season precipitation.

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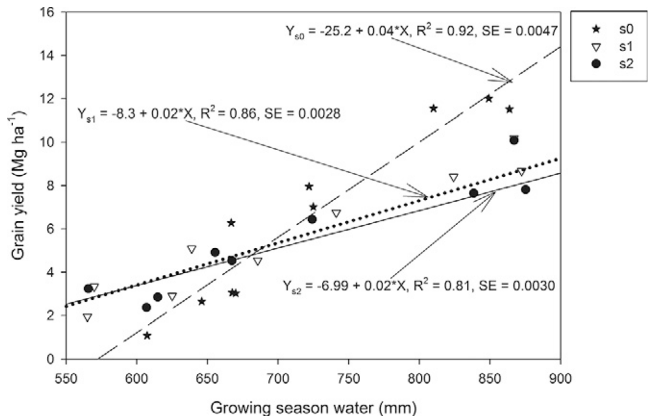

Fig. 4. Relationship between growing season water (initial profile soil water plus growing season precipitation) and sorghum grain yield across 10 site-years in Nebraska as affected by row configuration. Y = grain yield; s0 = conventional planting with all rows planted; s1 = alternate rows planted; s2 = two rows planted alternated with two rows skipped. SE = standard error of the slope.

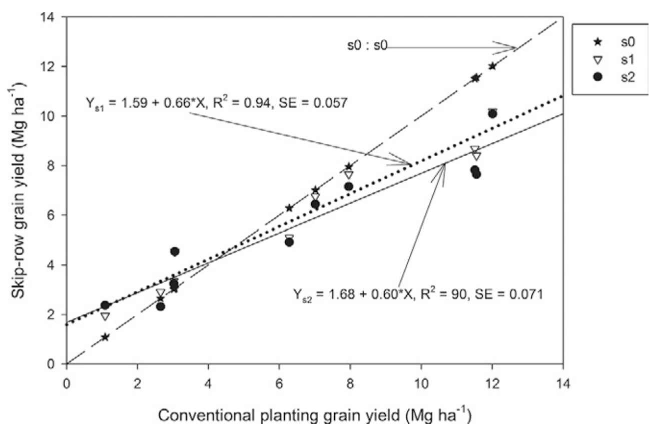

Fig. 5. Relationship between sorghum grain yield with conventional and skip-row planting averaged over plant populations for 10 site-years in Nebraska. s0 = conventional planting with all rows planted; s1 = alternate rows planted; s2 = two rows planted alternated with two rows skipped. SE = standard error of the slope.

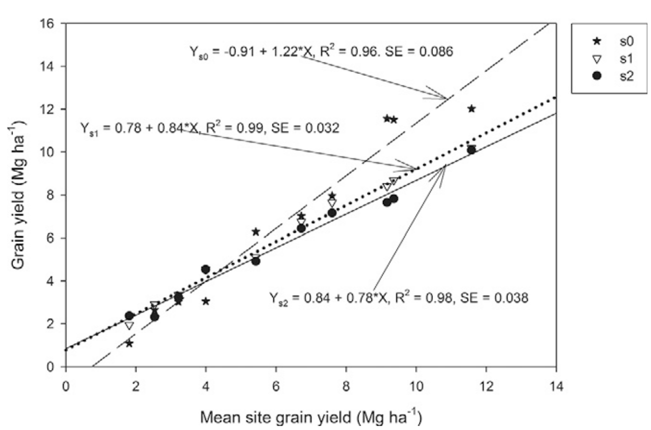

Fig. 6. Response of sorghum grain yield to yield potential for three row configurations across 10 site-years in Nebraska. s0 = conventional planting with all rows planted; s1 = alternate rows planted; s2 = two rows planted alternated with two rows skipped. SE = standard error of the slope.

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