Dryland Cropping Systems

Grain Sorghum and Corn Comparisons: Yield, Economic, and Environmental Responses

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ABSTRACT

Grain sorghum [*Sorghum bicolor* (L.) Moench] is often grown where water stress is expected. But, improved drought tolerance in corn (*Zea mays* L.) hybrids has resulted in increased dryland corn production in preference to grain sorghum. However, grain sorghum may still have a yield advantage over corn in drought prone environments. This study was conducted to determine if grain sorghum has either a yield or economic advantage over corn when drought or temperature stress occurs. Yield and weather data from crop performance testing programs in Kansas and Nebraska (1992–2005) were analyzed. Grain sorghum produced higher yields than corn in environments where corn yields were <6.4 Mg ha^{-1}. When net returns ($ ha^{-1}) were considered for grain sorghum prices that were set at 70, 87, 100, and 117% of corn prices, grain sorghum net returns were higher than corn net returns when corn yields were ≤4.4, 6.6, 8.8, and 13.6 Mg ha^{-1}, respectively. Both corn and grain sorghum yields were positively correlated to June through August precipitation and negatively correlated to June through August maximum temperatures. The yield difference (grain sorghum minus corn) increased as July and August maximum temperatures increased. Monthly minimum temperatures affected corn yield less than grain sorghum yield. Producers in this region likely can minimize production risks by considering this historical yield information. At locations in this region where corn yields are consistently <6.4 Mg ha^{-1}, producers should consider producing grain sorghum.

Because of its drought tolerance, grain sorghum often is grown in environments where precipitation is erratic and water stress is expected (Krieg, 1988). In 1970, approximately 2.0 million ha of grain sorghum and 1.4 million ha of dryland corn were planted in Kansas and Nebraska (National Agricultural Statistics Service, 2007). The area planted to each crop remained relatively steady until 1992 when corn hybrids better adapted to drought and temperature stresses became readily available (Thompson, 1986; Nissanka et al., 1997).

As a result of increased drought tolerance in corn, dryland corn planting increased in Kansas and Nebraska to 2.1 million ha in 2006 (National Agricultural Statistics Service, 2007) and sorghum planting declined to 1.0 million ha over the same period. Recent droughts throughout the region resulted in low corn yields—a reminder that crop selection can be a critical management decision in areas with erratic rainfall patterns.

Two field studies in Kansas (Norwood, 1999; Gordon and Staggenborg, 2003) evaluated crop water use and N responses of both corn and sorghum. In both of these studies, corn yields were greater in years with higher yield potential (timely and adequate rainfall) and sorghum had greater yields in the drought prone years. Because weather events beyond a couple of days are impossible to predict with any accuracy, it is necessary to use a wide range of environments, including environments that have erratic rainfall and the potential for high temperature and drought conditions (i.e., continental climates), to evaluate crop performance. The variety performance testing programs maintained by most land-grant universities in the United States provide a long-term and uniform source of crop performance information. Corn and grain sorghum performance tests have been conducted in Kansas since 1939 (Clapp, 1940) and 1957 (Clapp, 1958), respectively. Variety performance tests compare leading hybrids for a given era within a given region and are an excellent source of information about annual yield variability in a region. And, since most of these tests are conducted using crop production techniques and technology that are current to the era, they represent conditions similar to those used by producers in the region. These factors permit these tests to be used to evaluate regional crop performance across a range of environments.

As dryland corn production expanded in central and western Kansas and Nebraska, so did dryland corn performance testing. In 2006, performance tests for both corn and grain sorghum were conducted at 14 Kansas locations. In most cases, the distance between the two tests was <1 km, making measured differences between the crops relatively good estimates of genetic by environment interactions.

The first objective of this study was to determine if grain sorghum has either a yield or economic advantage over corn when drought or temperature stress occurs. The second objective was to evaluate the environmental effect on relative yields of both crops.

MATERIALS AND METHODS

Field Data

A majority of these data used in this study were collected by the Crop Performance Testing Programs for Kansas and

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Nebraska at locations in the two states where both corn and grain sorghum were grown during the same year. In Kansas, all tests were conducted at research facilities operated by the Kansas Agricultural Experiment Station and the two crops were grown within 1 to 2 km of each other. In Nebraska, tests were conducted at University of Nebraska research facilities and on producer fields. For inclusion of the producers' field data, both corn and grain sorghum tests had to have been conducted in the same county. Locations included in the analyses are shown in Table 1 and Fig. 1. Data from Norwood (1999) and Gordon and Staggenborg (2003) were also included in the analyses.

For each location and year, cultivars were ranked in descending order based on yield and the top 10 cultivars were selected because they were assumed to represent elite genetics available each year for each crop. Mean yields of the top 10 cultivars for grain sorghum and corn at each location were used to calculate the yield difference between the two crops for each location and year. The grain sorghum yield minus corn yield difference was regressed against corn yields. Corn yields were chosen to describe yield potential (independent regression variable) for several reasons. Compared with grain sorghum yields, corn yields are typically lower during periods of drought and higher when rainfall is greater. These characteristics allow corn yields to provide a wider numeric range, a desirable trait in regression analysis. The second reason for using corn yields as the independent variable in the analysis is that most crop producers in the region have corn growing experience, but many may not have recent sorghum growing experience. Thus, using corn yield as the common frame of reference makes the results easier to understand and apply.

Because annual differences exist for commodity prices and production costs for each crop, net economic returns were calculated for each crop each year. Production costs for each crop were obtained from Kansas State Research and Extension Farm Management guides (Dumler and Duncan, 2006a, 2006b; Dumler and Thompson, 2006a, 2006b, 2006c, 2006d; Fogleman and Duncan, 2006a, 2006b; Fogleman and Kilgore, 2006a, 2006b) and Nebraska crop budgets (Selley and Barrett, 2006). Cost categories were seed, fertilizer, land rent, pesticides, drying, machinery, labor, and interest. Income categories were price and government payments.

Historically, grain sorghum prices have averaged approximately 87% of corn prices in Kansas (Kansas Agricultural Statistics Service, 2007) with a minimum grain sorghum to corn price ratio of 0.70 and a maximum price ratio of 1.17 occurring since 1973. Based on these minimum and maximum ratios, the economic analyses conducted in this study used four grain sorghum to corn price ratios (0.70, 0.87, 1.00, and 1.17) to reflect markets where grain sorghum is priced lower and higher than corn. As was done with yield, grain sorghum minus corn net return was calculated and regressed using linear regression against corn yield to determine the relative economic advantage of either crop across all environments.

Table 1. Locations, years, corn prices, and base production costs for the Kansas and Nebraska Crop Performance Testing Programs where corn and grain sorghum yields were accumulated for this study.

				Production costs†	
State	County	Years	Corn price	Grain sorghum	Corn
			$ kg^{-1} × 100	$ ha^{-1}	
Kansas	Brown	2003	9.08	626.02	683.62
Kansas	Ellis	2003–2004	10.10	570.32	544.66
Kansas	Franklin	1992–2005	8.96	649.51	724.67
Kansas	Greeley	1994–1995, 1997–1998, 2002–2003, 2005	10.10	553.35	597.81
Kansas	Harvey	1999–2003, 2005	9.39	508.05	706.27
Kansas	Nemaha	2005	9.08	626.02	850.84
Kansas	Riley	1992–2005	9.11	580.62	678.90
Kansas	Republic	1993–1999, 2001–2005	9.11	580.62	678.90
Kansas	Stafford	1992, 1994, 2000, 2001	9.39	508.05	639.73
Kansas	Thomas	1994–2005	10.10	570.32	656.45
Nebraska	Cheyenne	2000–2001, 2003	10.10	576.62	683.70
Nebraska	Clay	2002–2003	9.11	581.46	670.48
Nebraska	Gage	2002–2003, 2005	9.11	581.46	670.48
Nebraska	Harlan	2002	10.10	576.62	683.70
Nebraska	Hayes	2002–2004	10.10	576.62	683.70
Nebraska	Lancaster	2001, 2004	9.11	581.46	670.48
Nebraska	Lincoln	2000	10.10	576.62	683.70
Nebraska	Nuckolls	2000	9.11	581.46	670.48
Nebraska	Perkins	2000	10.10	576.62	683.70
Nebraska	Red Willow	2000–2004	10.10	576.62	683.70
Nebraska	Saline	2005	9.11	581.46	670.48
Nebraska	Webster	2001	10.10	576.62	683.70

† Base costs include seed, fertilizer, land rent, pesticides, labor, interest, machinery costs, and base harvest costs. Total harvest costs are determined based on yields for each location-year. Harvest costs above the base cost are a function of yields and are calculated as: Additional harvest cost = ((yield – base yield) × extra harvest cost) + (hauling cost × yield). Base yields for grain sorghum and corn are 2260 and 4780 kg ha^{-1}, respectively. Extra harvest costs for grain sorghum and corn are 0.57 and 0.61 $ kg^{-1} × 100, respectively and hauling costs for grain sorghum and corn are $0.56 and $0.50 kg^{-1} × 100, respectively.

Environmental Factors

Several key environmental factors that can affect grain sorghum and corn yields were analyzed using correlation and both linear and multiple regression techniques. Variables evaluated were longitude, latitude, altitude, and growing season average temperature and rainfall. Growing seasons were defined as April through September for both crops. Monthly average values for maximum and minimum air temperatures and total precipitation were used. After correlation analysis, all variables that were correlated with corn or grain sorghum were then

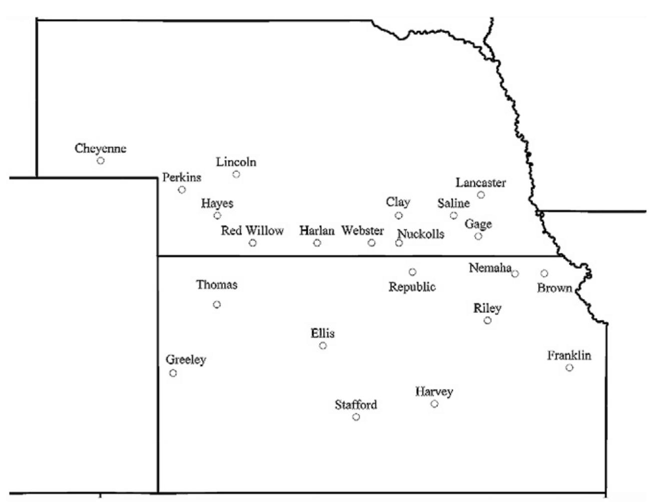

Fig. 1. Locations of corn and grain sorghum yield data obtained from the Kansas and Nebraska Crop Performance Testing Programs.

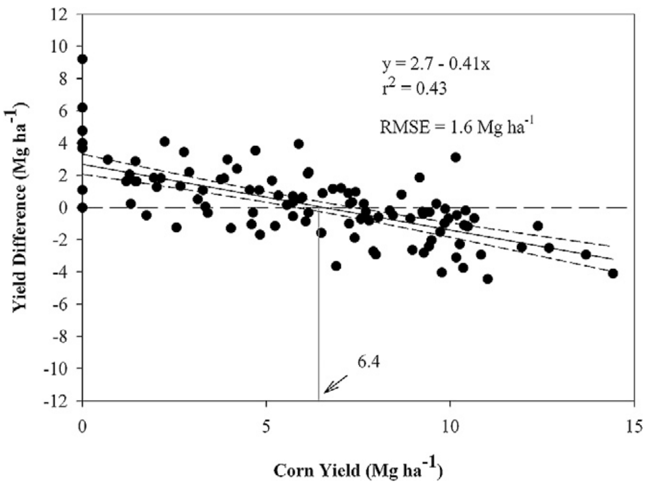

Fig. 2. Yield difference (grain sorghum minus corn) as function of corn yields for 113 site-years where corn and grain sorghum were grown at the same locations in Kansas and Nebraska from 1992 to 2005. Dashed lines represent 95% confidence interval.

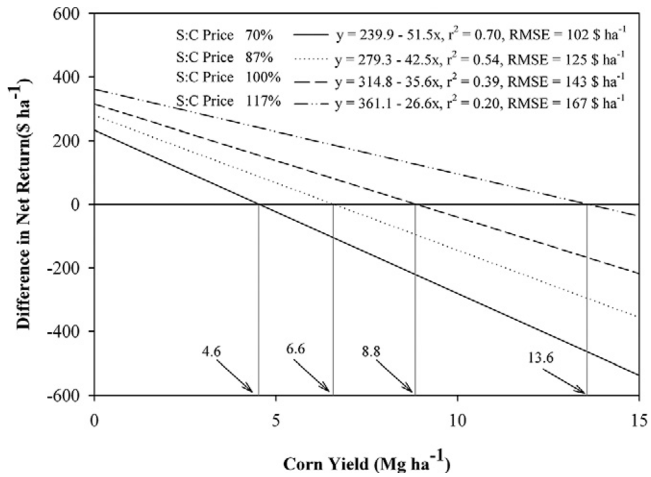

Fig. 3. Difference in net returns (grain sorghum minus corn) based on four grain sorghum to corn price ratios as a function of corn yields for 113 site-years where corn and grain sorghum were grown at the same locations in Kansas and Nebraska from 1992 to 2005.

included in a stepwise regression analysis to develop a multivariate regression to describe corn or grain sorghum yield as a function of environmental variables.

RESULTS AND DISCUSSION

Yields

Corn yields ranged from 0 to 14.4 Mg ha^{-1} with a mean of 7.9 Mg ha^{-1}. Grain sorghum yields ranged from 0 to 13.3 Mg ha^{-1} with a mean of 6.9 Mg ha^{-1}. The calculated difference between grain sorghum and corn yields ranged from −4.4 to 9.2 Mg ha^{-1} and declined consistently from a positive yield difference to a negative yield difference for grain sorghum as corn yields increased (Fig. 2). When grain sorghum yield to corn yield differences were regressed against corn yields, the relationship was linear with a y-intercept of 2.7 Mg ha^{-1} and a slope of −0.41. The x-intercept of 6.4 Mg ha^{-1} is important because it indicates that grain sorghum produced higher yields than corn in environments where corn yields were below this value. The 95% confidence interval indicates that this point ranges from 5.8 to 7.3 Mg ha^{-1}, indicating that in environments where corn yields are low, drought and temperature tolerance of grain sorghum may provide a production advantage over corn. According to Nielsen et al. (2005), drought and temperature are the most consistent yield-limiting factors in the region where this study was conducted.

Net Returns

When net returns were analyzed with the same approach used for yields (i.e., grain sorghum net returns minus corn net returns regressed against corn yields), the focus was placed on corn yield levels where the differences in net returns were equal to zero (Fig. 3). When grain sorghum price was 70% of corn price, net returns for grain sorghum were greater than corn net returns when corn yields were <4.6 Mg ha^{-1}. When grain sorghum prices were 87, 100, or 117% of corn prices, grain sorghum net returns were greater than corn net returns when corn yields were 6.6, 8.8, and 13.6 Mg ha^{-1}, respectively. One reason for the increase in corn yield thresholds for net returns was because grain sorghum production costs were $78 ha^{-1} less than corn production costs.

These results suggest that when feed grain producers are faced with growing conditions where drought or temperature stress is expected, corn yield potential and grain sorghum price should be factors in crop selection. Neither crop is without risk of low yields. For example, there were 11 occurrences of corn yields <1.2 Mg ha^{-1} and four such occurrences for grain sorghum (data not shown).

Environmental Influence on Yield

Understanding how environmental conditions influence both corn and grain sorghum yields can be helpful in crop selection. In this study, correlation analyses of environmental variables provided a more specific understanding by identifying relationships between grain sorghum and corn yield responses to varying environmental conditions.

Corn yields increased when rainfall in July, August, and September increased as well as when total growing season rainfall increased (Table 2). Corn yields increased 0.02 Mg ha^{-1} for each additional millimeter of rain received during each of these months (data not shown). Corn yields decreased as the average maximum temperature during June, July, and August increased. Corn yields declined at the rate of −0.4, −1.3, and −0.7 Mg ha^{-1} for each 1°C increase in average maximum air temperature for June, July, and August, respectively (data not shown). Potential kernel number development (potential ear size) would normally occur during June. Pollination and early kernel development normally begins in late June and continues into July across the study region. Subsequent grain fill occurs during the latter portion of July and early August. High temperatures during these time periods often result in temperature stress, drought stress, or both. Corn yields also declined as rainfall decreased during July, August, and September. July rainfall and July maximum temperatures were correlated ($r = 0.58$), indicating that years with high average maximum temperatures were often also the same years that July rainfall was low. In those years, crops were more likely to suffer from both temperature and drought stress during pollination and early grain

Table 2. Correlation coefficients for grain sorghum and corn yields and 24 environmental and location variables.

Variable	Grain sorghum yield	Corn yield
	r	
Geographic parameters		
Longitude	0.46*	0.39*
Latitude	0.01	0.04
Altitude	–0.45*	–0.37*
Temperature parameters		
Seasonal temp.	0.10	–0.02
April max. temp.	0.13	–0.14
May max. temp.	0.12	0.11
June max. temp.	–0.19*	–0.23*
July max. temp.	–0.50*	–0.65*
August max. temp.	–0.38*	–0.45*
September max. temp.	0.05	0.01
April min. temp.	0.28*	–0.16
May min. temp.	0.39*	0.33*
June min. temp.	0.31*	0.23
July min. temp.	0.25*	–0.07
August min. temp.	0.10	–0.01
September min. temp.	0.36*	0.31*
Precipitation parameters		
Seasonal precipitation	0.56*	0.46*
April precipitation	0.25*	0.15
May precipitation	0.25*	-0.16
June precipitation	0.27*	0.28
July precipitation	0.49*	0.45*
August precipitation	0.29*	0.23*
September precipitation	0.25*	0.18*

* Significant at the 0.05 probability level.

fill. Numerous researchers have reported that drought or temperature stress during these stages can reduce yields (Robins and Domingo, 1953; Denmead and Shaw, 1960; Duncan et al., 1965; Musick and Dusek, 1980; Schlenker and Roberts, 2006).

Corn yields increased as minimum temperatures in May and September increased. Because daily minimum temperatures typically occur during the night, these yield increases during the coolest parts of the growing season (early and late growing season months) likely resulted from higher daily growth rates. For both months, yields increased at the rate of 0.54 Mg ha^{-1} per 1°C increase in average minimum temperature (data not shown).

All of the variables that were correlated with corn yield were included in a stepwise regression analysis (Table 3). Maximum temperatures in July were entered first followed by growing season rainfall. The following variables added were maximum air temperatures in April, altitude, maximum air temperatures in August and June and minimum temperatures in May. The multivariate regression accounted for approximately 57% of the variability in corn yields.

Like corn, grain sorghum yields increased as growing season precipitation increased (Table 2). Unlike corn, grain sorghum yields were positively correlated to rainfall for all months analyzed with July precipitation having the highest correlation to grain sorghum yields. Grain sorghum yields increased approximately 0.1 to 0.2 Mg ha^{-1} for each millimeter of rainfall received during each month with July having the highest rate of 0.2 Mg ha^{-1} mm^{-1} (data not shown). Like corn, grain sorghum yields declined as maximum temperatures in June, July, and August increased. Correlations between yield and precipitation are expected because growing season water supply can often be the yield-limiting factor in this region (Maman et al., 2003; Nielsen et al., 2005; Norwood, 1999). Grain sorghum panicle exertion and pollination normally occurs in late July and early August throughout this region. Temperature or drought stress during these critical growth stages can reduce sorghum caryopsis set and subsequent yields (Craufurd et al., 1993; Tolk et al., 1997; Rao et al., 1999; Berenguer and Faci, 2001).

Table 3. Regression coefficients that were attained with stepwise regression analysis and describe corn and grain sorghum yields from 113 location-years in Kansas and Nebraska.

Variable	Parameter estimate: Grain sorghum yield	Corn yield
Intercept	22.057	52.713
Altitude		–0.002
April max. temp.		–0.463
June max. temp.		–0.190
July max. temp.	–0.604	–0.675
August max. temp.	–0.165	–0.387
May min. temp.		0.366
July min. temp.	0.417	
September precipitation	–0.009	
Seasonal precipitation	–0.005	
MSE, Mg ha^{-1}	3.79	5.84
R^2	0.49	0.56

Grain sorghum yields increased as average minimum temperature increased from April through July and in September (Table 2). These yield increases likely are related to soil temperatures at planting and during the crop's vegetative growth stages. Because grain sorghum is tropically adapted, it is not unexpected that plant growth rates would slow at low temperatures and increase as temperatures warmed. Saeed and Francis (1984b) reported similar relationships between early season minimum temperatures and grain sorghum yields.

Grain sorghum yields increased as minimum average temperatures in September increased (Table 2). For most locations included in this analysis, grain maturation is completed during September, and crop growth rates during September are an important factor in determining final caryopsis weights and subsequent yields. Average minimum air temperatures in September across the study's location-years ranged from 5 to more than 18°C. As a result, grain sorghum growth rates during September ranged from levels that were slow during low temperatures to near maximum at higher temperatures. Saeed and Francis (1984a) reported that grain sorghum yields were less in low nighttime temperature environments compared with high nighttime temperature environments. Wardlaw and Bagnall (1981) reported that phloem transport was reduced 33% for grain sorghum plants that were also exposed to temperatures below 10°C for more than 4 h. Grain sorghum yields also were negatively correlated to altitude, an environmental factor that was correlated to average minimum temperatures in September ($r = -0.58$). These results demonstrate the importance that planting dates and hybrid maturity selection can have in a grain sorghum production system as elevation increases. If a hybrid with a maturity requirement that is too long is chosen, grain fill will occur as daily temperatures are decreasing and crop development is slowing during September. If development and growth rates are slowed sufficiently, grain yields will be reduced.

All of the variables that were correlated with grain sorghum yield were included in a stepwise regression analysis (Table 3). Growing season rainfall was the first variable entered followed by average maximum and minimum air temperatures in July.

The order in which other variables were added was September rainfall and maximum air temperatures in August. The multivariate regression accounted for approximately 49% of the variability in grain sorghum yields.

SUMMARY

This analysis of dryland grain sorghum and corn yields across Kansas and Nebraska indicates that when corn yields are 6.4 Mg ha^{-1} or lower, grain sorghum is likely to produce higher yields. If net returns per hectare are considered and grain sorghum prices are 70, 87, 100, and 117% of corn prices, threshold values for corn yields become 4.6, 6.6, 8.8, and 13.6 Mg ha^{-1}, respectively. An examination of 24 environmental variables revealed that yields of both crops increased as growing season precipitation increased and decreased as average maximum temperatures in June, July, and August increased. Corn was less affected by other environmental variables. For most months of the growing season, grain sorghum yields increased as average minimum temperatures increased, suggesting that it may be a better crop choice in this region where erratic rainfall and high temperatures are often experienced.

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