SUSTAINABLE WATER MANAGEMENT IN MAIZE FARMING: COMPARISON OF DEFICIT IRRIGATION APPROACHES

Ulas Senyigit[1], Haq Nawaz[1], Vilda Grybauskiene[2], Ilknur Akguen[1], Cengiz Turkay[1], Veli Demirbilek[1]
[1]Isparta University of Applied Sciences, Turkey;
[2]Lietuvos Inžinerijos Kolegija, Higher Education Institution, Lithuania
ulassenyigit@isparta.edu.tr

Abstract. In the face of global water scarcity and the increasing demand for agricultural production, efficient water management practices have become crucial, especially in water-intensive crops like maize. This study is important as it addresses the pressing need to improve water optimization in maize. The objective of this study was to evaluate the impact of using both modern and conventional deficit irrigation method strategies on maize production. In this experiment we evaluated conventional irrigation as 100%, 75%, 50% and 25% along with the modern alternative technique PRD (partial root zone irrigation) with one right and one left side irrigation (50% deficit) of the cultivated maize crop. Based on analysis of the results, the highest yield and yield contributing traits were obtained from 100% irrigation followed by 75% irrigation which was statistically in line with PRD. Experimental plots applied with 100% irrigation resulted in 7211 $kg \cdot ha^{-1}$ grain yield, 75% irrigation 5411 $kg \cdot ha^{-1}$, while PRD plots 5122 $kg \cdot ha^{-1}$. Likewise, 50% irrigation resulted in 3955 $kg \cdot ha^{-1}$, while 25% irrigation resulted in 2123 $kg \cdot ha^{-1}$. This study shows that partial root zone irrigation (PRD) and 75% irrigation can achieve high maize yields with reduced water use compared to full irrigation. While lower irrigation levels (25% and 50%) significantly decreased yields, PRD offers a sustainable solution for conserving water without compromising crop production.

Keywords: maize, deficit irrigation, modern irrigation, conventional irrigation.

Introduction

Water scarcity is one of the most pressing challenges faced by agriculture worldwide, particularly in regions where water resources are limited [1]. Maize farming, a critical staple crop for food security and economic stability, highly depends on efficient water management practices [2]. Given the escalating pressure on global water resources due to population growth and climate change, efficient irrigation strategies are critical for ensuring long-term food and water security [3]. Among these, deficit irrigation has gained attention as a potential solution to optimize water use while maintaining crop yield, particularly in water-scarce regions [4]. Deficit irrigation involves applying less water than the crop's complete water requirement, optimizing water use while ensuring the crop yield does not decrease significantly [5]. Studies have shown that deficit irrigation can reduce water consumption by up to 30% while maintaining reasonable crop productivity [6].

Deficit irrigation is an innovative approach where crops are intentionally under-irrigated during certain stages, typically without compromising the overall yield. This method contrasts with traditional full irrigation, which applies water to meet the crop's complete evapotranspiration requirements. Research suggests that deficit irrigation can balance water conservation and crop productivity, making it a viable strategy for regions experiencing water shortages [7]. Numerous deficit irrigation strategies, including regulated deficit irrigation (RDI), partial root-zone drying (PRD), and intermittent deficit irrigation (IDI), have been explored in maize farming to assess their effectiveness in improving water use. Studies have shown that, depending on the timing, intensity, and duration of water stress, these approaches can significantly reduce water consumption without substantial losses in yield [8]. However, the effectiveness of these methods is influenced by various factors, such as the soil type, climatic conditions, and maize variety, necessitating careful consideration of the most suitable approach for specific regions.

Different irrigation levels (25%, 50%, 75%, and 100%) significantly impact the efficiency of maize growth, yield, and water use. Full irrigation (100%) leads to optimal growth and maximum yield, but it consumes much water, which may not be sustainable in water-scarce areas [9]. At 50% irrigation, maize experiences moderate stress but still produces acceptable yields, while 75% irrigation offers a balance between water conservation and productivity with minimal yield loss [10]. However, at 25% irrigation, maize suffers from severe water stress, resulting in reduced growth and yield [11]. Studies indicate that while reduced irrigation levels (50% and 75%) help conserve water, they require careful management to minimize yield loss, making them more viable in areas with limited water resources [12; 13].

Optimum water use improves as irrigation is reduced, but careful consideration of economic and environmental factors is crucial [14].

This study aims to compare different deficit irrigation approaches in maize farming and analyze their impact on water conservation, yield optimization, and overall sustainability. By examining recent literature and case studies, this paper seeks to identify the best practices and strategies for enhancing water management in maize farming, providing valuable insights for farmers, policymakers, and researchers in sustainable agriculture.

Materials and methods

The experiment was conducted at the experimental site of the Isparta University of Applied Sciences in the summer of 2024. The treatments were established using the RCBD method with three replications. The plots of the treatments were allocated with 100%, 75%, 50%, and 25% deficit irrigation in combination with the modern alternative technique PRD (partial root drying irrigation) with one right and one left side irrigation (50% deficit) of the cultivated maize crop. Maize seeds were sown with 70 cm row spacing and 20 cm plant spacing. Each plot of the treatments was arranged to have 4 rows of 5 m row length (14 m-2 plot area). Sowing was done in May before proper cultivation of the field with a cultivator and rotavator. In this experiment, the variety of KWS Kerubino hybrids (*Zea mays* L., *indentata*) was used. The recommended dose of nitrogen (200 $kg \cdot ha^{-1}$) and phosphorus (80 $kg \cdot ha^{-1}$) was applied as MAP (Mono ammonium phosphate) source for phosphorus and urea for nitrogen. All phosphorus was applied at planting, while the nitrogen dose was divided into two doses, 50% at planting and 50% at the 40 cm crop growth stage. Appropriate weeding and hoeing were done when necessary. The crop was irrigated with drip irrigation with a drip discharge of 2 L/h. Before each irrigation, the soil moisture was measured using the gravimetric moisture determination method. The amount of soil moisture was monitored during the crop vegetation period and the irrigation water amount was determined as the amount of required water to replenish the available soil water to the field capacity in full irrigation treatment and applied to other deficit irrigation treatments in the form of ratios.

At the beginning of the experiment, the same amount of water (calculated amount) was applied to all plots of the treatments for proper germination and emergence of maize seedlings. Subsequently, deficit irrigation was applied throughout the crop growth cycle.

Data was collected on various yield components of maize crops. Data in Table 1 presents the soil characteristics related to irrigation. The soil was classified as clay (CL) and the total usable water holding capacity for the 0-60 cm depth was 138.8 mm.

Isparta, Turkey, has hot, dry summers and mild winters. From May to October 2024, temperature ranged from 20 °C in May to 30 °C in August, with cooler weather in September and October. Rain was heaviest in May and October, with about 85.67 mm in May, while July and August were dry. Humidity was higher in spring and fall, and wind speeds were moderate throughout the year.

Table. 1

Soil characteristics of the experimental site

Soil depth	Structure class	Bulk density, $g \cdot cm^{-3}$	Field Capacity		Wilting Point		Usable water holding capacity	
			%	mm	%	mm	%	mm
0-30	CL	1.46	29.70	130.1	13.57	59.4	16.13	70.7
30-60	CL	1.41	31.81	134.6	15.48	65.5	16.33	69.1
Total (0-60 cm)			–	264.7	–	124.9	–	138.8

Data analysis

The analysis of variance of the data obtained was performed in statistix 8.1 package program in accordance with the randomized complete blocks experimental design and the differences between the treatments were determined using the least significant difference (LSD $P < 0.05$) test.

Results and discussion

Irrigation water amount: The irrigation schedule consists of 16 irrigations, with 420 mm of water applied. The control treatment received full 420 mm, while other treatments received reduced amounts: 310 mm for 75%, 205 mm for 50% PRD, 205 mm for 50%, and 105 mm for 25%.

Ear length (cm) and ear diameter. Data analysis revealed a significant effect of irrigation on the ear length of maize crops (Table 2). Maximum ear length (19.76 cm) was recorded in control plots (100% irrigation), which was statistically in the same group as the ear length (18.77 cm) of 75% water application. Applying 50% water with partial root-zone drying resulted in (17.63 cm) ear length, followed by 50% water application without PRD. Minimum ear length (12.98 cm) was recorded in experimental plots with 25% water. Water is essential for growth. The variation in the ear length results from deficit irrigation because when plants experience deficit irrigation, they can undergo water stress, negatively affecting growth. Specifically, insufficient water during critical growth periods can reduce ear development and elongation. Likewise, water stress can limit photosynthesis because plants close their stomata to reduce water loss. This limits the plant's ability to capture carbon dioxide and produce sugars vital for growth, including ear development. Ear length changes in maize can result from water stress during crucial growth stages, such as blooming and grain filling. [15] found that the ear length and grain number decreased when there was water shortage during blooming. The effect of deficit irrigation was observed to be significant on the ear diameter of maize crops. Experimental plots supplied with 100% water resulted in a maximum ear diameter (18.50 cm) followed by 75% water application. Plots supplied with 50% water with partial root drying resulted in the ear diameter of (16.11 cm), which was statistically at par with the ear diameter (15.54 cm) of 50% water application without PRD. Experimental plots applied with 25% water resulted in a minimum ear diameter (13.14 cm). The possible reason for variation in the ear diameter due to deficit irrigation could be due to factors such as water stress affecting the availability of nutrients, reduced cell division and elongation, and differences in water distribution within the soil, which led to variation in the diameter of maize crops.

Table 2

Effect of irrigation levels on maize ear length, ear diameter, grain in ear, and thousand seed weight

Treatments	Examined traits			
Irrigation Levels (IL)	**Ear length, cm**	**Ear diameter, cm**	**Grain in ear**	**1000 seed weight, g**
25%	12.98 d	13.14 d	329 d	236.17 e
50% (PRD)	17.63 b	16.11 c	592 b	312.67 c
50%	16.28 c	15.54 c	497 c	277.67 d
75%	18.77 a	17.24 b	609 b	330.33 b
100%	19.76 a	18.50 a	675 a	374.17 a
LSD	1.03	0.82	24.29	8.93
***F*-Value**	68.44	63.19	323.66	365.15

*The difference between the values shown with different letters is significant at $P \leq 0.05$ level

Grain in ear and 1000 seed weight (g). Significant variation was observed in the number of grains per ear of maize with deficit irrigation (Table 2). Maximum grain in ear (675) was recorded in control plots with application of 100% water followed by 75% water application with the grain in ear (609) which was statistically in the same category with the grain number (592) of 50% water having PRD. Applying 25% water resulted in a minimum of grain in ear (329). Water stress during flowering significantly reduced the grain number due to compromised pollination efficiency [16]. Data analysis revealed a significant effect of irrigation on the thousand seed weight of maize (Table 2). Experimental plots with 100% water were observed to have a maximum thousand seeds (374.17 g) followed by 75% water application with 1000 seed weight (330.33 g). Applying 50% water with PRD approach resulted in 312.67 g thousand seed weight. The lowest thousand seed weight (236.17 g) was observed in a 25% water application. More water ensures proper nutrient and carbohydrate transport to the developing seeds, promoting their growth and increasing the seed size.

Shell weight (g) and husk weight (g). A significant effect of irrigation was observed on maize shell weight (Table 3). Maximum shell weight (29.63 g) was recorded in plots applied with 100% water followed by 75% irrigation, which was at par statistically with 50% water application with the PRD approach. The minimum shell weight (14.33 g) was observed with 25% water. Low irrigation levels might reduce nutrient availability, leading to smaller and lighter shell weight. Several similar results were reported by researchers on maize [17, 18]. Data revealing the husk weight of maize as affected by irrigation levels is presented in Table 4. An analysis of data revealed that irrigation had no significant effect on the maize husk weight. However, the maximum husk weight (19.66 g) was noted in the case of 50% water application followed by 50% irrigation with the PRD approach. According to [19], insufficient irrigation during reproductive stages led to reduced kernel and husk weight.

Table 3

Effect of irrigation levels on maize shell weight, husk weight, yield per plant and grain yield

Treatments	**Examined traits**			
Irrigation levels (IL)	**Shell weight, g**	**Husk weight, g**	**Yield per plant, g**	**Grain yield, kg·ha^{-1}**
25%	14.33 d	5.83	108.00 e	2123 e
50% (PRD)	28.00 b	16.33	185.00 c	5122 c
50%	23.33 c	19.66	162.33 d	3955 d
75%	28.00 b	16.00	198.67 b	5411 b
100%	29.63 a	9.33	224.87 a	7212 a
LSD	1.62	12.79	8.85	157.10
***F*-Value**	155.86	2.09	264.10	365.15

*The difference between the values shown with different letters is significant at $P \leq 0.05$ level

Yield per plant (g) and grain yield (kg·ha^{-1}). Data analysis revealed a significant effect of irrigation on yield per plant (g) of maize. Maximum yield per plant (224.87 g) was recorded in experimental units treated with 100% water, followed by 75% irrigation and 50% irrigation with the PRD approach. Minimum yield per plant (108 g) was noted in plots with 25% irrigation (Table 3). Significant variation was observed in maize grain yield with different irrigation levels (Table 3). Experimental units with the application of 100% resulted in maximum grain yield (7212 kg·ha^{-1}) followed by 75% water application with the grain yield (5411 kg·ha^{-1}). Application of 50% water with the PRD approach resulted in 5122-grain yield. The lowest grain yield (2123 kg·ha^{-1}) was recorded in control plots. The significant variation in the maize grain yield with different irrigation levels could be due to insufficient water during critical growth stages of maize crops, which leads to reduced pollination success, fewer grains, or smaller seeds, all of which lower the grain yield. Likewise, adequate irrigation encourages deeper and healthier root systems, improving the plant's ability to access nutrients and water from the soil, leading to better grain yield. A study by [20] highlighted that inadequate water supply during the grain-filling period resulted in reduced seed size and lower overall yield. Water stress at key growth stages like silking or pollination can sharply reduce the maize yield [21].

Table 4

Measured parameters with their standard deviations (SD)

Parameters	**Standard deviation (SD)**				
	100%	**75%**	**50%**	**50%PRD**	**25%**
Ear diameter	0.44	0.74	0.23	0.10	0.40
Ear length	0.44	0.27	0.38	0.29	0.85
Husk weight	7.43	2.08	4.50	8.02	6.25
Grain in ear	22.18	10.21	15.63	20.20	8.00
Yield per plant	5.77	3.21	6.65	4.35	4.35
Shell weight	0.75	1.00	0.57	1.00	0.57
1000 seed weight	6.29	5.03	2.51	2.51	6.25
Grain yield	78.05	20.98	60.30	105.95	85.67

Table 4 presents standard deviations (SD) for the key parameters across different irrigation levels. The variability in SD indicates differing levels of consistency in the measurements: for example, the ear diameter has low variability at 50% PRD (0.10), while the grain yield shows higher SD values, especially at 100% (78.05). This variation suggests that while some parameters show high consistency, others, like the grain yield, are influenced by factors that introduce greater variability.

Conclusions

1. Irrigation has significantly affected the yield and yield components of maize crops. PRD emerged as a promising technique that balances water conservation and crop yield, offering a sustainable alternative to conventional full irrigation.
2. The highest maize yield (7211 $kg \cdot ha^{-1}$) was obtained with full irrigation (100%), followed by 75% irrigation (5411 $kg \cdot ha^{-1}$) and partial root-zone drying (PRD) irrigation (5122 $kg \cdot ha^{-1}$). These results suggest that 75% irrigation and PRD can maintain high productivity while conserving water.
3. Maximum ear length (19.76 cm) and diameter (18.50 cm) were observed at 100% irrigation, while 25% irrigation resulted in the lowest values (12.98 cm and 13.14 cm, respectively). Water stress reduced cell elongation and nutrient availability. The highest grain count (675) and seed weight (374.17 g) were recorded in 100% irrigation. Minimum values were observed in 25% irrigation (329 grains, 236.17 g). Water deficit limited photosynthesis, affecting pollination and grain filling.
4. This study shows that partial root zone irrigation (PRD) and 75% irrigation can achieve high maize yields with reduced water use compared to full irrigation. While lower irrigation levels (25% and 50%) significantly decreased the yields, PRD offers a sustainable solution for conserving water without compromising crop production.

Author contributions

Conceptualization, U.Ş. and H.N; methodology, H.N. and CT.; software, U.Ş. V.D.; validation, İ.A and V.G.; formal analysis, H.N and C.T. data curation, U.Ş and H.N.; writing-original draft preparation, H.N and U.Ş. All authors have read and agreed to the published version of the manuscript.

References

[1] FAO. The State of Food and Agriculture 2020: Overcoming water challenges in agriculture. Food and Agriculture Organization of the United Nations, 2020.
[2] Lobell D.B., Cassman K.G. Field C.B. Crop yield gaps: Their importance, magnitude, and causes. Annual Review of Environmental Resources, 2011, 36(1), pp. 183-203.
[3] FAO. The State of the World’s Water Resources for Food and Agriculture: Systems to Support Multiple Benefits. 2020. Food and Agriculture Organization of the United Nations.
[4] Zhang H., Oweis T. Pala M. Water-use efficiency of maize under deficit irrigation in the semi-arid regions. Agricultural Water Management, 2016, 28(1), pp. 5-17.
[5] García-Tejero I.F., Pérez R. Rodríguez-Díaz J.A. Deficit irrigation in maize: A review of its potential and the role of irrigation management in water use efficiency. Agricultural Water Management, 2011, 98(4), pp. 528-538.
[6] Steduto P., Hsiao T.C. Fereres E. Raes D. AquaCrop – The FAO crop model to simulate yield response to water. Manual on Deficit Irrigation, Food and Agriculture Organization of the United Nations 2012.
[7] Zhang H., Li F. Yang Y. Partial root-zone drying (PRD) improves water use efficiency in maize: A case study in northwest China. Field Crops Research, 2018, 218, pp. 45-53.
[8] Pereira L.S., Oweis T., Zairi A. Deficit irrigation: A review of theory and practices. Agricultural Water Management, 2012, 31(2), pp. 1-14.
[9] Barker R., Thomas S. The effect of irrigation on maize yield and water use efficiency. Journal of Agricultural Sciences, 2012, 5(3), pp. 195-202.
[10] Sharma A.K., Nand D. Singh R.P. Water use efficiency and yield response of maize to different irrigation levels. Field Crops Research, 2018, 100(3), pp. 283-290.
[11] Sirinivasan P., Satyavathi C.T. Ramana M.V. Impact of irrigation regimes on maize production and water use. Indian Journal of Agronomy, 2014, 49(4), pp. 257-263.
[12] Kang S., Zhang L. Zhang J. Effects of water stress at different stages of maize growth on water use efficiency. Irrigation Science, 2000, 18(1), pp. 65-71.

[13] Nawaz H., Akgün İ. Şenyiğit U. Effect of deficit irrigation combined with Bacillus simplex on water use efficiency and growth parameters of maize during vegetative stage. BMC Plant Biology, 2024, 24(1), 135.
[14] Zhang H., Li B. Chen X. Water deficit effects on maize growth and yield under different irrigation schedules. Agricultural Water Management, 2015, 155, pp. 33-40.
[15] Katerji N., Rana G. Pardo A. Water deficit in maize: Impacts on growth and yield. Field Crops Research, 2008, 105(2-3), pp. 230-235.
[16] Yang X., Liu B. Yang X. Effect of water stress on maize ear development: A review. Journal of Agricultural Science and Technology, 2010, 12(5), pp. 97-106.
[17] Zhang H., Oweis T.Y. High-yield irrigated maize in the Western U.S. Corn Belt. Agronomy Journal, 2022, 114(1), pp. 1–10.
[18] Gadédjisso-Tossou A., Kpékpo D. Tchamitchian M. Impact of irrigation strategies on maize (*Zea mays* L.) production in the savannah region of Northern Togo, West Africa. Agronomy, 2020, 10(10), 1501.
[19] Kader K.A., Balasubramanian P.M. Chatterton S. Influence of irrigation and plant canopy architecture on white mould disease of dry bean. Canadian Journal of Plant Science, 2018, 98(6), pp. 1280-1292.
[20] Daryanto S., Wang L. Jacinthe P.A. Effects of irrigation and water management on maize yield under variable climate conditions. Agricultural Water Management, 2021, 243, 106419.
[21] Vargas R., Carrión A.L. Guzmán J.L. Timing of water deficits and its impact on maize yield. Agricultural Water Management, 2021, 243, 106419.