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Impact of irrigation, surface residue cover and plant population on sugarbeet growth and yield, irrigation water use efficiency and soil water dynamics

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ABSTRACT

Currently, sugarbeet producers in western Nebraska are facing the challenge of reducing their irrigation water usage due to ground water pumping restrictions and the unpredictable amount of rainfall that is available from year to year. Therefore, there is an increasing interest in developing season long deficit irrigation strategies for sugarbeet, the main objective of this study. The other objectives were to determine the impact of surface residue and plant population on sugarbeet production. Three field trials were conducted in eight consecutive cropping seasons (2008–2015). The average root and sugar yield for the full irrigation treatment were equal to 71.11 and 11.08 Mg ha^{-1}, respectively during the 6 years of the two irrigation studies (2008–2013) while applying 75% and 50% ETc on average caused 9% and 11% yield reduction, respectively (2008–2011). Plots under full irrigation treatment and rainfed showed highest and lowest water depletion, respectively. Overall based on six years of data (2008–2013), stressing moderate and severe late in growing season produced 1.03 and 1.87 Mg ha^{-1} more sugar while consuming about 13 mm less water than imposing same level of stress early in season. The residue covered plots produced 0.29 Mg ha^{-1} more sugar yield than bare soil plots on average across treatments and years. Overall, higher population rates resulted in higher sugarbeet yield. Findings of this research will deliver insight for sugarbeet irrigation management.

1. Introduction

1.1. Irrigation water management in the Nebraska Panhandle

The growing demand for food and fiber production along with the limited fresh water resources and the intrinsic uncertainty in rainfall patterns, due to climate variability and change, has focused a great attention on agricultural water management. World agricultural production over the last fifty years has grown between two and four percent per year on average while irrigation has doubled in the same time period. Irrigated agriculture has the highest rate of consumption of the fresh water resources (about 70%) and produces more than 40% of the food supply while using approximately 17% of the agricultural land area (FAO, 2013). In arid and semiarid climates, irrigation is essential for crop production wherein a crop failure or a significant reduction in the amount of yield would most likely occur without irrigation. The ever increasing demand for water and it's intense scarcity, creates a philosophy of "more crop per drop" and makes deficit irrigation a common practice, that by definition means to deliberately apply water below the evapotranspiration (ET) requirement.

Nebraska has the highest amount of irrigated area (over 3.5 million ha) in the US, making water a critical element of the state's economy and agricultural production. Sustainable irrigation water management has become a top priority since irrigated agriculture accounts for more than 90% of all ground water consumption across the state (Irmak et al., 2010; USGS, 2000). The western Nebraska high plains (Nebraska Panhandle) contains about 300,000 ha of irrigated agricultural land with hay & haylage, dry edible beans, sugar beets and corn being the predominant commodities. Irrigation district developments in western Nebraska began in the 1920's with reservoir construction in the Rocky Mountains, making it possible for diversions of surface flow through irrigation canals. Currently, irrigation water is largely supplied as surface water by canals, while

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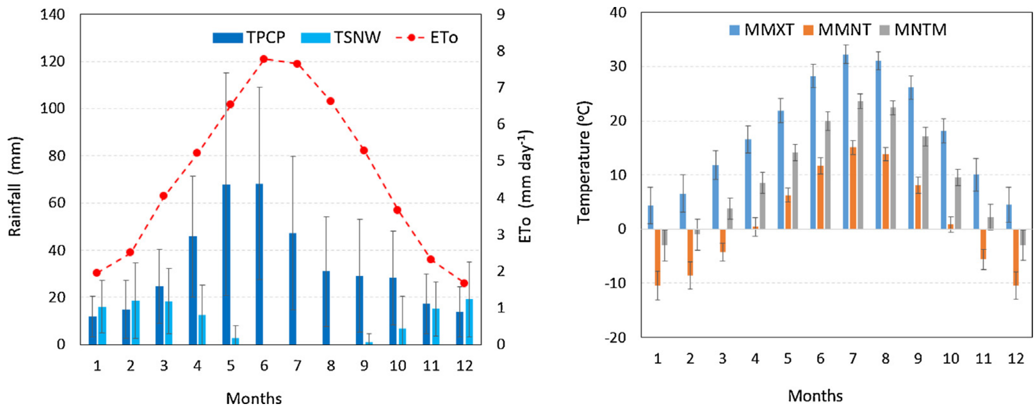

Fig. 1. Long term (1976–2015) average and standard deviation of the temperature and rainfall data for the study region located in western Nebraska (http://www.ncdc.noaa.gov/cdo-web/). The long term average ETo data (1981–2015) were obtained from the High Plains Climate Center (Changnon et al., 1990). MMXT: monthly mean maximum temperature (°C), MMNT: monthly mean minimum temperature (°C), MNTM: monthly mean temperature (°C), TPCP: total precipitation (mm), TSNW: total snowfall (mm).

groundwater irrigation wells are also common. Given the low average rainfall (356–406 mm year^{-1}) water shortage is more severe when compared to other regions across the state, hence the need for water conservation is more strategic. Since irrigation has the highest amount of fresh water consumption rate in the region, sustainability of water resources is highly influenced by irrigation water use efficiency (I_{WUE}).

1.2. Sugarbeet production in western Nebraska

Sugarbeet is a biennial crop that uses first year and second year growth to maximize root yield (accumulate sugar) and to produce seeds, respectively. The commercial sugarbeet has been created by intense breeding over time as a crop appropriate to the synthesis and storage of sucrose. Planting sugarbeet for sugar production has originated in central Europe in early 1800s and then spread around the world. In the United States, the first successful processing plant was built in California in mid 1800s which then was followed by other factories built in Nebraska and Utah. Sugarbeet has been an important agricultural crop in central high plains (Colorado, Montana, Nebraska and Wyoming) for the last century and currently annual sucrose production in the region is approximately 15% of the total sucrose produced in the US (Wilson and Smith, 2013).

The Nebraska Panhandle has a suitable range of climate and weather patterns for sugarbeet production wherein normally little rain falls over the growing season making irrigation essential for achieving economic yield and sustaining commercial production. Currently, sugarbeet producers in western Nebraska are facing the challenge of reducing their irrigation water usage and practicing deficit irrigation, with consideration to ground water pumping restrictions and the unpredictable amount of rainfall from year to year. Consequently, precise irrigation management is crucial for enhancing I_{WUE} and reducing the volume of water applied without seriously affecting sugarbeet yield. The findings of the previous sugarbeet irrigation studies in the region indicate that sugarbeets can tolerate moderate late season soil water stress and produce a profitable yield (Yonts et al., 2003).

It is critical to find efficient management approaches to minimize evaporation from soil surface, runoff, and deep percolation hence maximizing plant transpiration per unit of applied water. Planting directly into crop residue versus bare soil, may prevent stand reduction due to wind and heavy rain damage and also may have a positive impact on moisture retention at the soil surface for seedling development. Since the soil surface is partially protected from solar radiation and air movement above the soil surface is lower than bare soil, it is expected that a covered soil surface with residue shows lower evaporation rate. However, crop residue cover may also cause wet soil surface and lower temperature delaying planting date, and slower emergence. (Van Donk et al., 2010).

In the Nebraska Panhandle despite the average low in-season rainfall, pre- and early- season precipitation events are extremely important for growers since, if adequate, they significantly contribute in refilling the soil profile which in turn effects irrigation water requirement and management throughout the growing season. Growers, however, are likely to get some storms and hail damages with early season precipitation. When this happens, the main critical question is the economic feasibility of replanting and expected yield for different plant populations.

There is an increasing interest in developing efficient season long deficit irrigation strategies for sugarbeet among growers in the Nebraska Panhandle, the main objective of the current study. The specific objectives are to:

(i) Evaluate the impact of different irrigation scenarios (i.e. full irrigation, deficit irrigation and rainfed) on sugarbeet growth and yield indicators (i.e. plant height, leaf area index, root yield and sugar yield) in western Nebraska.
(ii) Determine the potential effect of surface residue cover on water conservation and in turn sugarbeet yield under the above mentioned irrigation management scenarios.
(iii) Establish seasonal water production functions (WPFs) for sugarbeet using regression models.
(iv) Monitor the soil water status within crop effective root zone at multiple depths throughout growing season on multiple experimental plots under a variety of irrigation and surface residue conditions and analyze the I_{WUE} for different irrigation regimes.
(v) Evaluate the sugarbeet production when plant population is less than optimal under overhead and gravity irrigation methods.

2. Material and methods

2.1. Deficit irrigation experiment (2008–2011)

A four-year experiment (2008–2011) was conducted at the University of Nebraska Panhandle Research and Extension Center (PREC) located at Scottsbluff, Nebraska (41.89°N, 103.68°W, elevation: 1189 m, annual precipitation: 394 mm) to study sugarbeet response to different deficit irrigation strategies. The soil at Scottsbluff is a Tripp very fine sandy loam (coarse-silty, mixed, superactive, mesic Aridic Haplustolls; pH = 7.3; organic matter content = 1.8%). The volumetric water content at field capacity