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Summary

Declining groundwater in the Central Great Plains is pressing producers to look for more efficient irrigation methods than the traditional center-pivot sprinkler and linear systems. Subsurface drip irrigation (SDI) can be a viable alternative when water is limited, or irrigation capacity is insufficient in conventional methods. However, the irrigation system does not guarantee all the potential benefits; adequate design and management are also required. The research was conducted at Kansas State University Northwest Research and Extension Center in Colby, KS, during the 2023 growing season to evaluate irrigation strategies, water use, water productivity, and corn yield as well as to simulate and calibrate the soil water redistribution model. Irrigation strategies were combinations of irrigation frequency/timing (weekly or bi-weekly) applied pre- and post-silking. Irrigation levels were 100%, 85%, 75%, and 65% of calculated well-watered ET minus rain. Average irrigation amounts ranged from 6.9 to 11.2 inches. Hybrid maturity was 112 days, planted at 28,000 seeds/a. Corn yields were slightly affected by irrigation strategies, ranging from 195.8 to 202.3 bu/a.

Introduction

Western Kansas farmers are under pressure from hydrologic and institutional restrictions to reduce withdrawals from the declining Ogallala aquifer. Indeed, the primary irrigation system in western Kansas is the center pivot sprinkler irrigation system. Nevertheless, only a few subsurface drip irrigation (SDI) systems are installed and operated for crop production. A major disadvantage of SDI systems is their high initial cost; however, there are some scenarios where the economics can compare favorably with center pivot sprinklers (Lamm et al., 2020), including rodent damage, hand labor, reparation of leaks, and constant monitoring and evaluating irrigation events. Lamm and Trooien (2003) reported that SDI can reduce irrigation water use for corn production by 35% to 55% compared with traditional irrigation methods. Camp (1998) indicated that yield for over 30 crops was greater or equal using SDI than that obtained with other irrigation methods and, in most cases, required less water. Experimental studies have evaluated numerous design factors for SDI systems for corn production on deep silt loam soils of the Central Great Plains. Dripline depths ranging from 8 to 24 inches were acceptable for corn production with no significant differences in water productivity (WP) and only slight reductions in corn grain yield (Lamm and Trooien, 2005).

Understanding the full potential of SDI requires improving design parameters, such as the frequency and duration of irrigation, the emitter discharge rate, space between drip lines, and placement depth. Numerical simulations efficiently investigate optimal drip management practices (Cote et al., 2003; Schmitz et al., 2002; Meshkat et al., 1999). Simulation models allow one to consider the physical processes governing water flow in the root-soil zone and, consequently, to evaluate the dimension of the wetting patterns as a function of the amount of applied water. Knowing the wetted soil volume dimensions as a function of time helps identify proper design parameters and the duration of the irrigation event (Provenzano, 2007). Using simulation models contributes to developing management scenarios and strategies for irrigation. To validate the accuracy of a model, it is necessary to calibrate the model by using experimental measurements (Provenzano, 2007). This study aims to evaluate the effect of different irrigation levels on corn yield, water use, and water productivity, as well as to simulate and calibrate the soil water redistribution model of HYDRUS-2D in a deep silt loam soil of semi-arid Western Kansas.

Experimental Procedures

Field studies were conducted at Kansas State University Northwest Research-Extension Center at Colby, KS, during the 2023 growing season on a deep, well-drained, loessial Keith silt loam soil (Aridic Argiustoll), described in more detail by Bidwell et al. (1980). The 8-ft soil profile holds 17.5 inches of available water at field capacity. The location's climate is semi-arid with a summer precipitation pattern and a long-term average annual rainfall of approximately 18.8 inches. Average long-term precipitation is approximately 16 inches during April through October. The average seasonal total crop evapotranspiration (ETc) for corn is 23 inches. The study consisted of a randomized complete block design of three replications of four different irrigation treatments (100%, 85%, 75%, and 65% of calculated well-watered ET minus rain). Each plot was 20 ft wide and 280 ft long, with driplines spaced at 5 ft running west to east. Buffer distances of approximately 20 ft and 40 ft were provided on the west and east edges of the study area, respectively, to reduce environmental influences from outside the study area.

The weather-based water budget was constructed using data collected from the NOAA weather station located approximately 0.37 miles northeast of the study site. The reference evapotranspiration (ETr) was calculated using a modified Penman combination equation. The specifics of the ETr calculations used in this study are fully described by Lamm et al. (1987). Alfalfa-based ETr gives better estimates than short-grass ETo in this region (Howell et al., 2008). Fertilization was applied to enhance yields. Herbicide control procedures were used to minimize weeds. The average flow rate in the system was 1.5 GPM. Soil water was measured in the complete root zone (8 ft) with neutron probes periodically throughout the season (two times per month) to quantify water stress periods and calculate crop water use. Hand harvesting of representative corn samples at physiological maturity was done to determine corn grain yield.

Crop water use was calculated as the sum of rainfall, irrigation, and the seasonal change in available soil water within an 8-ft soil profile. Crop water productivity was calculated as yield divided by the crop water use. The two-dimensional module of software HYDRUS 2D/3D version 2.x was used to simulate soil water movement. Information on field dimensions, soil type, weather, irrigation design, and management were used in the simulations. HYDRUS 2D/3D simulated the soil water flow and computed the soil volumetric water content's spatial and temporal distributions. The input data included root water uptake parameters, evapotranspiration, rain, initial soil water conditions, and irrigation water flux rates. Data analyses included comparisons of simulated and observed soil water content, the correlation of corn yield, seasonal water use, and water productivity as affected by the four irrigation treatments.

Results and Discussion

The growing conditions were satisfactory for decent corn production in the 2023 growing season. The average precipitation in 2023 was nearly 17.17 inches during April-October and 16.98 inches of rain from planting until harvest. The irrigation amounts applied were 11.2, 9.4, 8.1, and 6.9 inches for the 100%, 85%, 75%, and 65% ET - Rain treatments, respectively. Corn hybrid DeKalb DKC62-69RIB yielded well. Average corn yields were 202.3, 199.3, 197.8, and 195.8 bu/a for the 100%, 85%, 75%, and 65% ET - Rain treatments.

Crop water productivity was also high for this study, averaging 427, 452, 473, and 494 lb/a-inch for the 100%, 85%, 75%, and 65% ET - Rain treatments (Table 1). The results showed no significant differences in corn grain yield, demonstrating that even replacing irrigation at 75% of ET - Rain in a year with reasonable precipitation amounts, as in 2023, could be an acceptable irrigation strategy to save water and attain a high yield. However, the good precipitation and good water holding capacity for this deep, silt loam soil during the 2023 growing season may be buffering differences that would likely occur between irrigation treatments in drier years. Dripline distances of 5 ft in the area supply enough water to attain reasonably high yields at the planted population. Corn is a deep and extensively rooted crop that can explore a large zone within the soil. A large irrigation event would benefit wider spacings.

The HYDRUS-2D model reasonably predicted soil water contents in the growing season. HYDRUS-2D performance was evaluated by comparing simulated and observed soil water content, root mean square error (RMSE), and the coefficient of determination (R^2). Lower RMSE and higher R^2 were the criteria for evaluating the model's performance. The root-mean-square error (RMSE) for the simulated and measured volumetric water contents provides a quantitative measure of the good fit between the data and the simulation. Table 2 gives the RMSE value for the compared first neutron probe reading and HYDRUS-2D simulation results. The RMSE values range from 0.015 to 0.036 $cm^3\ cm^{-3}$. The lower the RMSE values, the better the model performance, indicating good accuracy. Regression results had similar slopes and y-intercept values. Figure 3 shows the slope values of the three replicates of actual water contents for the first irrigation treatment. They range from 0.7 to 0.95, and intercept values range from 0.03 to 0.1 $cm^3\ cm^{-3}$. Similarly, the three replicates yielded high R^2 values (0.96, 0.90, 0.99), indicating a strong relationship between predicted and actual results. The results support using soil water simulation models as a valuable tool for simulating soil water dynamics. Correlations indicate that the model's ability to predict water contents shows a good agreement for the study area. The model calibration and validation can help irrigation engineers and extension agents model the soil water transport in corn with SDI.

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Table 1. Corn yields, total crop water use, and water productivity (WP)

Irrigation treatment	Repetitions	Yield	Water use	WP
		bu/a	inches	lb/a-inch
Trt 1: 100% ET	1	202.3	26.49	428
Trt 2: 85% ET		198.0	24.64	450
Trt 3: 75% ET		198.6	23.40	475
Trt 4: 65% ET		196.0	22.15	495
Trt 1: 100% ET	2	201.5	26.59	424
Trt 2: 85% ET		199.6	24.74	452
Trt 3: 75% ET		196.5	23.50	468
Trt 4: 65% ET		195.5	22.25	492
Trt 1: 100% ET	3	203.1	26.48	430
Trt 2: 85% ET		200.4	24.63	456
Trt 3: 75% ET		198.4	23.39	475
Trt 4: 65% ET		196.1	22.14	496

Table 2. Root-Mean-Square-Error (RMSE) for the HYDRUS-2D simulation

Irrigation treatment	RMSE 1	RMSE 2	RMSE 3
Trt 1: 100% ET - Rain	0.022	0.020	0.018
Trt 2: 85% ET - Rain	0.021	0.017	0.012
Trt 3: 75% ET - Rain	0.017	0.022	0.027
Trt 4: 65% ET - Rain	0.015	0.033	0.036

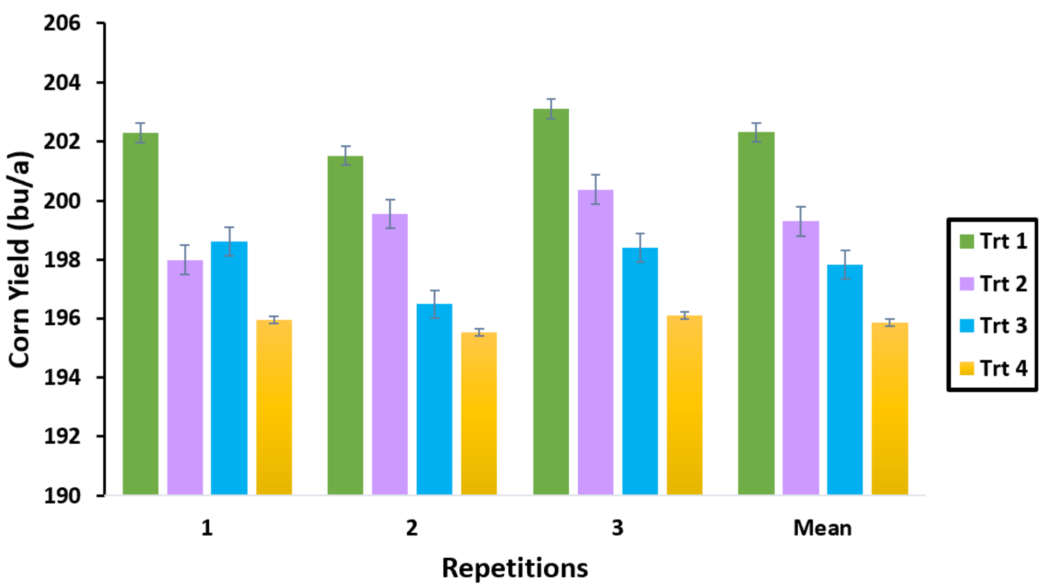

Figure 1. Corn grain yields (bu/a) for the four irrigation treatments designed to match 100%, 85%, 75%, and 65% of well-watered corn ET minus rain.

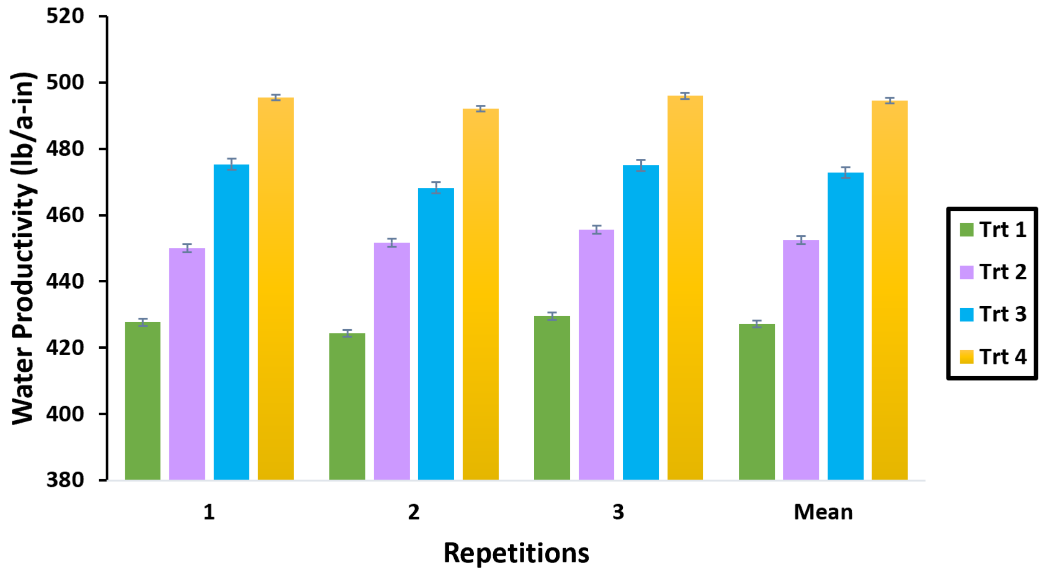

Figure 2. Water productivity (lb/a-inch) for the three irrigation treatments designed to match 100%, 85%, 75%, and 65% of well-watered corn ET minus rain.

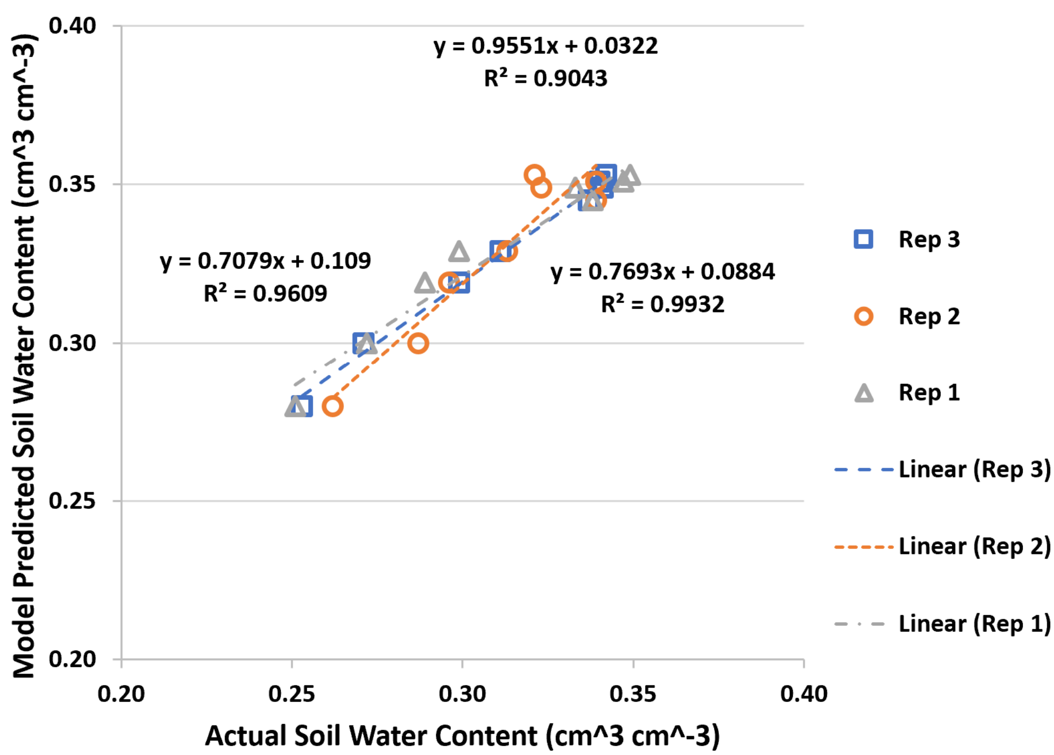

Figure 3. Correlation of predicted vs. actual water content.