Defining a Dryland Grain Sorghum Production Function for the Central Great Plains

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Introduction

Grain sorghum (*Sorghum bicolor* L. Moench) is widely grown throughout the world and is a drought tolerant C4 species capable of making use of limited available water supplies. It is suitable for dryland crop rotations in the Central Great Plains.

A water use/yield production function would be useful to farmers in assessing production risk encountered when utilizing sorghum in rotations.

Previously published production functions vary widely in reported slope, with many being much less than expected for a C4 species (Table 1, Fig. 1).

Objectives

Determine the relationship between grain sorghum water use and grain yield to determine a water use/yield production function.

Use the production function with the long-term precipitation record to assess grain sorghum production risk under varying available soil water contents at sorghum planting.

Materials and Methods

Location: Akron, CO (Weld silt loam); **Years**: 2006-2016

Two Experiments: 1) Alternative Crop Rotation Experiment, 2006-2016; 2) Sorghum Production Function Experiment, 2016

Alternative Crop Rotation Experiment: W-Sorg-F rotation with sorghum planted in Plant 2 Skip 2 row spacing; rainfed

Sorghum Production Function Experiment: Sorghum following sorghum, planted in 0.76 m row spacing. Four water treatments: rainfed and 50%, 75%, and 100% ET replacement by irrigation. Weekly Penman-Montieth Potential ET was calculated with the REF-ET program (www.uidaho.edu/cals/kimberly-research-and-extension-center/water-resources/) to which a sorghum crop coefficient (Sammis et al., 1985) was applied.

Soil water measured with neutron probe, 30-180 cm ;soil water in the 0-30 cm layer measured by TDR

Water use calculated by water balance from soil water content changes plus precipitation and irrigation

Grain Sorghum Production Functions from the Literature

Table 1. Grain sorghum water use-yield production functions from literature (either reported by authors or constructed from data presented in tables and figures). The production function has the form Yield (kg/ha) = Slope X (Water Use [mm] – offset). *References are ordered by slope magnitude.*

Location	Slope	X-axis Offset	# Years	Year Range	Water Use Range	Reference
	kg ha^{-1} mm^{-1}	mm			mm	
Bushland, Texas	11.1	76	2	1992-1993	334-688	Tolk et al. (1997)
South Africa	11.2	121	4	years not specified	217-382	Beukes et al. (2004)
Bushland, Texas	14.0	-55	2	1998-1999	195-600	Tolk et al. (2008)
Davis, California	14.5	-37	3	1971-1973	304-588	Stewart et al. (1975)
Sidney, Nebraska	15.0	57	2	2000-2001	214-503	Maman et al. (2003)
Bushland, Texas	15.5	127	6	1963-1965, 1979-1981	140-725	Stewart and Steiner (1990)
Bushland, Texas	15.9	59	2	1983-1984	183-269	Steiner (1986)
Texas Panhandle	16.0	100	11	1989-2002	290-780	Klocke et al. (2012)
Tribune, Kansas	16.6	136	31	1973-2003	25-330	Stone and Schlegel (2006)†
Davis, California	16.9	171	1	1977	253-708	Faci and Fereres (1980)
Bushland, Texas	19.5	82	2	1998-1999	302-540	Tolk and Howell (2003)
Bushland, Texas	20.4	125	3	2010-2012	286-661	Bell et al. (2013)
Garden City, Kansas	21.0	138	5	2005-2009	150-527	Klocke et al. (2012)
Colby, Kansas	21.6	178	6	2007-2014	192-521	Aiken et al. (2015)
Bushland, Texas	23.0	281	3	2009-2011	280-970	O'Shaughnessey et al. (2014)
Tryon, Nebraska	24.2	166	2	1977-1978	300-510	Garrity et al. (1982b)
Zaragoza, Spain	25.5	253	1	1995	274-588	Farre and Faci (2006)
Garden City, Kansas	25.5	173	7	2006-2012	190-580	Klocke et al. (2014)
Bushland, Texas	26.0	88	2	1998-1999	100-335	Tolk and Howell (2009)‡
Kansas, Texas	28.0	204	38††	1984-2014	190-570	Moberly (2016)
Kansas	30.1	176	not given	not given	not given	Stone et al. (2006)
Bushland, Texas	34.4	307	1	2009	342-656	O'Shaughnessey et al. (2010) ‡‡

†Production function based on available soil water at planting and growing season precipitation, not evapotranspiration
‡ Production function based on transpiration, not evapotranspiration
††Modeled results based on 38 site years
‡‡Very high planting rate (197,600 seeds ha^{-1}) and N fertilizer application (240 kg N ha^{-1})

Slopes are widely varying (11.1 to 34.4 kg ha^{-1} mm^{-1}), even at one location such as Bushland, TX, with many far below what would be expected for a C4 species.

Corn, another C4 species, has reported production function slopes of

22.4 kg ha^{-1} mm^{-1} at Bushland, TX (Colaizzi et al., 2001)

25.7 kg ha^{-1} mm^{-1} at Akron, CO (Nielsen et al., 2011)

28.0 kg ha^{-1} mm^{-1} in west-central Nebraska (Payero et al., 2006)

28.1 kg ha^{-1} mm^{-1} in western Kansas (Klocke et al., 2014)

32.8 kg ha^{-1} mm^{-1} in Kansas (Stone, 2003)

34.8 kg ha^{-1} mm^{-1} in eastern Colorado (Trout and Bausch, 2012)

36.2 kg ha^{-1} mm^{-1} in eastern Colorado (Nielsen and Schneekloth, 2017)

Proso millet, another C4 species, has a reported production function slope of

32.6 kg ha^{-1} mm^{-1} in eastern Colorado (Nielsen and Vigil, 2017)

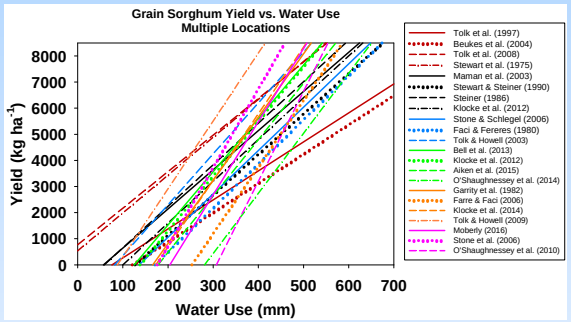

Fig. 1. Grain sorghum water use-yield production functions from literature (either reported by authors or constructed from data presented in tables and figures). See Table 1 for locations and years.

Production Function

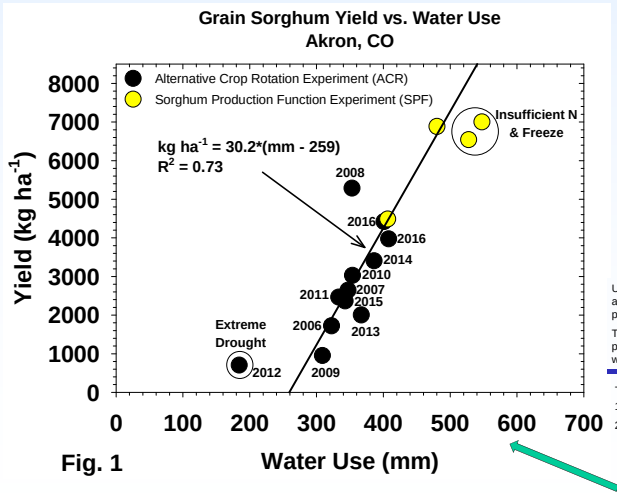

Fig. 1

Yield Exceedance Probability

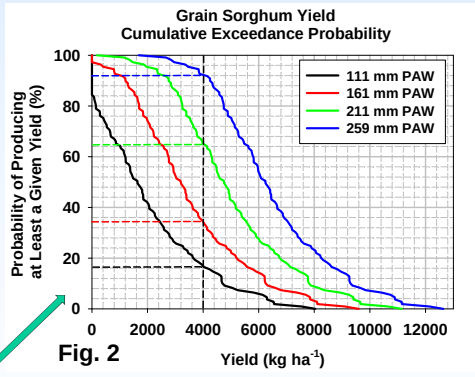

Fig. 2

Using the production function with the long-term (1908-2016) precipitation record and four levels of plant available water at sorghum planting as an estimate of water use provides an opportunity to assess production risk.

There is a 16% chance of getting at least a 4000 kg ha^{-1} yield when 111 mm of plant available water is present at planting (39% of field capacity). The probability of producing at least 4000 kg ha^{-1} rises to 92% when 259 mm of plant available water is present at planting (91% of field capacity).

- The regression analysis did not include three data points (circled)

1. The 2012 ACR point due to extreme drought conditions.
2. The two high water use points from the 2016 SPF experiment. The yield for those two points was likely restricted because of insufficient nitrogen to take advantage of the higher amounts of available water (fertilizer application was 67 kg N/ha). Also termination of growth prior to maturity likely occurred due to a frost on 5 October. The non-water-stressed condition of these high water use treatments likely delayed physiological maturity.

- A well defined linear relationship between grain sorghum water use and yield was determined.

Conclusions

- A water use/yield production function was determined from a broad range of water use and yield data collected over an 11-year period.
- The slope of this production function (30.2 kg ha^{-1} mm^{-1}) is what would be expected for a C4 plant species in this region.
- The production function can be used with a long-term precipitation record to create cumulative yield probability exceedance graphs in order to assess production risk for grain sorghum in this region of the Central Great Plains.
- The production function is useful to farmers in making decisions about incorporating grain sorghum into dryland crop rotations in this region.

Acknowledgements

The authors acknowledge the important contributions made to this study by Delbert Koch, David Poss, Paul Campbell, Gene Uhler, Ken Fetzer, Cody Hardy, Linda Hardesty, Albert Figueroa, Jamie Sauer, Martin Walker, Gordon Nielsen, Christopher Pieper, Ben Nielsen, Katie Strand, Garrick Friedley, Taylor Krause, Morgan Woods, Shelby Guy, Alexis Thompson, Shelby Dunker, Kiara Guy, and Kelsey Guy who assisted with plot preparation, maintenance, and data collection.