Policy Research Journal
ISSN (E): 3006-7030 **ISSN (P) :** 3006-7022 Volume 4, Issue 4, 2026

COMPARATIVE STUDY OF YIELD AND WATER PRODUCTIVITY OF MAIZE UNDER AUTOMATED DRIP AND FLOOD IRRIGATION

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DOI: https://doi.org/10.5281/zenodo.19883996

Keywords
Zea mays L., water scarcity, water use efficiency, soil moisture sensors

Article History
Received: 11 February 2026
Accepted: 21 March 2026
Published: 06 April 2026

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Abstract
Water scarcity in Pakistan is a growing concern that significantly affects agricultural productivity, particularly in crops like maize (Zea mays L.), which is a staple food and a major cash crop in the country. Sowing was done with Pneumatic planter 76.2 cm wide raised bed with furrow of 45.7 cm wide. To compare of water accounting and budgeting of maize under automated drip irrigation (ADI) and flood irrigation (FI) field experiment was conducted. In Kharif seasons a maize hybrid variety (DK-8148) was sown in consecutive two seasons of Kharif season of 2022 and Kharif 2023. Seeds (10 Kg/acre) were sown on mid-July and harvested on end of October. The experiment was executed on a laser-leveled field at Water Management Research Farm, Renala Khurd, Okara. It was observed that total water applied through ADI was 329 mm, while in FI it was 550 mm. Yield was 2.60 tons/acre in ADI, while 2.40 tons/acre in flood irrigation. So, crop water productivity (CWP) of ADI (1.95 Kg/m3) was significantly higher than observed in FI (1.08 Kg/m^3). ADI saved 221 mm of water compared with FI. It was found that automated drip irrigation improves yield and water productivity for maize plant.

INTRODUCTION

Maize (*Zea mays* L.), a staple crop belonging to the *Poaceae* family, plays a significant role in Pakistan's agriculture. In the 2023-24 period, maize was cultivated on 1.6 million hectares, reflecting a 4.5% decrease from the previous year's area of 1.7 million hectares, as reported in the Pakistan Economic Survey (2024). This reduction in cultivation area led to a 10.4% decline in total maize production, which dropped to 9.8 million metric tons (MMT). In the broader context of agriculture, total crop production across the country also saw a slight decline of 0.4%, with the aggregate falling from 88.0 million tons in 2022-23 to 87.6 million tons in 2023-24. However, despite the lower area under cultivation, the increase in yield per hectare indicates that Pakistan's agricultural policies are having a positive impact, driving more efficient production practices.

Maize is the third most important cereal crop globally, trailing only wheat and rice, and is a key raw material for a variety of products including starch, oil, protein, alcoholic beverages, food sweeteners, and biofuels (Chen et al., 2022). It is grown over approximately 201.98 million hectares worldwide, with an average yield of 5.75 tons per hectare. Maize thrives particularly well under irrigation and resource conservation practices, especially during the winter season. During the rainy season, the average productivity of maize is 4.3 tons per hectare, while in the winter season, it reaches 6.2 tons per hectare, showcasing its enhanced performance when properly managed (Ray et al., 2024).

Water scarcity is a critical challenge and the primary limiting factor in agricultural crop production. Agriculture is the largest consumer of freshwater, accounting for about 75% of global water withdrawals. Despite this, irrigated agricultural systems contribute to approximately 40% of global food production, while occupying just 18% of the total land area used for food production (Elmahdi et al., 2024). With the growing demand for food, livestock feed, and biofuels, coupled with the impacts of global climate change, pressure on freshwater resources is expected to intensify. Competition for these limited water resources is already a significant issue in many major irrigated cropping systems around the world. In this context, precision farming and mechanized farming are crucial to ensuring high yields while managing water use efficiently (Sun et al., 2024).

Irrigation is the largest sector of human-driven water consumption and plays a crucial role in improving agricultural productivity and mitigating the impacts of drought. However, the precise contribution of irrigation to global crop yield improvement is still uncertain (Wang et al., 2021). One of the key factors in maximizing the effectiveness of irrigation is the frequency of irrigation, particularly in drip irrigation systems. The timing and frequency of water application significantly affect soil water dynamics, water and nutrient use efficiency, and ultimately crop yield, even when the total volume of water applied remains the same. Proper scheduling is essential to optimize these factors and achieve sustainable agricultural outcomes (El-Hendawy et al., 2008).

Evapotranspiration (ET) plays a crucial role in influencing soil water availability, making effective water management strategies essential for maize production. Cao et al. (2022) conducted a two-year field experiment that highlighted the negative effects of water scarcity on the growth and yield of summer maize. Their study showed that using alternate surface and subsurface drip irrigation resulted in a grain yield of 6939.5 kg ha^{-1}, which was 4.8% higher than the yield of 6625.0 kg ha^{-1} under subsurface drip irrigation and 13.3% higher than the 6126.5 kg ha^{-1} yield from conventional surface drip irrigation. The Crop Water Productivity (CWP) followed a similar pattern, with alternate surface and subsurface drip irrigation outperforming both subsurface drip irrigation and conventional surface drip irrigation in both 2018 and 2019. In recent years, there has been a growing focus on improving the water productivity of maize through the use of High Efficiency Irrigation Systems (HIES) (Ray et al., 2024).

Global climate change and its impact on food crop production, particularly maize, has become an increasingly critical area of research. The effects of climate change on maize yield are complex, involving changes in temperature, precipitation patterns, and extreme weather events. This study explores how climate change influences the maize growth cycle, including shifts in the growing season, drought and water stress, and the detrimental effects of higher temperatures and heat stress on maize development and productivity. As climate change continues to challenge global food security, adaptive strategies for managing water and crop production will be key to ensuring sustainable maize yields (Li et al., 2024).

The positive correlation between water availability and fertilizer application suggests that when a plant's water supply decreases, fertilizer input must also be reduced to maintain safe and efficient production. This means irrigation and fertilization practices must be managed together—either increased or decreased simultaneously—to achieve optimal agricultural outcomes (Bian et al., 2024). In maize cultivation, improving water productivity remains a major challenge, especially under the pressures of climate change and rising food demand (Mehmoob et al., 2022). Effective irrigation scheduling is therefore essential (Kadasiddappa and Rao, 2018). Numerous studies have shown that drip irrigation significantly enhances water use efficiency and water productivity compared to traditional surface or gravity-fed irrigation systems (Oker et al., 2018; Roja et al., 2020). Research by Trout and DeJonge (2017) in the U.S. highlands over four years reported an average water productivity of 2.5 kg/m³, with grain yields reaching 125 tons/ha corresponding to a crop evapotranspiration of 630 mm. Building on this understanding, the present study aims to evaluate how deficit irrigation influences the yield and water productivity of Zea mays L. under drip irrigation. Similar findings have been reported in China, where drip irrigation improved maize growth, yield, and water use efficiency (Liu et al., 2022), and demonstrated high returns with superior yield and water productivity in arid regions (Zang et al., 2017).

Crop Water Productivity (CWP) is defined as the ratio of crop output to water supply across various spatial scales, and it serves as a reliable metric for assessing agricultural water use efficiency (Edreira et al., 2018). Kasem et al. (2015) found that sunflower water use efficiency, water productivity, and yield were optimized when irrigation was applied at 80% and 100% of reference evapotranspiration (ETo), with 80% ETo recommended for better water conservation. CWP is widely recognized as a dependable benchmark for evaluating crop output in relation to available water supply at different spatial scales. Given the importance of high efficiency in irrigation systems, this study aims to evaluate and compare the water accounting and budgeting performance of maize cultivated under automated drip irrigation and flood irrigation systems.

Materials and Methods

The present study was conducted under the project titled "Water Productivity Enhancement through Regenerative Climate Smart Agriculture (WP-RCA) (Pilot Project)". Maize hybrid variety (DK-8148) was sown in two consecutive Kharif seasons, 2022 and 2023, using a pneumatic planter on both sides of a 76.2 cm wide raised bed with a furrow of 45.7 cm. The seeds were sown at a rate of 10 kg per acre in mid-July and harvested at the end of October. The experiment was carried out on a laser-leveled field at the Water Management Research Farm, Renala Khurd, Okara, with GPS coordinates N 30°85.8196' E073°546761' and an altitude of 146 meters. To prevent seed-borne diseases, the seeds were treated with Imidacloprid 70 WS at a rate of 5-7 g per kg. The beds were 80 cm wide with a furrow of 46 cm. A pre-emergence weed control treatment was applied, using Pendimethalene E 330 at 5 L/ha and Atrazin 720 SC at 2000 ml/ha, which was irrigated after 20 hours of sowing. For further control of narrow-leaf weeds, Halo-sulforan methyl 75% WDG at 50 g/ha was used.

The maize plants were irrigated based on the actual ETo and Kc for 44 days to support normal growth from sowing. Armyworm was managed using Chlorpyriphos 40 EC at 1000 ml/ha. After 44 days, the applied water in various treatments was maintained at 100% of the water calculated according to ETo. As a basal dose, 5 bags of SOP per acre and 5 bags of DAP per hectare were applied. Additionally, 4 bags of urea per hectare were applied in various splits for the flood irrigation (FI) blocks. In the FI blocks, the measured quantity of water was applied using the Crop-WATT (8) model. In the case of automated drip fertigation, the schedule is provided in Table 8.2. The experiment was replicated three times in a Randomized Complete Design (RCBD). Irrigation flow was measured using the ADI system (Spirit Pro PLC, Gavish Control System), following a specific formula for accurate water measurement.

$$Crop\ Water\ Requirement = \text{Kc x ETo}$$

A moisture meter was used to verify the moisture contents of the soil. In FI treatments, water was measured by cut throat flume. Data regarding the number of ears, fresh ears weight, grain yield, number of grain rows per ear, number of grains per row, 1000 grain weight, above-ground biomass, and water productivity was measured. Soil characteristic of the experimental area is described in Table 8.1.

Table 8.1. Soil characteristics of experimental area at Water Management Research Farm, Renala Khurd, Okara

Depth (cm)	pH	Organic Matter (%)	Available Phosphorus (mg/kg)	Available Potash (mg/kg)	Saturation (%)	Soil type
0-15	8.0	0.55	7.0	60	33	Loam
15-30	7.9	0.48	6.8	40	35	Loam

Discharge Measurement by Trajectory Method

For flood irrigation the discharge of tube-well was followed by Trajectory Method. It has three essential requirements for discharge measurement. Inside diameter of the pipe, measurement of X-coordinate of flow (Horizontal distance measured from the end of the pipe), measurement of Y-coordinate of flow (Vertical distance measured down from horizontal point to the top of the water jet).

$$Diameter of\ pipe = 6\ inches, X = 50\ cm, Y = 28\ cm$$

$$Q = \frac{0.0174 x D^2 x X}{(Y)^{1/2}} = \frac{0.0174 x (15.24)^2 x 50}{(28)^{1/2}} = 38.18 \text{ liter/sec}$$

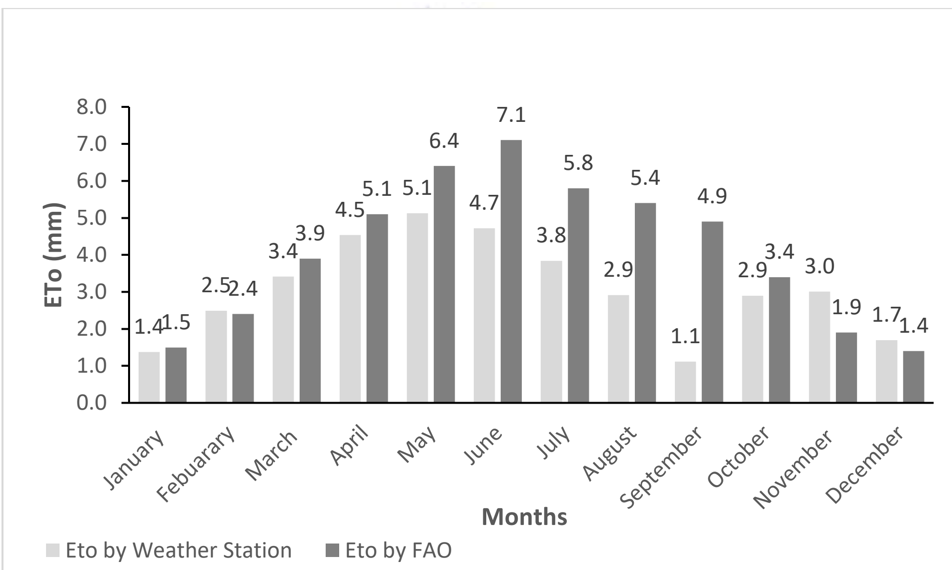

Figure 1: **ET_o values for the month of August and September had shown significant variation due to excessive rainfall during these months at WMRF, Renala Khurd, Okara**

Table 8.2. Fertilizer application schedule of the experiment of automated drip irrigation

Plant Phase	Fertigation Days	Fertilizer Kg/Zone/Day		
		Nutrafil Urea	NP	WS-SOP
Vegetative Phase	30	0.32	0.37	0.3

Flowering Phase	20	1.37	0.37	1.0
Cobe Development Phase	30	2.09	--	1.9
Grain Development Phase	30	1.05	--	1.0

Table 8.3. Detail of irrigation water applied in recommended and different deficit irrigation levels irrigation water applied in each irrigation according to real-time ET_o during Kharif 2022 and 2023.

Sr. No	Treatments	Depth of water applied (mm)	Volume of water applied per hectare
1	Automated Drip Irrigation	329	3292 m^3
2	Flood Irrigation	550	5500 m^3

Determination of oil content

To determine the oil content, the grain was first ground into a fine powder. A 2 g sample of the ground material was weighed and placed into the thimble of a Soxhlet extractor. Petroleum ether was added to the boiling flask, and the solvent was heated. The heated solvent cycled through the sample, dissolving the oil. After several cycles, the solvent containing the dissolved oil was evaporated, leaving behind the extracted oil. The remaining oil was then weighed after the solvent had been fully removed

Oil content (%) = Weight of the oil extracted/Weight of the sample x 100

Determination of starch content

A 2 g ground sample was taken for starch analysis. The starch was hydrolyzed by treating the sample with α-amylase at a controlled temperature. After the amylase treatment, the starch was further hydrolyzed using amyloglucosidase to release glucose. The amount of glucose released was measured using glucose oxidase in a colorimetric or enzymatic assay. The starch content was then calculated by converting the glucose value to starch, using a conversion factor where 1 g of glucose is equivalent to 0.9 g of starch.

Determination of protein content

A 2 g maize grain sample was ground and digested with concentrated sulfuric acid and a catalyst, converting the nitrogen into ammonium sulfate. The digested sample was then neutralized with sodium hydroxide. Next, ammonia was distilled from the sample and collected in a known volume of boric acid solution. The distilled ammonia was titrated with a standard acid solution, such as hydrochloric acid. The nitrogen content was calculated based on the titration results. To estimate the protein content, the nitrogen value was multiplied by a conversion factor of 6.25 (Protein = N × 6.25), which is the typical factor for maize, based on the assumption that proteins contain, on average, 16% nitrogen.

Statistical Analysis

Analysis of variance was computed by Statistics 8.1 software. The significance of the means for each treatment was compared by the HSD Tukey Test.

Results

It was found that average cob length of both the years was 5.42 cm in ADI system while 5.03 cm was found in FI. Silk lines/cob were 13.95 regarding FI and 15.11 regarding ADI. Grain per cob drip irrigation found 456.6, while FI 431.6 grains/cob. ADI provided plant length 231.4 cm per plant which at par with 231.35 cm was found in FI (Table 8.4).

Table 8.4. Cob length (cm), silk lines/cob, grains/cob, plant length (cm) of maize under ADI and FI in consecutive two kharif seasons

Season	Cob length (cm)		Silk lines/cob		Grains/cob		Plant Length (cm)	
	ADI	FI	ADI	FI	ADI	FI	ADI	FI
Kharif 2022	14.73 ± 0.29	16.30± 0.31	15.44± 0.77	14.78± 0.73	504±25.2	460±23.8	231±11	231.4±10
Kharif 2023	12.77 ± 0.31	16.28 ± 0.30	14.78± 0.79	13.11± 0.77	409±22.5	402±21.2	231.6±13	231.3±11
Overall	13.75 B	16.29 A	15.11 B	13.95 B	456.66 A	431.62 A	231.4 A	231.35 A

It was observed that the average total water applied (including rainfall) of both the years through ADI (after 90% efficiency) was 329 mm, while in FI (after 60% efficiency) was 550 mm. Yield was 2.60 tons/acre in ADI, while 2.40 tons/acre in flood irrigation. So, CWP of ADI was (1.95 Kg/m3) was significantly higher than observed in FI (1.08 Kg/m3) (Table 8.5).

Table 8.5. Yield and water productivity of maize under ADI and FI in consecutive two kharif seasons

Season	Water Applied (mm) (Included rainfall)		Yield (tons/acre)		CWP (Kg/m^3)	
	ADI	FI	ADI	FI	ADI	FI
Kharif 2022	333	552	2.68± 0.13	2.24± 0.12	1.91± 0.07	1.00 ± 0.05
Kharif 2023	325	548	2.52± 0.14	2.56± 0.13	1.98 ± 0.06	1.18 ± 0.05
Overall	329 B	550 A	2.60 A	2.40 B	1.95 A	1.08 B

The average oil content of both the years was found significantly higher in plants sown under ADI (4.4%) than sown under FI (3.9%). While protein content were 12.4% in ADI and 11.5% in FI. There was non-significant difference in starch content as 52.65% found in under ADI and 50.8% in FI maize (Table 8.6).

Table 8.6: Response oil, protein and starch contents (%) grown under ADI and FI grains of maize in consecutive two kharif seasons

Treatments	Oil%			Protein %			Starch %		
	Kharif 22	Kharif 23	Mean	Kharif 22	Kharif 23	Mean	Kharif 22	Kharif 23	Mean
ADI	4.5± 0.23	4.3± 0.25	4.4 A	13.0±0.65	11.8±0.63	12.4 A	52.1±2.6	53.2±2.3	52.65 A
FI	4.0± 0.24	3.8± 0.23	3.9 B	12.7±0.61	10.3±0.62	11.5 B	50.0±2.3	51.6±2.4	50.8 A

Discussion

Irrigation efficiency is significantly influenced by the irrigation methods used. High Efficiency Irrigation Systems (HEIS), such as Automated Drip Irrigation (ADI), provide better nutrient and water distribution to the root zone, promoting healthy crop growth and improving yield (Li et al., 2024). Enhancing water productivity remains a challenge, particularly in water-scarce areas (Comas et al., 2019). It was observed that the total water applied through ADI was lower than that applied through flood irrigation. Despite this, grain yield was higher with ADI compared to flood irrigation. Flood irrigation (FI) delivers water and nutrients to the base of the plant near the rooting zone, improving water use and productivity. Sandhu et al. (2019) highlighted the importance of optimizing drip irrigation and nitrogen management practices to enhance crop yield, nitrogen use efficiency, and water productivity in a maize-wheat cropping system on permanent raised beds.

Various climatic change scenarios have different impacts on grain yield and crop water productivity (Yang et al., 2017). Under these scenarios, both grain yield and fertilizer use efficiency were improved without compromising water productivity. The combined optimization of water and nutrients through drip fertigation led to a more significant increase in maize yield and partial factor productivity (PFP) compared to water optimization alone through drip irrigation. Additionally, drip fertigation also contributed to an improvement in water productivity, demonstrating its effectiveness in enhancing both yield and efficient water use (Wu et al., 2019).

Researchers have conducted numerous trials on optimizing irrigation schedules. Greaves and Wang (2017) evaluated five irrigation quotas for maize and found that water deficit irrigation did not significantly impact yield but notably improved irrigation water use efficiency. In the current research, reduced and effective irrigation, which targeted the root zone of maize plants, enhanced water use efficiency, as observed with 329 mm of water applied through surface irrigation. Similarly, Dhayal et al. (2023) reported a significant increase in yield-related attributes with an irrigation depth of 336 mm, which aligns with the findings of the current study, further supporting the conclusions of both research works.

In the present research, the quality of maize was higher in drip-irrigated maize, which aligns with the findings of Irfan et al. (2014), who noted the significant impact of irrigation management practices and water quality on maize production and water use efficiency (WUE). Admasu et al. (2019) concluded that the critical irrigation depth for moisture-stressed areas should not fall below 85% of the full maize water requirement to ensure relatively high grain yield while improving crop water productivity (CWP). In the current study, maize crop water productivity improved by 45.7%, which is consistent with the findings of Mekonnen et al. (2022), who reported an average increase of 71% in water productivity on Nebraska farms through effective irrigation practices.

The present research, which recorded a maximum yield of 2.6 tons/acre under Automated Drip Irrigation (ADI), contrasts with the 13.33 tons/ha observed under ADI by Mansour and El-Melhem (2013). This difference may be attributed to variations in varietal characteristics or climatic conditions of the respective regions. Additionally, Lai et al. (2023) recorded a water use efficiency (WUE) of 3.42 kg/m^3 for the QS51 maize hybrid, which is similar to our findings of 3.16 kg/m^3. The slight difference in WUE values could be due to different geographical conditions, soil types, and maize hybrids. Dumet-Montoya et al. (2013) reported maize water productivity ranging from 1.84 to 2.79 kg/m^3 in Azul, Argentina, further highlighting the variability in water productivity depending on local conditions.

Drip irrigation is increasingly used in maize cultivation to improve water use efficiency and crop yield (Ma et al., 2021). This method delivers water and nutrients directly to the crop's root zone through high-frequency irrigation, creating a spherical or ellipsoidal wetting pattern in the soil (Qi et al., 2020). Plants grown under drip irrigation typically show higher quality attributes, such as oil and protein content, compared to those grown under flood irrigation. This improvement is likely due to the precise and efficient application of water and nutrients provided by drip irrigation (Lu et al., 2024). Additionally, irrigation regimes have been shown to be directly linked to dry matter content and yield, as well as to the foliage water use efficiency of maize (Çarpıcı et al., 2017). This could be attributed to the positive impact of irrigation on soil enzyme activity, where the combined use of fertilization and irrigation, within an optimal range, maximizes enzyme activity and supports better crop development (Qu et al., 2024).

A field-based study was conducted to evaluate the effects of different tillage practices on the productivity and grain composition of *Zea mays* L. The study revealed significant differences in yield depending on the tillage depth. Deep plowing at 30 cm resulted in the highest grain yield of 10.1 tons per hectare, whereas shallow disking at 15 cm led to a reduced yield of 8.88 tons per hectare. In addition to yield, tillage intensity was found to impact the nutritional composition of the maize grain. Under deep plowing (30 cm), the maize kernels exhibited the following biochemical characteristics: starch content at 70.9%, crude fiber at 2.12%, protein concentration at 10.2%, and crude fat content at 4.2%. These findings highlight that soil tillage depth is crucial in determining both maize yield and grain quality, with deeper tillage promoting superior productivity and improved nutritional profiles. The study also emphasized the significant influence of tillage methods on key grain quality parameters, including starch, crude fiber, protein, and crude fat content (Viktorivna et al., 2024).

Conclusion

Based on the above results, it can be concluded that automated drip irrigation is essential for conserving water and enhancing crop water productivity in maize cultivation. High Efficiency Irrigation Systems (HEIs) not only save water but also improve the quality of the produce by delivering water and nutrients directly to the root zone of the maize plant, fostering optimal growth and better crop quality.

Acknowledgement

All authors acknowledge Punjab Agriculture Research Bord (PARB) for establishment of automated drip irrigation system at the experimental site of Water Management Research Farm, Renala Khurd, Okara.

Contribution of Authors

Mujahid Ali executed the research and applied treatment plan, Asif Iqbal and Muhammad Mohsan designed the experiment and supervised, Habib ur Rehman and Hafiz Muhammad Bilal crop husbandry/data collection for research. Tahir Mehmood defined objectives of the research and ensured project aims. Haseeb Ahsan and Imran Ahmad supervised successful treatment execution, Muhammad Aasim Rafiq guided about data collection and analysis. All authors contributed equally in writing the article.

Conflict of Interest

The authors declared there is no conflict of interest.

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