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Grain sorghum production functions under different irrigation capacities

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ABSTRACT

Water is the major factor limiting crop production in semi-arid regions of the southern and central US High Plains. The Ogallala Aquifer is the major source of irrigation water in the region. The water levels in the aquifer have been declining due to water withdrawals for irrigation exceeding mean annual recharge. As a result, some of the wells in the region are not able to meet the crop water requirements due to lower irrigation capacity (IC). Grain sorghum, one of the major crops grown in western Kansas is considered drought tolerant. There is limited literature on the effect of IC on grain sorghum yield under erratic rainfall patterns of the semi-arid High Plains. Study objectives were to: (1) evaluate the Decision Support System for Agrotechnology Transfer – Cropping System Model (DSSAT-CSM) for assessing grain sorghum yield and water productivity; (2) develop grain sorghum water production functions under five different IC, two cultivars and three irrigation scheduling strategies; and (3) evaluate response of grain sorghum under various IC in western Kansas based on long term historical weather; 4) to determine the minimum irrigation capacity required for irrigating grain sorghum in western Kansas. A calibrated and validated late maturing cultivar in prior study was used, while measured yield and phenology data of an early maturing cultivar was used to evaluate an existing cultivar in DSSAT model. Results showed that the cultivar in DSSAT were representative of the cultivars in the field with Normalized Root Mean Square of Error (*NRMSE*) 18%, index of agreement (*I*) of 0.97 and percent of deviation (*d*) −19 to 29%. The corresponding statistical goodness of fit values for days to flowering was 12%, 0.99 and 0–17%, respectively. Overall, the simulated yield and phenology values agreed with the measured indicating the satisfactory simulation performance of the model. Highest yield, crop water productivity and irrigation water use efficiencies were obtained from IC of 2.5–3.6 mm/day under the irrigation scheduling strategies from panicle initiation to grain filling. However, long term simulation showed that the minimum IC for growing grain sorghum varied depending on the minimum yield goal to be met based on long term perspective. In some wet years, lower IC up to 1.7 mm/day or even in some of the wettest years no irrigation was suitable. Our findings indicate that it might not be necessary to irrigate grain sorghum from planting to maturity but if producers are forced to do so by climatic conditions, an IC of 1.7–2.5 mm/day was found to produce a yield of at least 5 t/ha similar to that of 5 mm/day IC in 75% of the long-term growing seasons. If producers have to irrigate grain sorghum from panicle initiation to maturity, the 2.5 mm/day IC was found to be adequate to meet a minimum yield goal of 5 t/ha in 3 out of 4 years based on soils and long-term average climate around western Kansas. IC of 3.6 mm/day was found to be adequate if producers wish to irrigate only from panicle initiation to grain filling to meet a minimum yield goal of 6 t/ha in 75–90% of the long-term seasons.

1. Introduction

Agriculture is the economic backbone of Kansas. However, crop production in the semi-arid western part of the state is limited by crop water stress. To achieve potential yield, irrigation is needed in most years. The Ogallala Aquifer is the main source of irrigation water in this region. Numerous studies have shown that the aquifer water levels are declining and will cause significant negative socio-economic consequences if water is not used efficiently and sustainably (Rogers and Lamm, 2012; https://www.scientificamerican.com/article/the-ogallala-aquifer/). Lamm et al. (2007) noted that many wells in western Kansas have insufficient capacity to meet full crop water requirements.

Grain sorghum is one of the main crops grown in western Kansas

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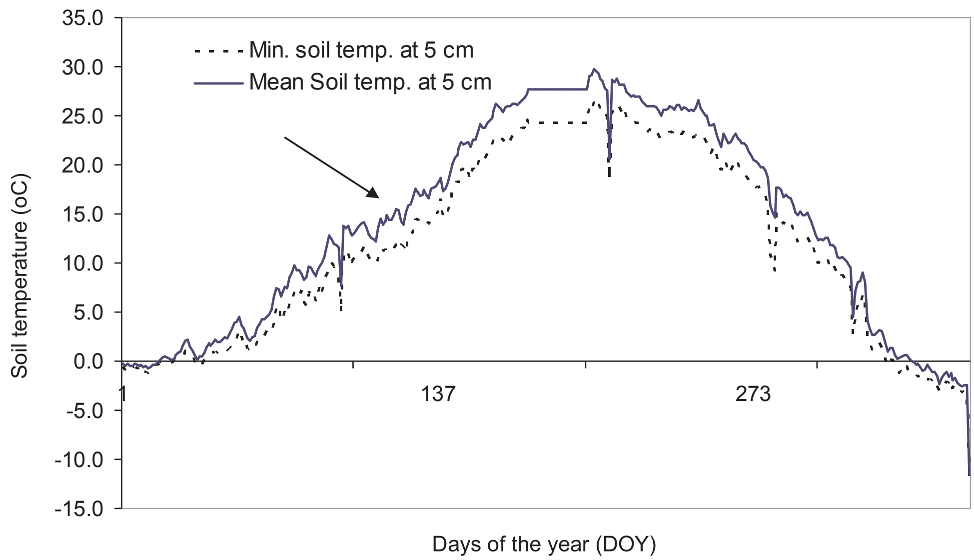

Fig. 1. Measured short-term (2010–2016) soil temperature (°C) for the top 5 cm at the Kansas State University Southwest Research-Extension Center near Garden City, Kansas. The arrow indicates the soil temperature above which planting of grain sorghum was recommended.

(Rogers et al., 2003). Grain sorghum is relatively tolerant to drought compared to other cereal crops (Wani et al., 2012). Many studies have shown that grain sorghum is well-suited to water limited semi-arid areas like western Kansas (Lamm et al., 2007; Aiken et al., 2015; Kisekka et al., 2016) and can be grown as a companion crop to high water consumptive crops like corn in order to optimize crop water use (Klocke et al., 2012). It is imperative to know the response of grain sorghum to various IC and understand the minimal irrigation system capacity considering erratic rainfall conditions and yield goals. Understanding the response of grain sorghum to various IC could help to optimize land-water allocation and cropping pattern, reduce the cost of production, improve profitability, increase the water use efficiency and enhance the sustainability of the aquifer. Producers can increase or decrease irrigated area depending on the irrigation well capacity and by assessing the possible yield or economic returns from different IC, which are a function of land-water allocation.

Previous and current grain sorghum irrigation studies conducted at the Kansas State University Southwest Research-Extension Center near Garden City are shortterm, limited to three to five years (Klocke et al., 2012; Kisekka et al., 2016). Klocke et al. (2012) imposed five different levels of stress in relation to non-stressed treatment (full irrigation) and found that the least irrigated grain sorghum treatment was able to use more stored soil water compared to the fully irrigated and mild stressed treatments. They reported that the least yield was found to correspond with about 90% of the fully irrigated treatment which indicated that grain sorghum might be best suited for low IC (Klocke et al., 2012). Kisekka et al. (2016) reported no significant differences between fully irrigated treatments and deficit irrigated treatment from a multisite grain sorghum irrigation study. These studies were important for understanding grain sorghum yield response to irrigation but did not include long-term inter-decadal variations in climate and their influence on grain sorghum response to water. In this study, we assess the effect of IC on grain sorghum when irrigation initiated at planting versus when irrigation is initiated at panicle initiation for two widely used grain sorghum cultivars in western Kansas.

The objectives of this study were to: 1) evaluate the DSSAT-CSM (hereafter DSSAT) model for simulating grain sorghum growth and development in semi-arid western Kansas, 2) apply the evaluated model to generate grain sorghum production functions for five different IC as a function of irrigation scheduling and cultivars (short versus long season), and 3) evaluate response of grain sorghum under various IC in western Kansas under variable climate using long term historical weather data; 4) determine the minimum irrigation capacity required for irrigating grain sorghum in western Kansas.

2. Materials and methods

2.1. Study site

The study was conducted at the Kansas State University Southwest Research–Extension Center near Garden City, Kansas with the geographical location of 38° 1′ 20.87″ N, 100° 49′ 26.95″ W, and elevation of 887 m above mean sea level. The climate is semiarid with the main growing season for grain sorghum between May and October. The estimated long term (1950–2013) annual rainfall and reference evapotranspiration based on FAO-Penman Monteith (Allen et al., 1998) were approximately 455 mm and 1405 mm, respectively. The average maximum and minimum air temperature between May to October were reported to be 28.3 and 12.3 °C, respectively, with frost-free period of about 170 days (Klocke et al., 2012). Ulysses silt loam is the major soil type in the study site with bulk density of 1.36 g/cm^3, and field capacity, wilting point, and water content at saturation of 0.33, 0.15 and 0.46 mm/mm, respectively (Klocke et al., 2012).

2.2. Agronomic management

Grain sorghum was planted after the top 5–10 cm soil temperature reached at least 16 °C or above (Fig. 1). Germination of grain sorghum is halted if temperatures are below 15 °C (Wani et al., 2012). According to Fig. 1, on an average, after day of year (DOY) 136 is a suitable time for planting grain sorghum. Other criteria such as initial soil moisture were also considered (60–70%). Planting date was set in the model to be June 15th. Two cultivars were considered for scenario analysis: late (long) (120–140 days) and early (short) (90–110 days) maturing cultivars. Based on local practices, plant population was assumed to be 18 plants per m^2 and nitrogen applied was 102 kg N/ha (time of application of N was: 22 kg at time of planting and 80 kg N/ha a month after planting).

Irrigation was applied using a center pivot sprinkler with assumed irrigation efficiency of 90%. The treatments included two cultivars (late and early maturing), three irrigation scheduling scenarios: – irrigated from (1) planting to maturity, (2) panicle initiation to grain filling and (3) panicle initiation to maturity (Table 1). Normally the decision to apply irrigation may depend on the irrigation needed, cost or yield goal