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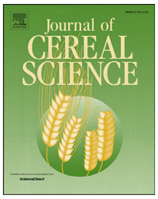

Evaluating effects of deficit irrigation strategies on grain sorghum attributes and biofuel production☆

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ABSTRACT

With reduced water resources available for agriculture, scientists and engineers have developed innovative technologies and management strategies aimed at increasing efficient use of irrigation water. The objective of this research was to study the impact of deficit irrigation strategies on sorghum grain attributes and bioethanol production. Grain sorghum was planted at Southwest Research-Extension Center near Garden City, KS, under five different irrigation capacities (1 inch every 4, 6, 8,10, or 12 days) and dryland in 2015 and 2016 growing seasons. Results showed average kernel weight, kernel diameter and test weight of grain sorghum increased as irrigation capacity increased, whereas kernel hardness index decreased as irrigation capacity increased. Starch and protein contents of sorghum ranged from 69.45 to 72.82% and 8.22–12.50%, respectively. Starch pasting temperature and peak time decreased as irrigation capacity increased. Irrigation capacity had a positive impact on bioethanol yield, whereas both year and interaction between irrigation capacity and year did not show significant effect on bioethanol yield resulting from above normal rainfall received during the growing seasons.

1. Introduction

In the United States, ~80% of the nation's consumptive water use is used for agriculture and more than 90% of the nation's water in many semi-arid and arid areas (USDA-ERS, 2016). Irrigation is an essential technology as it supplements inadequate rainfall to enhance crop yield. However, the availability of water for irrigation has been decreased due to the depletion of the Ogallala Aquifer (McGuire, 2012) in areas such as the southern High Plains. With reduced water resources for agriculture, scientists and engineers have developed innovative technologies and management strategies aimed at increasing the efficient use of irrigation water including deficit irrigation strategies.

Researchers have studied the effects of limited or deficit irrigation on crop yield. Van Donk et al. (2010) studied yield response of corn to deficit irrigation in west-central Nebraska. Their research showed that it takes 65–100 mm of water for an extra yield of 1.6 Mg ha^{-1} of corn. Irmak et al. (2016) evaluated the effects of deficit irrigation on corn production and developed crop yield response factors for field corn. Wheat yield, biomass, and water productivity response to deficit irrigation was studied in western KS (Berhe et al., 2017). El-Hendawy et al. (2017) also studied the effects of full and limited irrigation on wheat growth (El-Hendawy et al., 2017) as well. Zhang et al. (2016) reported rice production improved 4–8% and reduced 20.5% water consumption using regulated deficit irrigation and fuzzy control in Heilongjiang province, China. Chai et al. (2016) reviewed the influence of regulated deficit irrigation on crop production under drought stress in terms of growth stage-based deficit irrigation, partial root-zone irrigation and subsurface dripper irrigation.

Grain sorghum response to water and deficit irrigation management has been studied extensively in Kansas by several investigators (Araya et al., 2016; Kisekka et al., 2016; Klocke et al.,

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☆ Names are necessary to report factually on available data; however, the U.S. Department of Agriculture neither guarantees nor warrants the standard of the product, and use of the name by the U.S. Department of Agriculture implies no approval of the product to the exclusion of others that may also be suitable.

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2012; Stone and Schlegel, 2006). These studies in Kansas show that grain sorghum is a good crop under water limited scenarios and has potential to reduce income risk compared to corn over time. In addition to crop yield, deficit irrigation can also significantly impact crop quality and other non-food application, such as bioethanol production.

In the United States, 200 operating ethanol biorefineries in 28 states produced a record 15.25 billion gallons of bioethanol in 2016, along with 42 million metric tons of high-protein animal feed as by-products (RFA, 2016). The majority of bioethanol was produced from corn with only ~4% produced from grain sorghum. While an overall minor component of total bioethanol production, the portion of bioethanol made from sorghum represents ~45% of the grain sorghum produced in the United States, primarily in plants located in the High Plains regions (RFA, 2016). With the increase in bioethanol production, corn has become overused as a renewable source, which may impact the amount of corn used for human food and directly as animal feed consumption. If all of the corn in the United States was converted into bioethanol, it would only meet 25% of that needed to replace gasoline (Conca, 2014).

Grain sorghum has good potential as a bioethanol crop due to its fit as a more cost effective crop for semiarid regions in the United States (Yan et al., 2011). In 2015, grain sorghum production increased by 38% compared with 2014, while corn production decreased by 4% (USDA-NASS, 2016). This shift in production demonstrates there is a possibility for grain sorghum to be incorporated at greater rates in bioethanol production and to move towards less dependence on corn alone.

Previous research has been carried out to evaluate grain sorghum for bioethanol production. Wu et al. (2007) reported that high starch content and low viscosity during liquefaction were favorable characteristics for the conversion of grain sorghum to bioethanol, whereas tannin content and low protein digestibility had negative impacts. Yan et al. (2011) evaluated the fermentation performance of waxy grain sorghum for ethanol production and reported that the advantages of using waxy sorghums for ethanol production include easier gelatinization and low viscosity during liquefaction, higher starch, and protein digestibility, higher free amino nitrogen (FAN) content, and shorter fermentation times.

Our previous research reported effect of irrigation levels on sorghum physical and chemical properties and ethanol yield (Liu et al., 2013). In this study, we focus on the impact of deficit irrigation strategies (detailed in Irrigation Management) on sorghum grain attributes and bioethanol production.

2. Materials and methods

2.1. Field experimental

The experiment was conducted at the Kansas State University Southwest Research-Extension Center Finnup farm near Garden City, KS, with latitude and longitude of 38°01′20.87″N, 100°49″26.95W and elevation of 887 m above mean sea level. The soil at the experimental site is characterized as a deep well drained Ulysses silt loam with organic matter content of 1.5% and pH of 8.1. The climate is semi-arid with mean annual precipitation of 450 mm.

2.1.1. Irrigation management

The study was conducted under a lateral move sprinkler irrigation system modified to apply irrigation water in any desired treatment combination. The experimental design was a randomized complete block design with four replications and six treatments: 1) full irrigation,100% evapotranspiration (ET); 2) 50% ET irrigation prior to booting of grain sorghum, 100% ET after boot and total irrigation limited to 250 mm; 3) 100% ET irrigation (total irrigation limited to 250 mm); 4) 50% ET irrigation prior to booting of grain sorghum, and 100% ET after boot, and total irrigation limited to 150 mm; 5) 100% ET irrigation (total irrigation limited to 150 mm); and 6) dryland.

As a case study, two limitations on total irrigation were compared to full irrigation as described in Kisekka et al. (2016). The limitations were 150 and 250 inches. The fully irrigated treatment was managed as a non-water limiting crop with 100% ET replenishment. Soil water in the 2.4 m soil profile was measured as a check for adequacy of the ET-based irrigation schedule and also for determination of crop water use. Soil water measurements were made using neutron scattering technique (neutron probe). In-season irrigation events were adjusted to account for rainfall amounts received during the growing season. Total irrigation applications in 2015 were 194, 169, 169, 169, 169, and 44 mm for treatments 1 through 6, respectively. Total irrigation applications in 2016 were 244, 194, 244, 169, 194, and 16 mm for treatments 1 through 6 respectively.

2.1.2. Agronomic management

The hybrid used was Pioneer 84G62, because it is full season and well adapted under both irrigated and dryland environments. Grain sorghum was planted at a seeding rate of 40,485 seeds per hectare on June 4, 2015 and on May 23, 2016. Best management practices for fertilizer and weed control for high yielding grain sorghum were followed. For example, at planting 10:34:0 fertilizer was applied at a rate of 15 l/ha and at least 179 kg N/ha was applied. Some of the herbicides used for weed control included atrazine 4 L at rate of 383 mL/ha and Lumax EZ at a rate of 958 mL/ha. Grain sorghum was harvested on October 20, 2015, and October 13, 2016.

2.2. Sample preparation and grinding

Sorghum was cleaned using a Gamet sieve shaker (Dean Gamet Manufacturing, Minneapolis, MN) with a 6.35 mm screen to remove broken kernel and small foreign material. Large broken kernels and foreign materials were manually pick removed. An UDY sample cyclone mill (UDY Corporation, Fort Collins, CO) equipped with a 0.5 mm screen was used to grind clean samples into flour. Afterward, ground sorghum was sealed in plastic bags and stored in a sealed plastic box at a laboratory with stable environmental conditions of 25 °C and 30% humidity.

2.3. Physical properties of sorghum

Sorghum 1000 kernel weight, single kernel diameter, and hardness were analyzed using a SKCS 4100 (Perten Instruments, Huddinge, Sweden) as previously reported (Bean et al., 2006). Test weights of sorghum samples were determined according to the AACC International Method 55–10.01 “Test Weigh per Bushel”. Moisture contents of sorghum samples were determined according to the AACC International 44–15.02 “Moisture Air-Oven Methods”.

2.4. Chemical composition of grain sorghum

Total starch contents of grain sorghum samples were determined according to the AACC (Method 76.13.01) using a Megazyme starch assay kits (Megazyme International Limited Company, Ireland). Megazyme Mega-Calc™ software (Megazyme International Limited, Ireland) was used to calculate the total starch content from the absorbance data and the moisture content based on a dry weight basis. Protein, fat, and fiber contents of grain sorghum samples were determined according to AOAC official methods 990.03–2002, 920.39–1920 and 962.09–2010, respectively.