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A PLACE FOR GRAIN SORGHUM IN DEFICIT IRRIGATION PRODUCTION SYSTEMS?

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INTRODUCTION

Crop selection and management, under deficit irrigation, will likely shape water requirements and yield potential. Deficit irrigation indicates the available water supply and/or distribution system cannot meet the requirements of a fully irrigated crop. One strategic decision can guide water allocation within a deficit irrigation production system: shall limited irrigation capacity be spread throughout the field? Or shall limited irrigation capacity be concentrated on a portion of the field, which can be fully irrigated. Grain sorghum provides management opportunities for deficit irrigation production system, whether water is spread throughout the field, for a deficit-irrigated crop or concentrated on a portion of the field, for a fully irrigated crop.

Crop Water Production Functions

Crop water productivity, also known as water use efficiency, is the ratio of grain yield and crop water use. Crop water production functions also relate expected yield to crop water use. A production function for grain sorghum, derived from the Kansas Water Budget (KSWB; Stone et al., 2006) is shown in Figure 1. This production function indicates that a yield threshold of 5.3” of crop water use; more than 5.3” of water use is required for expected grain production. Further, the production function indicates that 529 lb/A (9.4 bu/A) grain production is expected for each additional inch of water use, beyond the yield threshold. The symbols shown in Figure 1 correspond to grain sorghum yields and crop water use observed in a long-term dryland tillage study conducted at Colby, Kansas (2007 – 2014). The dashed line, fit by regression to these data, also relates expected grain yield to crop water use. This regression indicates a yield threshold of 7.0”, with yield response of 489 lb/A (8.7 bu/A) for each additional inch of water use. The small yield threshold for grain sorghum (5.3” or 7.0”) and positive yield response (9.4 or 8.7 bu/A in), along with heat tolerance, indicate advantages for grain sorghum relative to deficit irrigation. The yield threshold and response to water use, derived from KSWB are not statistically different from the regression relationship derived from the long-term tillage study.

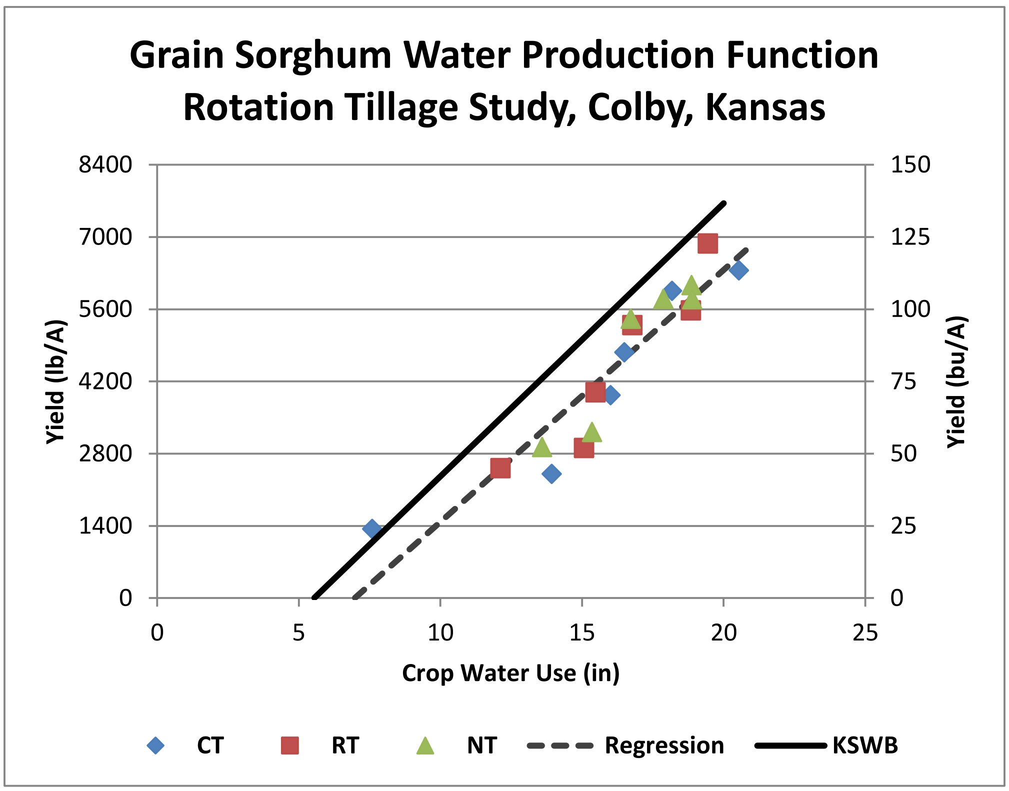

Figure 1. Grain sorghum yield is shown in relation to crop water use. The solid line is a crop water production function derived from the Kansas Water Budget (KSWB; Stone et al., 2006). Symbols correspond to tillage treatments (CT: convention tillage; NT: no-tillage; RT: CT after sorghum and NT after wheat) on a long-term dryland tillage study. The dashed line was derived by regression from the tillage study. Yields and water use from 2009 and 2011 were excluded due to effects of an early freeze (2009) and hail damage (2011).

Deficit Irrigation Crop Sequence

One strategy for spreading limited irrigation water is to maximize the utility of precipitation through improved capture, storage and use which helps prevent crop failure. As an example, splitting a pivot in half could support a two-year, three-crop sequence such as winter wheat and double-crop soybean on one half, with grain sorghum on the other half. This deficit irrigation crop sequence was included in a limited irrigation study conducted at Colby in 2004 – 2007. Irrigation amounts of 2.25" were applied at once using flood irrigation to wheat at boot; to soybean at V8, R1 and R6; and to grain sorghum at V10, boot, post bloom and soft dough stages. Both the winter wheat/soybean phase and the grain sorghum phase of the crop sequence received 9" irrigation during the growing season. Crop water use (precipitation, irrigation and soil water depletion) and grain production, averaged over the four growing seasons, are shown in Table 1. This illustrates the use of grain sorghum in a deficit irrigation system which is more reliant on precipitation than a fully irrigated crop.

Table1. Water use and grain productivity of winter wheat/soybean – grain sorghum crop sequence under deficit irrigation; conducted at Colby, Kansas, 2004 – 2007.

Crop	Water Use (in.)[1]	Yield (bu/A)[2]
Winter wheat	12.8	29
Soybean[3]	11.1	17
Grain Sorghum	20.1	136

Spreading versus Concentrating Water, considering Grain Sorghum

Declining pumping capacities and frequent droughts confront a growing number of western Kansas growers. These constraints on irrigation provide new challenges for water allocation. Howell et al. (2012) framed the problem in terms of 'spreading' or 'concentrating' water. The decision to apply water over many acres under deficit irrigation is referred to as 'spreading' the water; the decision to irrigate only a portion of a field and meet full crop ET is referred to as 'concentrating' the water. A related question is which crop mix would optimize net returns? Grain sorghum being a drought tolerant crop might be suitable for limited irrigation.

We applied a limited irrigation decision support tool called Crop Water Allocator (CWA) to assess the effect of concentrating the water or spreading the water on net returns and also to determine under what scenarios grain sorghum would be most suitable. Howell et al. (2012) provides a good review on the topic of spreading versus concentrating water, for this paper we will focus on demonstrating how CWA could be used in aiding decision making in relation to crop and water allocation. CWA was developed to aid producers in making such decisions (Klocke et al., 2006; Rogers et al., 2015). This tool uses Yield-Crop water use relationships (production functions) derived from an empirical water balance model called the Kansas Water Budget coupled with experimental data. To execute CWA, the user needs to provide values of input and operating costs, crop price, total area, soil type, gross irrigation, annual rainfall, irrigation efficiency, and land split. Default values are available for western Kansas if information is not available. Rogers et al. (2015) provides more details how to run CWA and use CWA. Since production functions are site specific, before applying CWA we validated it against simulations from Kansas Water Budget for grain sorghum and adjusted the maximum yield to 161 bu/ac (based on 3 year average yield from a limited irrigation sorghum study in Colby KS, Table 1) in order to improve the fit between KSWB and CWA as shown in Fig. 2.

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[1] Water use calculated from in-season precipitation, irrigation and soil water depletion; average of four years.
[2] Yield, average of four years.
[3] Soybean planted as double-crop, after wheat harvest.

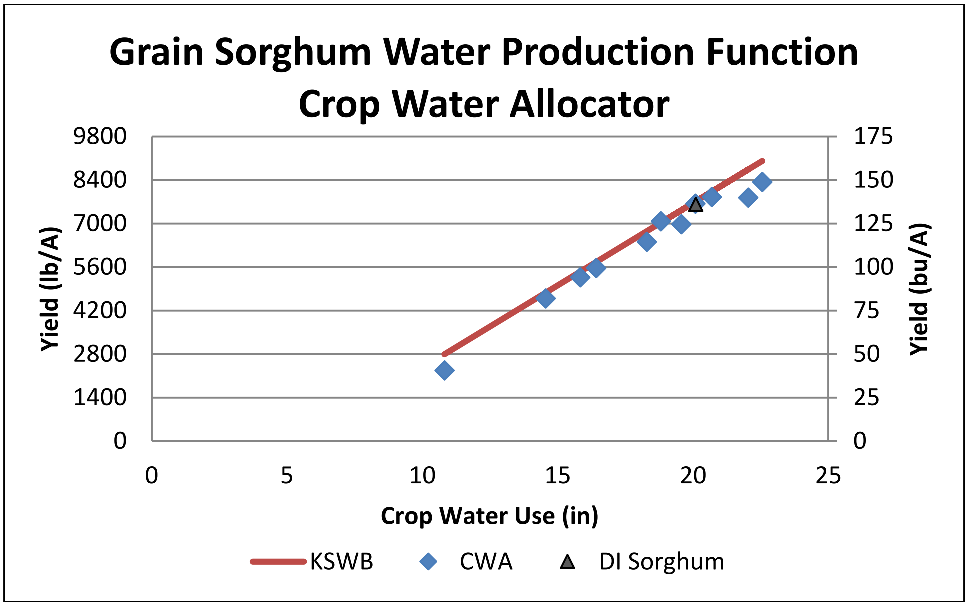

Figure 2. Grain sorghum production function of yields versus crop water use generated from Kansas Water Budget and Crop Water Allocator models, assuming grain sorghum maximum yield of 161 bu/A, corresponding to yield and water use reported in Table 1.

In this analysis we assessed a cropping system with three crop choices (corn, grain sorghum and wheat), well capacity was limited to 300 gpm (equivalent to 11 inches per year), and different land splits (100%, 50-50%, 75-25%, 33-33-33% and 50-25-25%). Maximum yield for corn and wheat were set to 220 bu/ac and 75 bu/ac respectively. Input and operating costs were obtained from Cost-Return Budgets for irrigated corn, grain sorghum and wheat in western Kansas (Dhuyvetter et al., 2014a; Dhuyvetter et al., 2014b; Dhuyvetter et al., 2014c). Various scenarios were tested under normal (18 inches) and below normal annual rainfall (12 inches). This analysis was based on prices of 4.94, 4.44 and 6.88 $/bu for corn, grain sorghum, and wheat respectively. The pumping cost associated with irrigation was set at $3.03/acre-inch. Top options for different crop choices, land splits, and water allocation are shown in Figs 3 to 5 and Table 2 & 3. The best option is one that maximizes net returns over the entire field. These results illustrate how a producer could develop allocation strategies, given limited water resources; results are not intended to represent specific allocation recommendations.

RESULTS AND DISCUSSION

Results from this analysis indicate that annual precipitation affects the decision on whether to spread or concentrate the water. In years with 18" annual precipitation (well capacity was 300 gpm), net returns were maximized with 100% corn even with low irrigation capacity (300 gpm; Table 2, Fig. 3). Splits of 75% corn and 25% grain sorghum or wheat resulted in slightly smaller net returns. Spreading water over whole fields of grain sorghum or wheat resulted in substantially less net returns.

Under very low annual precipitation (12 inches) fallowing 33% of acres while concentrating water on the remaining 67% of the acres under corn with a water allocation of 16.7 inches maximized net returns (Table 3, Fig. 4). A corn-grain sorghum-fallow 50-25-25% split was slightly more profitable than a corn-fallow 50-50% split, with water allocation concentrated on the corn crop. A corn-sorghum or a corn-wheat-grain sorghum crop mix might be selected when multiple management objectives might be pursued, such as minimizing risk to net returns, desire to keep all acres irrigated, weed control through crop rotation, though expected net returns would be reduced compared to concentrating water on corn and fallowing the rest of the acres (Table 3 and Figures 4 to 5). Crop mixes with strategic allocation of deficit irrigation provided greater net returns than spreading water over sole crops of corn, sorghum or wheat. Grain sorghum was included in the crop mixes with greater net returns and where multiple management objectives may be pursued, under the drought conditions simulated with 12” annual precipitation.

Table 2. Best land and water allocations options which maximize net returns for corn, grain sorghum and wheat for annual precipitation of 18 inches and well capacity of 300 gpm supplying a typical 130 acre center pivot.

Land Split (acres)	Crop	Yield (bu/ac)	Gross Irrigation (in)	Operating Cost ($/ac)	Total Returns ($/ac)	Net Returns ($/ac)	Net returns
130	Corn	169.6	11	497	838	341	341
97.5	Corn	178.0	11.7	511	879	368	340
32.5	Corn	140.6	8.8	439	695	255	
97.5	Corn	189.4	13.2	532	936	404	340
32.5	G. Sorghum	92.5	4.4	263	411	148	
97.5	Corn	189.4	13.2	532	936	404	335
32.5	Wheat	46.6	4.4	193	321	128	
130	G. Sorghum	140.2	11	359	622	263	263
130	Wheat	69.0	11	250	475	225	225

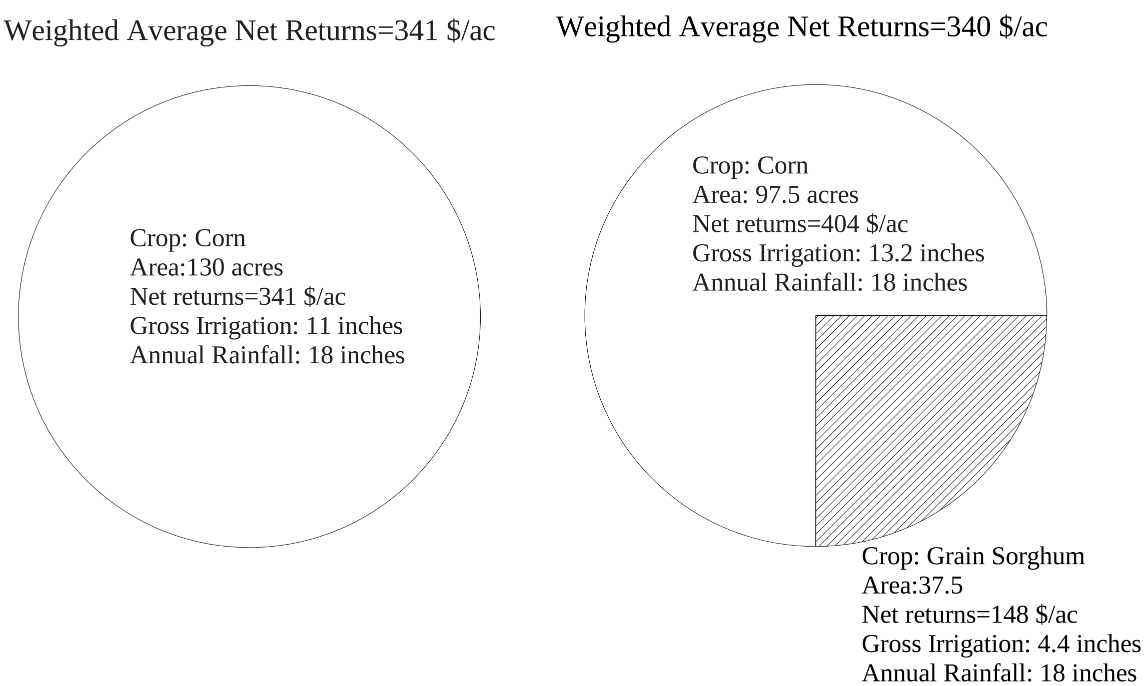

Figure 3. Showing weighted net returns ($/ac) for different land, water, and crop allocation under a typical 130 acre center pivot assuming normal rainfall.

Table 3. Best land and water allocations options which maximize net returns for corn, grain sorghum and wheat for annual precipitation of 12 inches and well capacity of 300 gpm supplying a typical 130 acre center pivot.

Land Split (acres)	Crop	Yield (bu/ac)	Gross Irrigation (in)	Operating Cost ($/ac)	Total Returns ($/ac)	Net Returns ($/ac)	Net returns
42.9	Fallow	0.0	0.0	38	0	-38	194
85.8	Corn	169.0	16.7	524	835	311	
32.5	Fallow	0.0	0.0	38	0.0	-38	189
32.5	G. Sorghum	88.4	8.8	276	393	117	
65.0	Corn	177.8	17.6	539	878	339	
65.0	Corn	207.7	22.0	616	1026	410	186
65.0	Fallow	0.0	0.0	38	0	-38	
65.0	G. Sorghum	48.6	4.4	203	216	13	176
65.0	Corn	177.8	17.6	539	878	339	
65	Corn	177.8	17.6	539	878	339	174
32.5	Wheat	0.0	0.0	97	0	-97	
32.5	G. Sorghum	88.4	8.8	276	393	117	
97.5	G. Sorghum	88.4	8.8	276	393	117	172
32.5	Corn	177.8	17.6	539	878	339	
130	G. Sorghum	105.9	11	312	470	158	158
130	Corn	108.0	11	411	534	123	123
130	Wheat	47.6	11	216	327	111	111

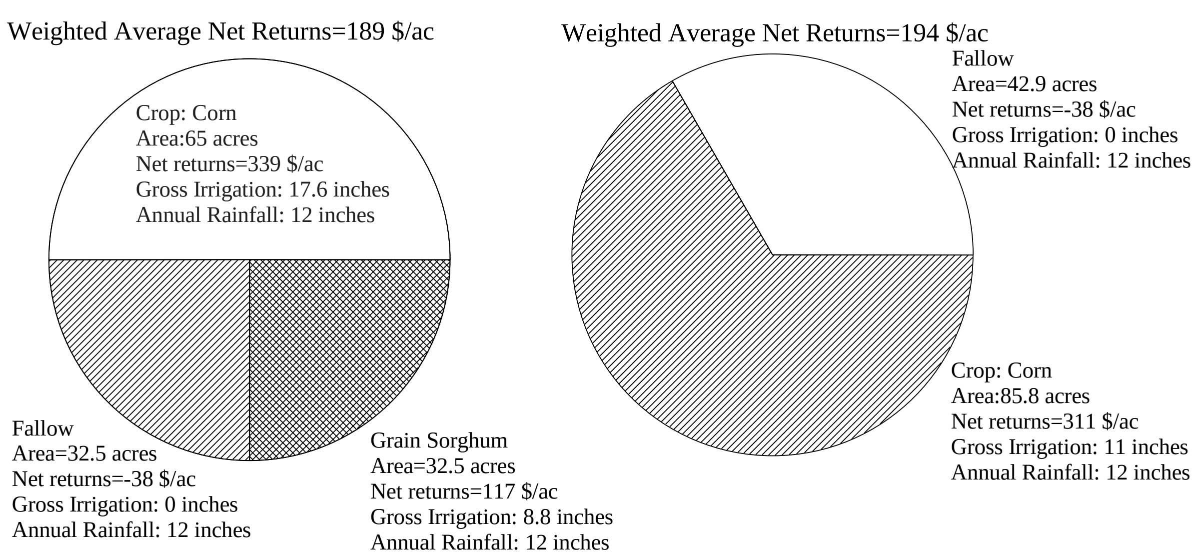

Figure 4. Showing weighted net returns ($/ac) for the split that maximized net returns assuming 12 inches of annual rainfall.

CONCLUSIONS

Field data support a grain sorghum production function showing 8.7 – 9.4 bu/A-in yield response to water use, when water use exceeded a corresponding yield threshold of 7.0" or 5.3" water use. Annual precipitation affects the productivity risk of split-pivot water allocation alternatives. Under normal conditions, spreading deficit irrigation over corn maximized net returns. Under drought conditions, concentrating water on fewer corn acres maximized net returns but a portion of the area was fallowed. Splitting land and water allocation to corn and sorghum resulted in similar but smaller net returns under both normal and drought conditions. Sorghum was important for crop mixes where multiple management objectives are involved such as the desire to keep all acres irrigated or harness benefits of crop rotation.

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