University of California
Agriculture and Natural Resources | California Institute for Water Resources

Sorghum as a low-input crop for bioenergy, food and feed in California.

Principal Investigators:

Jeffery A. Dahlberg (Principal Investigator)
UC-ANR-KARE

Technical Completion Report for project: NIWR2015CA340B
Project period: March 1, 2014 – February 28, 2016

Project Summary

TECHNICAL SUMMARY REPORT

Grain Evaluations: Strong genotype by environmental (GxE) interactions were observed in the three years of grain research over the locations; however, GxE was random and therefore cultivar evaluation was based on mean performance and stability across all environments. Figure 1 shows the mean performance of the hybrids across environments and their stability in yield. For the most part, grain yields were relatively stable, while R-0413 and KN8416 had yields slightly lower than the grand mean and were highly unstable across years and locations.

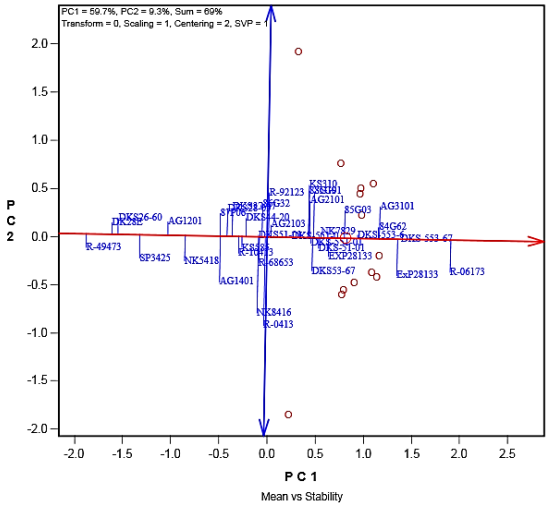

Figure 1. Mean performance of hybrids across environments and their stability in yield.

Sorghum Deficit Irrigation Studies: This study included forage and grain sorghum entries in three study years (2013, 2014, and 2015) at both KARE (sandy loam site) and WREC (clay loam soil). While total applied water for the treatments was about the same at both sites and across all three years of the studies, the frequency of the irrigation was adjusted due to the differences in water infiltration/permeability between the KARE and WREC sites. Larger volumes of water can be applied in the clay loam soil at WREC, so that 3.7 inch water application average per irrigation approximates a furrow irrigation at WREC while about 2 inches approximates an average water application at KARE. Figure 2 shows an example of the type of yield data that will be available from this study, showing the impacts of irrigation treatment (Irr 1 through Irr 5 treatments), year and cultivar on forage yields. As the data is analyzed, this same type of data will be summarized for both sites for all cultivars and all irrigation treatments for the three years and updated Water Use Efficiency numbers will be provided for sorghum grown in California.

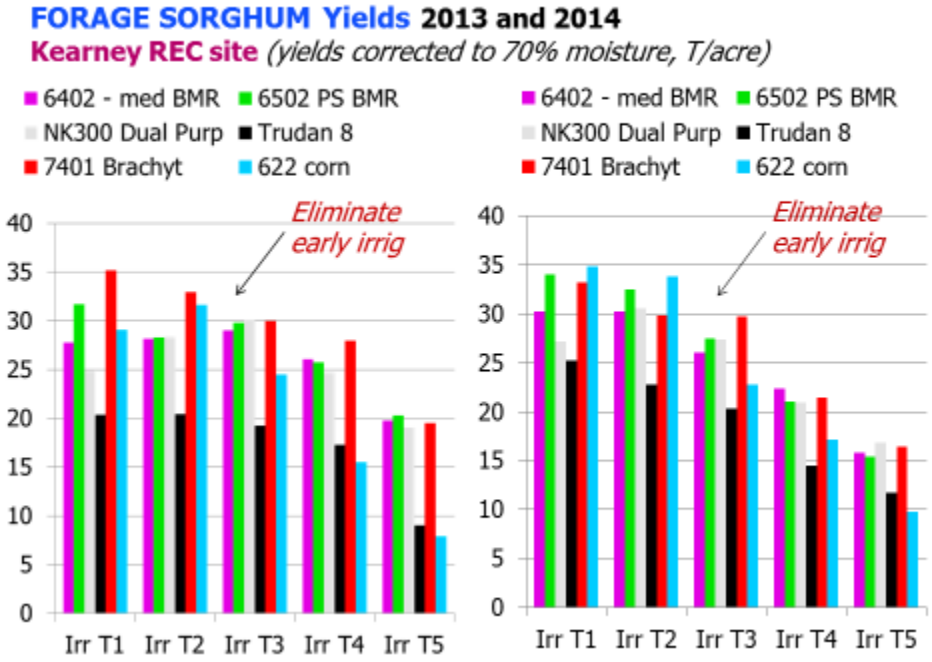

Figure 2. Forage sorghum harvest yields corrected to 70% moisture for 2013 and 2014 field trials at the KARE site.

Forage Quality and Bioenergy Potential: Forage sorghum samples were taken at time of harvest from 4 locations around the state of California and analyzed for forage quality. This included research sites at UC Davis, WREC in Five Points, El Centro (DREC) and from two trials (early and late-planted crops) at KARE. NIRS was used to determine crude protein, ADF, aNDF, dNDF30, dNDF48 and TDN, among other quality parameters. NIRS involve grinding samples, scanning, managing calibrations, and doing wet chemistry to confirm the NIRS calibrations. Forage sorghums typically have crude protein values similar to corn, and ranged from 7.0 to 10.6 across the state. Crude protein (CP) ranged from 8.0% -10.2% for the late and early-planted trials, respectively, at KARE.

Probably more important than CP is the fiber analysis and the fiber digestibility. Acid Detergent Fiber (ADF) ranged from 34.0%-42.1%, and amylose-Neutral Detergent Fiber (aNDF%) ranged from 57.0%-66.9% across locations. Thus, as a forage, sorghum is quite higher in fiber concentration than many forages, and somewhat higher than corn, but not corn stover. BMR (Brown Mid-rib) types of sorghum on average have higher digestibility than non-BMR sorghums, but it is important to note that there are large variations within a type. Further work on digestibility of the fiber fraction (since it's so high as a percentage of the dry matter), and the issues associated with quality for biofuel production are undergoing further analysis. Differences in analysis between silage-processed sorghum and sorghum samples analyzed directly from the field are on-going.

Sorghum Forage Quality from California Locations 2015. Crude Protein% Results.					
Hybrid	WSREC	KAC (Early plant)	KAC (Late plant)	UCD	El Centro
1990	6.3	9.3	8.5	7.6	11.7
9500	7.1	9.8	7.6	10.0	9.5
Alta 6402	8.5	11.0	8.5	9.5	9.9
Alta 7401	8.9	11.4	9.3	9.8	12.1
Great Scott BMR	8.5	12.2	8.5	10.9	10.5
NK300	6.1	10.3	7.1	9.2	10.0
Pacesetter BMR-Red	7.4	10.4	8.8	8.3	10.7
Silo 700D	5.8	10.5	7.4	9.0	9.7
Sordan Headless	5.8	11.1	7.7	8.1	11.9
SS405	5.5	6.6	6.3	8.7	10.2
Average	7.0	10.2	8.0	9.1	10.6

APSIM Modeling: The APSIM program is highly customizable and past CIMIS weather data (**California Irrigation Management Information System**; **www.cimis.water.ca.gov/**) from each of our locations, soil characteristics, soil water and nutrient levels, and select dates and amounts for management operations, such as planting, irrigating, and fertilizing, have been uploaded to the model. Preliminary testing with the APSIM model has been positive, especially for grain sorghum. It has accurately predicted the grain yield and maturity date from one of our past trials and it is being evaluated on other years and locations to see if further modifications are needed. The sweet sorghum model has promise for predicting results for forage sorghum, but more testing needs to be done. It is possible to write code to more accurately describe the particular sorghum varieties used in our trials, and this is being explored.

Research Program

OBJECTIVES

This project investigated sorghum as a low-input crop for the production of bioenergy, food and feed in California and had three broad goals:

Goal 1: Identify the best sorghum varieties for the production of bioenergy, food and feed in California. Hybrid trials for both forage and grain types of sorghum were planted in four locations (five trials) across the State. The locations were UC-ANR Desert REC (DREC), UC-ANR Westside REC (WREC), UC-ANR Kearney Agricultural Research & Extension Center (KARE), and UC-Davis. Two planting dates were tested at KARE, while one planting date was evaluated at each of the other sites. This component of the project was used to determine the following:

1. The optimal varieties of sorghum for bioenergy, food and feed production in California, with the goals of identifying varieties performing the best at individual sites as well as any with better performance at multiple locations with different growing season conditions.
2. The average yield of each variety at each site and averaged across sites.
3. The performance of the sorghum varieties relative to corn in terms of productivity and suitability for bioenergy, food and feed.

Goal 2: Conduct experiments to determine irrigation management responses and water use of forage and grain sorghum types in California. While the original project was focused on forage sorghum evaluations, grain sorghum was added to the goals of this project to further develop improved estimates of water use for both forage sorghums and grain sorghums. Due to the status of grain sorghum as an advanced biofuel according to the EPA (late 2012), and its potential use in the grain-to-ethanol bioenergy plants here in California, we determined that it was important to add grain to our evaluation. Two experimental plots were planted annually, one at WREC and one at KARE.

Five irrigation treatments and three replications of each treatment were used for the experiment. The goals of these irrigation research projects were:

1. Develop improved estimates of crop water use with grain and forage sorghum germplasm representing a range of types and maturity periods of potential interest to California producers;
2. Identify yield and select quality component impacts of some deficit irrigation approaches that could be considered.

Goal 3: Validation, calibration and implementation of crop production and economic models. Results from the variety trial and water use research is being used to test the accuracy of the APSIM model (Agricultural Production Systems sIMulator) for predicting sorghum production and resource utilization (water, nutrients) in California production conditions. The model will then be used to determine how sorghum will behave under different irrigation and fertilization regimes, as well as under future climate scenarios.

PROJECT OUTCOMES

Demonstrated relevance and likelihood of impact on significant agricultural, economic, environmental, and social issues in California: California has been dealing with severe drought over the last 4 years and this has impacted the dairy industry that has relied on heavily irrigated corn silage for their dairy feed. Currently 400,000 acres of silage are produced to support the dairy industry, which is predominately planted to corn silage and alfalfa in the summer months. Prior to our research efforts beginning in 2011, approximately 20,000 acres of sorghum silage were planted in the California according USDA-FSA data. In 2015 those acres were reported to be approximately 55,871. Our outreach and extension efforts have provided information to farmers in the Valley, who have looked for forage options that use less water and provide an alternative, high quality forage. This is reflected in the number of hits to the sorghum.ucanr.edu website, which have totalled over 6,000 since its launch in August 20, 2014.

Describe how this project produced additional resource: We have been able to leverage this research into several new funded projects that build on some of the initial data and collaboration, which has allowed the UC sorghum group to expand into additional areas of drought and other research. Table 1 outlines the different research projects, support funding and funding agencies, and collaborators over the last 3 years.

Table 1.

Project Title or Creative Activity/ Duration	Collaborators (with affiliation)	Support over last 3 years	Support Source
California in State Sorghum Research	Aemetis, Inc.; Pacific Ethanol Development, LLC; Calgren Renewable; Tim Jacobsen, Field Reseaerch Manager, Int'l Center for Water Technology, CSU-Fresno.	**$150,000.00 ANR Share**	**CDFA**
Principles underlying the success of the weedy invader Sorghum halepense ('Johnsongrass'), toward its containment and mitigation	Andrew Paterson, Director Plant Genome Mapping Laboratory, University of Georgia; Mike Smith, Professor Dept. of Entomology, Kansas State Univeristy; Clint Magill, Professor Dept. Plant Pathology & Microbiology, Texas A&M University; Jacob Barney, Assist. Professor, Plant Path Physiology & Weed Sci, Virginia Tech; Gary Odvody, Associate Professor, Texas AgriLife; Wesley Everman, Dept. Crop Science, NC State University	**$52,233.00 ANR Share**	**USDA-NIFA**
Epigenetic Control of Drought Response in Sorghum	Peggy Lemaux, CE Specialist, Dept. Plant & Microbial Biology, UC Berkeley; Bob Hutmacher, Extension Agron., UCCE, Westside Center; Christer Jansson, Director Environmental Molecular Science Lab, Pacific Northwest National Laboratory; Chia-Lin Wei, Group Lead, Sequencing Technologies, DOE Joint Genome Institute; Devin Coleman-Derr, Assit. Adj Professor, USDA-ARS Plant Gene Expression Center; John Taylor, Professor, Plant & Microbial Biology, UC-Berkeley; Elizabeth Purdom, Assit. Professor, Dept. of Statistics, UC Berkeley	**$1,185,920.00 ANR Share**	**DOE**
Consortium for Advanced Sorghum	Christer Jansson, Director Environmental Molecular Science Lab, Pacific Northwest National	**$290,345.78 ANR Share**	**DOE**

Project Title or Creative Activity/ Duration	Collaborators (with affiliation)	Support over last 3 years	Support Source
Phenomics (CASP)	Laboratory,; Peggy Lemaux, CE Specialist, Dept. Plant & Microbial Biology, UC Berkeley; Bob Hutmacher, Extension Agron., UCCE, Westside Center; Scott Staggenborg, Director Product Portfolio & Technolgy Advancement, Chormatin, Inc.; Hui "Wayne" Shen, Project Leader Marker-assisted Breeding & Traits, Chromatin, Inc.; Matt Colgan, Senior Systems Engineer & Project Lead, Blue River Technology; John Vogel, DOE Joint Genome Institute		

Information Transfer/Outreach Program

Paper/Article	Refereed Journals	Six articles are being assembled for publication in various refereed Journals with expected publication dates in 2017.
Website	Website	http://www.sorghum.ucanr.edu
Article/paper	Magazines Newspaper	Kearney & West Side RECs: Studies of sorghum's adaptation to drought push the frontiers of crop improvement (http://californiaagriculture.ucanr.org/landingpage.cfm?article=ca.v069n04p208&fulltext=yes) Drought-resistant genes research (http://californiaagtoday.com/drought-resistant-genes-research/) A spotlight on Sorghum (http://ucfoodobserver.com/2016/03/01/a-spotlight-on-sorghum/) Drought-tolerant sorghum solid option as livestock forage (http://westernfarmpress.com/miscellaneous/drought-tolerant-sorghum-solid-option-livestock-forage) Don't treat forage sorghum like corn forage (http://www.progressiveforage.com/forage-types/other-forage/don-t-treat-forage-sorghum-like-corn-forage) Valley Researchers to study how plants in drought change their genes (http://kvpr.org/post/valley-researchers-study-how-plants-drought-change-their-genetics)

		It's a bird, it's a plane. No it's a drone! (http://www.reedleyexponent.com/articles/2015/09/22/publications/parlier_post/news/doc5601c3d9f10ed796329218.txt) Sorghum in "California Farm Equipment" written by Don Curlee Drought in "UCLA Newspaper" interviewed by UCLA student reporter
Other Visual images	Radio Video	Understanding the benefits of sorghum silage for California dairies (https://www.youtube.com/watch?v=-TTETFwfz6s) KARE and Sorghum interview with "The Big Show" 1/15/13 California Ag and Sorghum interview with Doug Cooper with "The Big Show" 5/4/15 Preview of "The Walking Dead" – searching for sorghum (www.amc.com/shows/the-walking-dead/video-extras/season-06/episode-10/sneak-peek-episode-610-the-walking-dead-the-next-world)

Notable Achievements

LAY SUMMARY OF ACCOMPLISHMENTS

The Issue

Sorghum is an annual crop that could be both a short-term and long-term solution for California's need for more drought-tolerant annual crops for use in food, feed, and renewable products and fuels. Drought continues to plague California growers and drought-tolerant crops, such as sorghum, can help farmers mitigate some of the water issues they faced in 2015 and beyond. Sorghum is a C_4 plant that is drought- and flood-tolerant and uses less fertilizer inputs than other crops, like corn, but which can respond very well to both additional irrigation and fertilizer. Quantifying and estimating economic benefits of sorghum in California will assist producers in making wise crop choices for their farming operations in the future.

What has ANR done?

Replicated field trials of sorghum have been planted throughout the State at various ANR Research Centers and at UC Davis. These were aimed at evaluating grain and forage sorghum's potential as an alternative cropping system that would provide greater water savings and a wide range of end-use products that could enhance farming systems throughout California. ANR research is working to answer questions such as:

1. Can forage sorghums be used to replace corn silage and help save water and increase profitability for dairy farmers of California?
2. Can sorghum be used as a renewable, viable energy crop in California?

ANR has established a California Sorghum website that provides a local source of information on sorghum research taking place in California, and also highlights research from around the United States that could benefit producers here in the state. The website can be accessed at: http://sorghum.ucanr.edu. Replicated irrigation studies are finished as we research sorghum's Water Use Efficiency (WUE) and the impact of various irrigation limitations on yield and quality

parameters in both grain and forage sorghums. ANR research will provide better answers to water use questions for growers of sorghum in the state, such as:

1. What is the WUE of sorghum under various California growing conditions?
2. How can this information be used to tailor limited irrigation opportunities to optimize sorghum yield and profitability?

The payoff?

The payoff of this research can already be seen in the Valley as more forage sorghums are being planted to offset the limited water that is available to dairy farms for forage production. In 2014, FSA estimated that approximately 85% of all forage grown in the valley was corn silage; however, in conversations with various dairy personnel and with forage silage choppers, this number is looking to change in the near future as dairy producers struggle with drought and water restrictions. Some of this shift can be attributed to the information provided through research and educational efforts of this UC-ANR research grant, and the subsequent research projects that are resulting from this work.