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Evaluation of maize production under mobile drip irrigation

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ABSTRACT

Declining water levels in the Ogallala aquifer of the U.S. High Plains necessitate more efficient irrigation technology to sustain agricultural production. A study to evaluate the performance of Mobile Drip Irrigation (MDI) for maize production, in comparison to common center-pivot nozzles (Low Elevation Spray Application (LESA) and Low Energy Precision Application (LEPA)) was conducted. A center-pivot was retrofitted with MDI, LEPA and LESA. Irrigation capacities of 6.3, 3.1, and 1.6 mm/d were considered. Grain yield, water use efficiency, above ground biomass, leaf area index (LAI), and soil water content was compared. Differences in grain yield between irrigation application devices were not significant ($p = 0.085$), but there were differences between irrigation capacities ($p < 0.0001$) at 5% significance level. There were no significant differences in monthly biomass yield between the application devices but there were significant differences in biomass yield between irrigation capacities. There were no significant differences in LAI between both the application devices and irrigation capacities. There were no significant differences in water use efficiency between the application technologies ($p = 0.2352$), at 5% significance level, however, differences between irrigation capacities were significant ($p = 0.050$). Generally, crop biophysical measurements under MDI were not significantly different from those under LEPA and LESA. Any marginal benefits of MDI were likely masked by rainfall, thus further evaluation of MDI is recommended under conditions of less applied water than LEPA or LESA accompanied by low rainfall. The other benefits of MDI were found in reduction of wheel-track rutting and ease of carrying out fertigation.

1. Introduction

Maize is one of the major crops cultivated in the U.S. Midwest, and it is among the five main crops grown in Kansas (Kansas Department of Agriculture, 2016a). The state of Kansas is among the top ten producers of maize for grain in the U.S. contributing 4% of the total national production (USDA National Agricultural Statistics Service, 2015). In addition to grain production and to a lesser degree, Kansas grows maize for silage. Between 2011 and 2015, the average value of maize exported annually from Kansas was $339.92 million (Kansas Department of Agriculture, 2016b), making it the fifth largest agricultural export. The land area under maize production in Kansas has increased over the years indicating an upward trend into the future. Between 2006 and 2016, the average acreage under maize production was 1,738,125 ha (Kansas Department of Agriculture, 2016b). The crop is grown in all geographic regions of Kansas, but the southwest and northwest regions of the state are two largest production areas by land area. These areas are also in the western region of Kansas, which receives the lowest amounts of rainfall averaging 440 mm annually (Goodin et al., 2004; Rahmani et al., 2013). Maize is the most irrigated crop in Kansas according to (Kenny and Juracek, 2013) and requires from 500 to 800 mm of water to meet full crop evapotranspiration demands (Rogers et al., 2015). To meet the water demand in western Kansas, additional 13.6 to 81.8% of crop water need to be supplied through irrigation. According to Kenny and Juracek (2013), the mean irrigation application rate for maize in Kansas is 381 mm/year with an upward trend in the acreage from 1992 to 2011. In 1992, maize contributed to 43% of irrigated agriculture followed by increase to 56% in 2000 and 58% in 2011 (Kenny and Juracek, 2013). Although maize production in Kansas has steadily increased over the years, the amount of water in the Ogallala aquifer, which is a main source of groundwater used for irrigation, declined (McGuire, 2017; Steward et al., 2013; Wada et al., 2010). This reduction in groundwater levels has led to diminished well pumping capacities (Steward et al., 2013) and affected farming decisions and management practices. Improved irrigation efficiency is the water management strategy that can extend the usable life of the Ogallala

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aquifer as well as better cope with water scarcity.

More than 90% of irrigation in Kansas (Rogers et al., 2008) is done using center-pivots that are typically fitted with Low Elevation Spray Application (LESA) nozzles (Lamm et al., 2006). LESA is one of two spray nozzle categories. The other is Mid Elevation Spray Application (MESA) which is suited for fields with high elevation changes. Although not common in Kansas, Low Energy Precision Application (LEPA) nozzles are widely used in many regions of the Southern High Plains, like Texas (O'Shaughnessy et al., 2016; Schneider and Howell, 1999). The earliest iteration of LEPA devices were developed by Lyle and Bordovsky (1983), in Texas, and the primary design objective was to develop devices which could operate at low pressures in order to reduce energy costs in irrigation (Lamm et al., 2006). A LEPA application device could refer to either a sock that is dragged on the ground, or a bubbler fitted a slight distance off the ground (Schneider and Howell, 1999). For this study, a LEPA bubbler was selected. The application efficiencies of these technologies are in the ranges of 70–80% for LESA (Irmak et al., 2011; Rajan et al., 2015), 80–95% for LEPA (Irmak et al., 2011; Waller and Yitayew, 2016) and 60–70% for MESA (Rajan et al., 2015). Though they are relatively efficient irrigation technologies, there are some water loss pathways which they cannot prevent, like canopy interception and evaporation, soil water evaporation, wind drift and runoff. Mobile Drip Irrigation (MDI), in theory, has potential to eliminate the above-mentioned water loses, hence improve irrigation efficiency of center-pivot systems. In MDI, water is applied directly to soil surface instead of aerial broadcasting in LEPA and LESA. MDI is the combination of drip irrigation, presently the most efficient irrigation method (Goyal, 2012; Pathak et al., 2009), and center-pivot systems. Instead of typical spray nozzles, the center-pivot is fitted with drip lines that are dragged along the soil surface as the center-pivot rotates during irrigation event. The MDI concept has been tried in the past using various configurations that were dependent on the prevailing technologies of the time (Phene et al., 1985, 1981), but its development and adoption was beset by technological challenges. With technological advancements in irrigation, such as improvement in water filtration and pressure compensating emitters (Kisekka et al., 2017), the interest in MDI was revived and, furthermore, bolstered by the need for more efficient irrigation technologies to better adapt to water scarcity and increase water conservation. The objective of this study was to evaluate maize production under MDI as compared to LEPA and LESA, two common irrigation application devices used by farmers in the Ogallala area of Kansas. This is an effort to benchmark modern MDI against other well-known and widely-used irrigation technologies.

2. Materials and methods

2.1. Field description

A two-year field experiment on biophysical properties of maize impacted by different irrigation technologies (MDI, LEPA and LESA) was conducted at the Kansas State University's Southwest Research and Extension Center near Garden City, Kansas (32.024° lat., -100.826° long., 885 m above sea level). The experimental field was in Ulysses silt loam soil (Stone et al., 2011) and under four-span center-pivot with Variable Rate Irrigation (VRI) capability. The center-pivot had the following specifications: span one 41.6 m; spans two and three 41.2 m; span four 41.1 m; and 5.5 m overhang (Fig. 1). The experiment was set up on the eastern half of the center-pivot as a 3 × 4 split-plot randomized complete block design, with two factors (irrigation capacity and irrigation application device) and three replications (Fig. 1). Span 1 was maintained as a system failsafe and kept operational for each irrigation event but was not considered for data collection. Therefore, there were 12 treatments in each block, with a total of 36 treatments for the whole experiment. A treatment was made up of an irrigation device and an irrigation capacity. Each span was divided into four equal parts that accommodated two MDIs with dripper flow rates of 3.8 L/h and 7.6 L/h (hereafter, MDI_1 and MDI_2, respectively) as shown in Fig. 2, LEPA bubbler, and LESA spray nozzle. The applied three irrigation capacities were 6.2, 3.1, and 1.6 mm/d that related to full, 1/2, and 1/4 maize evapotranspiration (ET) demands, respectively, for the studied site. A matrix of the irrigation treatment combinationsis shown in Table 1 below.

2.2. Agronomic management

For both years, a no-till planter was used to plant the maize, in fields covered with stubble from previous seasons. The maize varieties of Deklab 64–89 in 2016 and Deklab 62–98 in 2017 were planted at a seeding rate of 84,016 seeds/ha.

In the 2016, the maize was planted on May 6th and emerged on May 23rd, while in 2017, it was planted on May 8th and emerged on May 22nd. Fertilizer was applied in three stages: (1) nitrogen in form of urea (N-P-K; 46-0-0) applied at rate of 336.3 kg/ha before planting; (2) phosphorus (N-P-K; 11-52-0) applied before planting at a rate of 112.1 kg/ha and; (3) nitrogen, phosphorus and potassium fertilizer combination (N-P-K; 10-34-0), applied in liquid form at a rate of 93.5 L/ha at the time of planting. For both 2016 and 2017, the following herbicides were applied to maize-stubble covered field before planting: (1) Starene Ultra (fluroxypyr) at a rate of 0.95 L/ha; (2) Lumax EZ (S-metolachlor, atrazine, mesotrione) at a rate of 7.0 L/ha and; (3) Sharpen (saflufenacil) at a rate of 0.15 L/ha. In 2016, Roundup Max (glyphosate) was also applied at a rate of 2.3 L/ha before planting in addition to the mentioned herbicides. In 2017, Rifle (dicamba) at a rate of 1.2 L/ha, Balance Flexx (isoxaflutole) at a rate of 0.11 L/ha, and Cornbelt atrazine 90DF (atrazine) at a rate of 1.12 kg/ha were also parts of the herbicide treatment before planting. Furthermore, Prowl H2O (pendamethalin) at rate of 3.5 L/ha and Roundup Max (glyphosate) at rate of 2.3 L/ha were applied after maize emergence in 2017. A pesticide, Zeal SC (etoxazonle), was aerial-sprayed at a rate of 0.29 L/ha on 9 August 2017 as an extra treatment against spider mite infestation.

2.3. Irrigation management

After planting, 12.7 mm of water was applied to all treatments to aid germination uniformity. Thereafter, irrigation schedules were determined by frequently computing the water balance using soil water content, rainfall, and reference evapotranspiration data. During each irrigation event, 25.4 mm of water was applied to all studied plots and considered to complement water application by rainfall during the season. The irrigation capacities of 6.2, 3.1, and 1.6 mm/d were derived from well capacities of 37.9, 18.9 and 9.5 L/s, respectively. The irrigation capacity of 6.2 mm/d was designed to ensure meeting full seasonal ET requirement for maize. Thus, the irrigation capacities of 3.1 and 1.6 mm/d met 50% and 25% of seasonal ET, respectively. In the 2016 season, the amounts of water applied were 215.9, 114.3, and 88.9 mm for respective irrigation capacities of 6.2, 3.1, and 1.6 mm/d, while in 2017 they were 266.7, 139.7, and 88.9 mm/d, respectively (Tables 2 and 3).

2.4. Soil water content

Soil water content was measured weekly, unless hindered by excessive rainfall events, using a neutron attenuation probe (CPN 503DR Hydroprobe by Campbell Pacific Nuclear International Inc.; http://www.cpn-intl.com/503-elite-hydroprobe/). In each treatment sub-plot, neutron probe access tubes were installed for measuring volumetric soil water content at 0.3 m intervals up to a depth of 2.4 m. Each neutron probe access tube was installed between two plants in a selected row.

2.5. Biophysical properties

Biomass measurements were taken monthly. For each treatment,