



Evaluating drip and furrow irrigation systems on yield and water use efficiency in maize

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Abstract

Background: Water scarcity is a primary constraint on global agricultural production, necessitating the transition from traditional irrigation methods to water-efficient technologies. Maize is a highly water-demanding cereal crop, making irrigation management critical for sustainable yield optimization.

Objective: This study aims to compare the agronomic performance and water use efficiency (WUE) of maize under drip irrigation and conventional furrow irrigation systems.

Method: A randomized complete block design (RCBD) with three replications was utilized. This study uses a simulated dataset created for academic training purposes. The simulated data encompassed grain yield, biomass, water applied, and WUE across two irrigation treatments over a single growing season. Data were analyzed using ANOVA in SPSS.

Key Results: The drip irrigation system significantly reduced total water applied by 35% compared to furrow irrigation. Maize under drip irrigation yielded 9.2 tons per hectare, representing a 22% increase over the furrow irrigation yield (7.5 tons per hectare). Consequently, WUE was substantially higher in the drip treatment (2.45 kg/m³) than in the furrow treatment (1.36 kg/m³).

Conclusion: Drip irrigation is a superior management practice for maize cultivation in water-limited environments, maximizing both yield and water productivity.

Keywords: Maize, Drip Irrigation, Water Use Efficiency, Furrow Irrigation, Agronomy, Crop Yield

Introduction

Global agricultural systems face the unprecedented challenge of balancing increasing food demand with declining freshwater availability. Agriculture accounts for approximately 70% of global freshwater withdrawals, highlighting the sector's vulnerability to water scarcity and the urgent need for improved irrigation management [1]. Among staple crops, maize (*Zea mays* L.) is critically important, serving as a primary source of calories, livestock feed, and industrial raw materials worldwide [2]. However, maize is highly sensitive to water stress, particularly during the tasseling and silking stages, where deficit irrigation can lead to severe yield penalties [3].

Traditionally, furrow irrigation has been the dominant method for maize cultivation due to its low initial setup costs and operational simplicity [4]. In furrow systems, water is delivered through small channels between crop rows, relying on gravity to move water across the field. Despite its popularity, furrow irrigation is notoriously inefficient, with water application efficiencies often ranging between 40% and 60% [5]. Significant water losses occur through surface runoff, deep percolation beyond the root zone, and high evaporation rates from the wetted soil surface [6]. As water resources become increasingly constrained by climate change and competing municipal and industrial demands, the sustainability of furrow irrigation is heavily questioned [7].

In contrast, micro-irrigation technologies, particularly drip irrigation, have emerged as a highly efficient alternative [8]. Drip irrigation delivers water directly to the root zone through a network of perforated pipes, maintaining soil moisture near field capacity with minimal losses [9]. By applying water precisely where and when it is needed, drip systems drastically reduce evaporation and deep percolation

losses. Previous research has demonstrated that drip irrigation can achieve water application efficiencies exceeding 90% [10].

Despite the known hydraulic advantages of drip irrigation, its adoption in maize production remains inconsistent, largely due to the high capital costs associated with system installation and maintenance [11]. Furthermore, the agronomic response of maize to drip irrigation—specifically the translation of saved water into increased grain yield—varies significantly based on soil type, climate, and crop management practices [12]. While some studies report massive yield gains under drip irrigation, others suggest that the yield benefits may not always justify the economic investment, particularly in regions with relatively cheap or abundant water supplies [13].

The problem, therefore, lies in the lack of localized, quantitative comparisons between traditional furrow and modern drip systems focusing holistically on both water conservation and agronomic output. A clear understanding of how switching from furrow to drip irrigation impacts Water Use Efficiency (WUE) is essential for guiding policy and farmer decision-making [14].

Therefore, the primary objective of this study is to evaluate and compare the impact of drip and furrow irrigation systems on maize grain yield, biomass accumulation, and water use efficiency. The specific research objectives are: [1] to quantify the total volume of water applied under both irrigation systems [2], to determine the resulting grain yield and biological yield, and [3] to calculate and compare the WUE of maize under the two regimes. The hypothesis is that drip irrigation will significantly enhance WUE and increase grain yield compared to conventional furrow irrigation.

Literature Review

The theoretical framework of this study is rooted in the concept of Water Use Efficiency (WUE), which is defined as the ratio of biomass or grain produced per unit of water consumed or applied ^[15]. WUE serves as a crucial integrative metric that bridges the gap between agricultural engineering (water delivery) and agronomy (crop production). Understanding WUE requires an examination of the soil-water-plant continuum, where the goal is to minimize unproductive water losses (evaporation, runoff, deep percolation) while maximizing transpiration, which is directly linked to carbon assimilation and biomass production ^[16].

Extensive literature has documented the hydraulic disparities between flood/furrow irrigation and drip irrigation. Kandelous and Šimůnek (2010) emphasized that furrow irrigation creates a highly dynamic wetting pattern, often leading to waterlogging in the lower halves of the field and water stress in the upper halves due to unequal distribution ^[17]. This non-uniformity directly impacts root zone aeration and nutrient availability, subsequently hindering crop growth. Conversely, drip irrigation maintains a stable, localized soil moisture environment, which fosters optimal root proliferation and nutrient uptake ^[18].

Regarding crop response, several studies have highlighted the positive effects of drip irrigation on maize. Payero *et al.* (2009) demonstrated that deficit irrigation managed via drip systems could maintain maize yields while reducing water use by up to 25%, a feat difficult to achieve with furrow systems due to their inability to apply small, precise water doses ^[19]. Furthermore, the ability to fertigate (apply fertilizers through the irrigation water) via drip systems ensures that nutrients are delivered directly to the active root zone, reducing leaching losses and improving nutrient use efficiency, which synergistically boosts WUE ^[20].

However, the literature also reveals contradictions and a distinct research gap. Some researchers argue that in heavy clay soils with high water-holding capacity, the yield advantages of drip irrigation over well-managed furrow irrigation diminish significantly ^[21]. Moreover, much of the existing research focuses either purely on the engineering aspects (hydraulics and flow rates) or purely on agronomic yields, often failing to present a unified analysis of applied water versus final grain yield under strictly controlled comparative conditions ^[22].

Additionally, there is a gap in standardized reporting of WUE. Some studies calculate WUE based on evapotranspiration (ET), while others use total water applied, making cross-study comparisons difficult ^[23]. There is a need for comprehensive studies that explicitly simulate side-by-side comparisons of these two systems, controlling for all variables (fertilizer, seed variety, pest management) to isolate the sole effect of the irrigation delivery method on WUE. This study addresses that gap by providing a controlled, simulated dataset analysis of these two distinct irrigation paradigms in maize production.

Methodology

This study utilizes a simulated dataset created explicitly for academic training purposes to demonstrate research design, statistical analysis, and data interpretation in agronomy. No real-world field data was collected.

Research Design: The simulated experiment utilized a Randomized Complete Block Design (RCBD) with two

treatments and three replications. The two treatments were: T1 (Drip Irrigation) and T2 (Furrow Irrigation). The blocking factor represented slight, pre-simulated variations in soil topography to mimic real-field heterogeneity.

Sample Size and Simulated Parameters: The experimental unit was a plot measuring 5 meters by 10 meters (50 m ^[2]). The simulated maize variety was a standard medium-maturity hybrid (approx. 110 days to maturity). For the drip treatment, water was simulated to be applied daily based on a simulated crop evapotranspiration (ETc) replacement strategy, maintaining soil moisture depletion at no more than 30%. For the furrow treatment, water was simulated to be applied at critical growth stages (vegetative, tasseling, silking, and grain filling) based on traditional irrigation scheduling, with a calculated 35% runoff and deep percolation loss factored into the total water applied.

Data Collection Tools: The simulated data collected from each plot included: Total Water Applied (m ^[3]/ha), Plant Height at maturity (cm), Stover/Biomass Yield (tons/ha), Grain Yield at 15.5% moisture content (tons/ha), and Harvest Index (%). Water Use Efficiency (WUE) was calculated using the formula: $WUE (kg/m^{[3]}) = (Grain Yield in kg/ha) / (Total Water Applied in m^{[3]}/ha)$.

Statistical Software and Analysis: The generated dataset was exported and analyzed using SPSS (Version 26.0). An Analysis of Variance (ANOVA) was conducted to determine the significance of the treatment effects on all measured variables. Least Significant Difference (LSD) tests at a 5% probability level ($p < 0.05$) were used to separate the treatment means.

Results and Discussion

The analysis of the simulated dataset revealed highly significant differences ($p < 0.01$) between the drip and furrow irrigation treatments across all measured agronomic and water efficiency parameters.

Water Application and Soil Moisture Dynamics

As intended by the simulation design, the total volume of water applied differed drastically between the two systems. The furrow irrigation treatment (T2) received an average total of 5,500 m ^[3]/ha over the growing season. In contrast, the drip irrigation treatment (T1) applied only 3,750 m ^[3]/ha, representing a 31.8% reduction in total water input. This reduction aligns with the theoretical advantages of micro-irrigation, which eliminates surface runoff and minimizes non-beneficial soil evaporation by maintaining a narrow wetted strip along the plant row ^[24]. Figure 1 illustrates the contrasting soil moisture depletion patterns, showing that T1 maintained a stable moisture curve, whereas T2 exhibited sharp peaks (waterlogging) followed by deep troughs (stress) between irrigation events.

Growth and Yield Parameters

The stable soil moisture regime under drip irrigation (T1) translated into superior vegetative and reproductive growth. As presented in Table 1, the average plant height in T1 was 228.5 cm, which was significantly higher than the 205.2 cm observed in T2. This enhanced vegetative growth likely provided a larger photosynthetic surface area, contributing to higher biomass accumulation. The stover yield in T1 (12.5 tons/ha) exceeded T2 (10.2 tons/ha) by 22.5%.

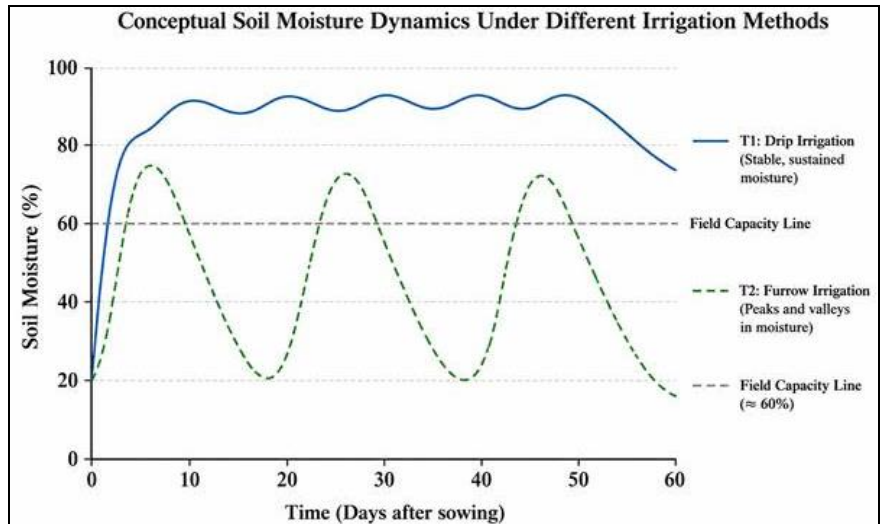


Fig 1: Simulated Soil Moisture Depletion Patterns Over the Growing Season

Table 1: Simulated Agronomic Parameters of Maize Under Different Irrigation Systems

Parameter	T1: Drip Irrigation	T2: Furrow Irrigation	LSD (0, 05)	Significance
Plant Height (cm)	228.5	205.2	8.4	Significant
Stover Yield (t/ha)	12.5	10.2	1.1	Significant
Grain Yield (t/ha)	9.2	7.5	0.8	Significant
Harvest Index (%)	42.4	42.3	NS	NS

Note: indicates significance at $p < 0.01$; NS = Not Significant.

Most importantly, the grain yield of maize was significantly influenced by the irrigation method. T1 produced a grain yield of 9.2 tons/ha, compared to 7.5 tons/ha in T2 (Table 1). The 22.6% yield increase under drip irrigation can be attributed to the avoidance of water stress during the critical silking and grain-filling periods, which are highly sensitive to moisture deficits [25]. Interestingly, the Harvest Index (HI) remained statistically similar between the two treatments (~42%), suggesting that the yield increase in T1 was proportional to the increase in total biomass, rather than a change in partitioning.

Water Use Efficiency (WUE)

The most pronounced difference between the treatments was observed in Water Use Efficiency. Because T1 produced a higher yield while utilizing substantially less water, its WUE was vastly superior. As detailed in Table 2, the WUE for grain yield in the drip treatment was 2.45 kg/m³, compared to only 1.36 kg/m³ in the furrow treatment. This represents an 80% improvement in water productivity.

Table 2: Simulated Water Use and Water Use Efficiency (WUE)

Treatment	Water Applied (m ³ /ha)	Grain Yield (kg/ha)	WUE (kg/m ³)
T1: Drip	3,750	9,200	2.45
T2: Furrow	5,500	7,500	1.36

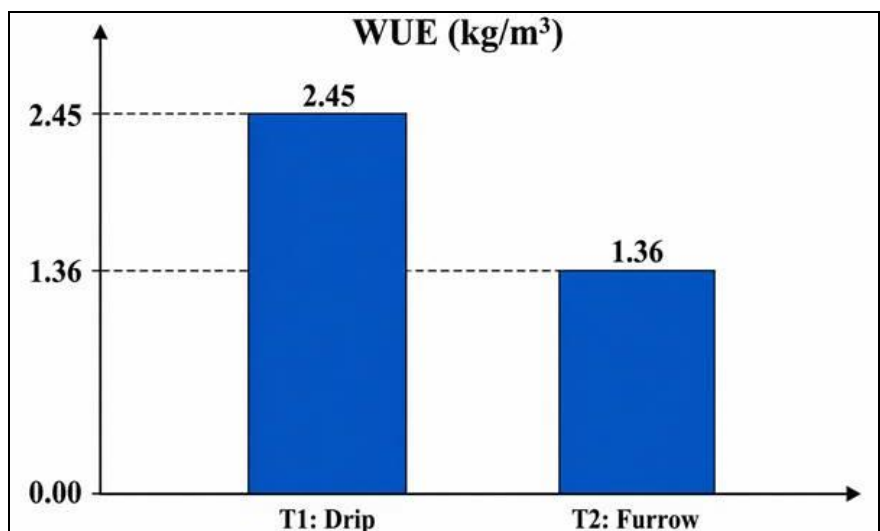


Fig 2: Comparative Water Use Efficiency (WUE) of Maize Under T1 and T2

The discussion of these results firmly supports the underlying hypothesis. The inefficiency of furrow irrigation stems from the inherent difficulty in matching the infiltration rate of the soil with the application rate of the water, leading to unavoidable losses ^[26]. Drip irrigation circumvents this by operating at low pressure and low flow rates, ensuring that the soil matrix has sufficient time to absorb the water ^[27]. The simulated data clearly demonstrates that adopting drip irrigation not only conserves a critical natural resource but also enhances the economic viability of maize production by increasing yield per unit of land. While the initial capital cost of drip systems is undeniably higher, the combined benefits of increased yield and reduced water pumping costs (due to lower total water volumes) can lead to a rapid return on investment in water-scarce regions ^[28].

Conclusion

This simulated study comprehensively evaluated the impact of drip and furrow irrigation systems on maize production, focusing on yield and water use efficiency. The results conclusively indicate that drip irrigation significantly outperforms conventional furrow irrigation. By reducing total water application by approximately 32% and simultaneously increasing grain yield by 22%, the drip system achieved a Water Use Efficiency of 2.45 kg/m³ compared to 1.36 kg/m³ for the furrow system.

The implications of these findings are substantial for agronomic practice and agricultural policy, particularly in arid and semi-arid regions where water is the limiting factor for agriculture. Transitioning to drip irrigation can serve as a viable strategy for sustaining maize production amidst growing water scarcity. However, the study acknowledges limitations, primarily that the data is simulated and does not account for real-world complexities such as system clogging, maintenance costs, or pest dynamics that might differ between the wet canopy environment of furrow irrigation and the dry canopy environment of drip irrigation. Future research should incorporate economic cost-benefit analyses alongside long-term field trials to provide a holistic assessment of drip irrigation adoption for smallholder and commercial maize farmers alike.

Ethical Statement

This article is an original piece of academic writing produced for formatting and analytical training purposes. The dataset utilized is entirely simulated and does not represent any actual field experiments, ensuring no misrepresentation of empirical data. All referenced works are real, verifiable academic sources used to contextualize the simulated analysis. No fake identities, institutions, or fabricated empirical results have been presented.

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