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Application of Sensor-Based Precision Irrigation Methods for Improving Water Use Efficiency of Maize Crop †

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Abstract: Soil moisture sensors and hydraulic modeling play a vital role in managing surface irrigation systems. Crop water productivity can be improved by managing the inflow cut-off time and optimizing the other field scale measurements. As such, hydraulic modelling and field experiments were carried out at the University of Agriculture Faisalabad-Pakistan. The soil moisture sensor (SEN-13322) and the WinSRFR model were used for this purpose. In total, nineteen treatments including eighteen simulated treatments and one conventional treatment were designed at two levels of discharge (Q_1:0.0025 and Q_2:0.0035 m^3s^{-1}), at three sensor positions (S_1:55%, S_2:65%, and S_3:75%) across the field length, as well as with three different border widths (B_1:6.4m, B_2:8.5m, and B_3:10.7m) after successful sensor and model calibration during the two growing seasons of 2016–2017 and 2017–2018. The results revealed a significant difference between the means and the treatment T_{10} i.e., $Q_2S_1B_1$ that were found to be highly efficient and uniform.

Keywords: cut-off time; WinSRFR model; border width; irrigation science; crop production

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1. Introduction

Water shortage has become a major problem and challenge around the world in recent decades. The shortage of water has also affected agricultural output and encouraged scientists to consider how best to manage the available water resources. Pakistan is a developing nation that struggles with problems, including the lack of water as a result of industrialization, urbanization, and the rising demand for water [1]. The current per capita amount of water resources in Pakistan ranges from 5600 m^3 to 1000 m^3 [2]. To address the issue of water scarcity and to satisfy the demand for agricultural products while maximizing the use of limited amounts of available water resources and minimizing water losses, efficient irrigation methods at the farm level are needed [3]. The farmers in Pakistan irrigate their crops using age-old techniques (i.e., flood irrigation) that involve flowing water like a sheet along the field's length.

With the flood irrigation technique, uncontrolled water runs toward the end of the field, which usually waterlogs the crop and irrigates it more than the crop water requirement, resulting in overall yield decrease and the wastage of water. If irrigation water is cut-off at the right time before it reaches the field tail-end boundaries, the effectiveness of the surface irrigation system can be improved [4]. To use the cut-off approach, a farmer must make numerous field rounds to determine when the dose of water has reached a particular distance from the starting end or away from the tail end. But this investigation could be difficult, therefore, advanced techniques are required for accurate measurements to cut-off water supply and to save water while increasing crop productivity. A common surface irrigation system is fitted with soil moisture sensors, which may help supply minimal water without over-irrigating [5]. Although there are many different hydrological models, the WinSRFR is a more sophisticated version of the SRFR model and offers more computational possibilities than other hydrological models [6]. In this study, the traditional sensor-based systems were also integrated with Wi-Fi and computer communication networks to automate Pakistan's irrigation system and determine the actual irrigation interval.

2. Materials and Methods

2.1. Experimental Site

This experiment was carried out at the Postgraduate Agriculture Research Station (PARS), University of Agriculture, and Faisalabad-Pakistan. For the experiment, a field of 33.84 m × 27.44 m was divided into 30 equal grids. Each grid was 5.64 m × 5.488 m, and soil samples were collected from each grid at the depth of 9 in for physical and chemical analysis. The field capacity in the experimental field area was determined using a soil moisture tester.

2.2. Hydraulic Simulation Model of Surface Irrigation System

In the present study, the USDA-developed WinSRFR 4.1.3 was used to simulate a surface irrigation system. The WinSRFR is the latest and most popular model being used for this type of study [7].

2.3. Model Calibration

The location of the single directing point affects the flow rate, cut-off time, and infiltration parameters. During land preparation, which includes making a border with varying width and length at the experimental site, 10 pegs of 30 cm height were positioned at equal intervals along the borders. Subsequently, the time was noted when the water reached each peg. Finally, the WinSRFR model and the advance times derived from field data were compared.

2.4. Experimental Design in WinSRFR

Almost ninety treatments were created in the model by combining different border widths, discharge cut-offs, and inflow cut-offs concerning distance. However, all the other parameters including field length, field slope, and field depth, etc. were held constant during the simulation process. Among these total treatments, 19 (one traditional and 18 simulated) were used in the actual field studies. These treatments had three levels for sensor position (55%, 65%, and 75%) and border width (6.4 m, 8.5 m, and 10.7 m).

2.5. Water Use Efficiency

In this study, crop yield and the total water consumed by the crop over the season was used to calculate water use efficiency (Equation (1)), which is also known as true agricultural water productivity [8].

$$\mathrm{CWP} = \frac{\text{Grain yield } (\mathrm{Kg\ ha^{-1}})}{\text{Water applied } (\mathrm{mm})} \quad (1)$$

3. Results and Discussion

3.1. Soil Chemical Analysis

The analysis of the soil samples showed that the soil pH ranged from 7.7 to 8.7 and had a range of 2 to 11 ppm for the readily available phosphorus. High phosphorus concentration in soil is recommended [9] because it appears to be crucial for soil fertility and for preventing soil from becoming zinc deficient. Additionally, the range of the amount of accessible nitrogen in soil samples was between 0.017 to 0.042%.

3.2. Moisture Sensors Calibration

The relationship between the moisture content and the sensor reading resistivity was successfully established. These sensors are excellent for irrigation scheduling due to the high coefficient of determination i.e., 0.98 (Figure 1).

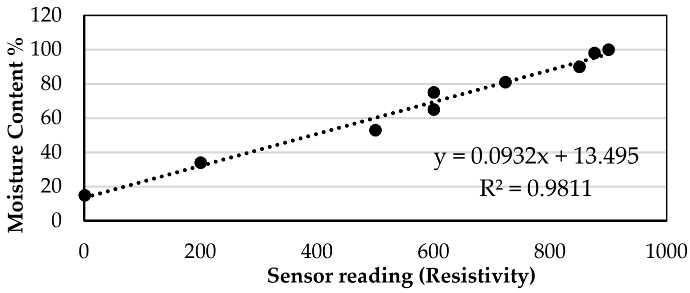

Figure 1. Comparison between soil moisture content (%) and sensor reading (resistivity).

3.3. WinSRFR Hydraulic Simulations

The WinSRFR model was successfully calibrated, and to prevent over- or under-irrigation, hydraulic simulations of all the treatments were run on the model. Application efficiency (AE) alone cannot provide a reliable indicator of how well surface irrigation is working. Additional measurements are needed that include the distribution uniformity lower quarter (DUlq) and the distribution uniformity minimum (DUmin) [10]. These three performance indices (i.e., AE = 92, DUmin = 87, and DUlq = 91) showed higher values, indicating that the treatment T_{10} has excellent uniformity and efficiency.

3.4. Plant Growth Parameters for Maize

The crop yield is affected by various plant growth factors, including the plant population per unit area, the plant height, the number of leaves per plant, the leaf area index, the length of a cob, the number of cobs per row, and the number of seeds per cob. The average number of plants for the treatments T_{10} and T_{11} was 230 and 225, respectively. The lowest counts were in the second year when there was an average of 215 and 170 plants for T_{12} and T_{14}, respectively. The smallest plant height in T_9 was 146.3 cm, while the largest in T_{14} was 181.44 cm.

3.5. Water Use Efficiency

Water use efficiency provides information about how effectively the field's crop utilized the applied water. A sensor was used to compare the differences in the irrigation water application between the two years based on the total rainfall and the soil moisture levels. Figure 2 displays the Water use Efficiency (WUE) of maize for the year 2016–2017 and 2017–2018. The Maximum WUE was 15.78 kg/ha/mm observed in T_{10}; 13.88 kg/ha/mm in T_{11}; 13.07 kg/ha/mm in T_1; and 3.17 kg/ha/mm using the conventional method in year 1. WUE for the treatment T_{10} in the second Year was 14.93 kg/ha/mm, followed by the treatment T_{11} at 13.64 kg/ha/mm and the treatment T_1 at 12.38 kg/ha/mm. The conventional treatment method showed the lowest WUE, at 3.64 kg/ha/mm.

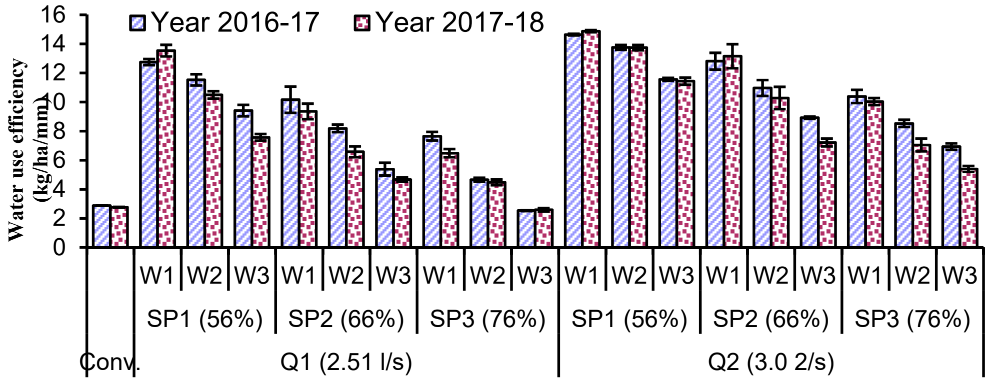

Figure 2. Comparison of WUE of Maize for the Year 2016–2017 and 2017–2018.

4. Conclusions

Managing irrigation practices precisely plays a vital role in saving ample amounts of water with an increase in WUE. The results of the present study revealed that the treatment T_{10} conserved the most water (1121 mm) and produced the most water (15.78 kg/ha/mm), followed by the treatments T_{11}, T_1, and T_{13}, respectively, compared to the control. All the Q_2 treatments (T_{10} to T_{18}) had higher efficiency and uniformity indices values than the corresponding Q_1 treatments (T_1 to T_9). The WUE was decreased by expanding the border because the water did not distribute evenly throughout the area. The reduced border width, ending the irrigation early, and the use of a high inflow rate together resulted in the improved hydraulic performance of surface irrigation, as demonstrated by the efficiency and the uniformity indicators.

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