



Evaluating Surface Irrigation methods for improved Agricultural Water Management

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Abstract

Efficient water management is essential to sustain agriculture, especially in arid and semi-arid regions where surface irrigation is widely practiced. Despite its simplicity and historical prevalence, surface irrigation often suffers from inefficiencies such as non-uniform water distribution, runoff, and deep percolation losses. This study evaluates various surface irrigation methods, including furrow, border, and basin irrigation, focusing on innovative approaches like surge flow and alternate furrow irrigation (AFI). These methods show promise in improving water use efficiency without compromising crop yields. A comprehensive review of literature and performance metrics, including application efficiency, storage efficiency, and distribution uniformity, provides actionable insights into optimizing surface irrigation systems. By adjusting factors such as inflow rates, furrow length, and irrigation scheduling, significant water savings and improved uniformity can be achieved. Automated systems utilizing real-time data further enhance efficiency by optimizing irrigation timing. The findings highlight the potential of surface irrigation optimization in addressing global water scarcity challenges, ensuring agricultural sustainability, and balancing resource use with productivity demands.

Keywords: Surface irrigation, water efficiency, furrow irrigation, surge flow irrigation, alternate furrow irrigation, agricultural sustainability

Introduction

Water is an indispensable resource for agriculture, particularly in arid and semi-arid regions where irrigation is necessary to sustain crop production. Among the various methods used to deliver water to crops, surface irrigation has been widely adopted due to its simplicity and historical precedence. However, in the face of increasing global water scarcity and rising competition for water resources, it has become critical to evaluate and improve the efficiency of surface irrigation methods. Water-use efficiency (WUE) is a pressing concern in agriculture, especially given that agriculture remains the largest consumer of freshwater globally. This study, titled "Evaluating surface irrigation methods for improved agricultural water management" seeks to explore how surface irrigation methods can be optimized to enhance the effective use of water in agricultural practices.

Background and Importance of Water Use Efficiency in Agriculture

Water management is a vital issue that cuts across various sectors, but its relevance is most pronounced in agriculture. Agriculture alone accounts for around 70% of all freshwater withdrawals globally. As water becomes an increasingly finite and contested resource, effective water use, particularly in agriculture, is paramount. In India, which accounts for a significant portion of the world's irrigated lands, irrigation remains the backbone of agricultural productivity (Anjum *et al.*, 2023). Unfortunately, much of this irrigation is plagued by inefficiencies, leading to substantial water losses, waterlogging, salinity (El Sabagh *et al.*, 2020) [13] and ultimately, resource degradation.

Surface irrigation, being one of the oldest and most extensively used methods, is subject to these inefficiencies.

Despite its extensive application, surface irrigation is often criticized for its low efficiency (Fadul *et al.* 2020) [17]. Water application is inconsistent (Wang *et al.*, 2021) [43], leading to non-uniform infiltration rates (You *et al.*, 2022) [47] across a field and increased water losses due to runoff (Wang *et al.*, 2019) [44], evaporation (Fuentes *et al.*, 2020) [21], and deep percolation. Thus, it is critical to evaluate the performance of surface irrigation systems to identify areas where improvements can be made to optimize water distribution and minimize wastage.

Surface Irrigation Methods and Their Challenges

Surface irrigation includes a range of practices where water is applied directly to the soil surface and distributed by gravity. This method, though simple, is influenced by numerous factors such as soil type (Zhong *et al.*, 2020) [49], field slope (Gu *et al.*, 2019) [24], water flow rates (Okasha *et al.*, 2022) [36], and crop type. Surface irrigation can be further divided into categories such as furrow, border, and basin irrigation.

The performance of surface irrigation is generally measured by key parameters such as application efficiency (Li *et al.*, 2020) [32], storage efficiency (Geleto *et al.*, 2019) [22], and distribution uniformity (Teshome *et al.*, 2018) [40]. Application efficiency refers to the proportion of the applied water that is effectively used by the crop (Alharbi *et al.*, 2024) [1], while storage efficiency reflects the percentage of applied water that is stored in the root zone (Amer, 2011) [3]. Distribution uniformity evaluates how evenly water is distributed across the field (Faria *et al.*, 2019) [18]. Achieving high values for these parameters is critical for effective irrigation, but surface irrigation systems often fail to meet these targets due to site-specific factors and operational shortcomings. One of the primary challenges in surface

irrigation is the variability in water infiltration rates across a field. Factors such as soil texture, slope, and roughness play significant roles in determining how quickly and evenly water penetrates the soil. Moreover, inadequate land levelling (Vohra & Franklin, 2021) ^[42] or poor field design (Eshete *et al.*, 2021) ^[15] can exacerbate these issues, leading to non-uniform water application and wastage.

The Need for Performance Evaluation

Evaluating the performance of surface irrigation systems is crucial for improving water-use efficiency and sustaining agricultural productivity. Performance evaluation involves assessing how effectively an irrigation system delivers water to crops, taking into account factors such as water losses, crop response, and overall system efficiency. Without such evaluations, inefficiencies persist, resulting in water wastage, increased costs, and reduced crop yields. Surface irrigation is often associated with higher water losses compared to other methods such as drip or sprinkler systems (Al-Jamal *et al.*, 2001; Darko *et al.*, 2017) ^[2, 10]. However, due to the large-scale use of surface irrigation, particularly in developing countries (Chathuranika *et al.*, 2022) ^[8], replacing it with more advanced systems is neither feasible nor economical in many cases. Thus, performance evaluations offer a practical means of identifying ways to improve surface irrigation systems without requiring wholesale replacement

Relevance to Future Water Resource Management

With increasing pressure on finite water resources, improving irrigation efficiency has become a priority in agricultural water management. Estimates suggest that as much as 40% or more of the water diverted for irrigation is wasted at the farm level due to inefficiencies (Tyagi, 2024; Bekchanov, *et al.*, 2024; Bekchanov, *et al.*, 2016) ^[6, 7, 41]. This presents both an environmental and economic challenge, as inefficient water use not only depletes a critical resource but also results in increased production costs and diminished returns for farmers.

In the context of climate change and growing populations, the demand for water is set to rise (Baggio *et al.*, 2021) ^[5] while water availability becomes increasingly uncertain (Martínez-Valderrama *et al.*, 2023; Douville *et al.*, 2022) ^[12]. Agricultural practices must adapt by improving water-use efficiency to ensure food security (Alharbi *et al.*, 2024) ^[1] and resource sustainability (Wu *et al.*, 2024) ^[46]. This study aims to review this effort by identifying design and management strategies that can enhance the performance of surface irrigation systems, particularly in terms of application efficiency, uniformity, and water conservation.

Material and Methodology

This review focuses on evaluating the performance of various surface irrigation techniques in improving water use efficiency in agricultural water management. The methodology involved a comprehensive review of existing literature on surface irrigation, particularly furrow, border, and basin irrigation techniques, as well as innovative approaches such as surge flow and alternate furrow irrigation.

Search Strategy and Sources

Relevant literature was collected from multiple academic databases, including PubMed, Scopus, and Google Scholar,

using keywords such as “surface irrigation,” “water use efficiency,” “furrow irrigation,” “surge flow irrigation,” and “alternate furrow irrigation.” The time frame for the selection of articles was limited to studies published between 2000 and 2024 to ensure the inclusion of up-to-date findings and technological advancements in the field of irrigation.

Inclusion and Exclusion Criteria

Articles selected for the review were primarily peer-reviewed studies that focused on the performance, efficiency, and challenges of surface irrigation methods. Studies dealing with irrigation in arid and semi-arid regions, where water management is critical, were prioritized. Non-peer-reviewed articles, studies without quantitative data and research focusing on unrelated irrigation methods, such as drip or sprinkler irrigation, were excluded.

Data Extraction and Analysis

The selected studies were reviewed and categorized based on key performance indicators such as water application efficiency, distribution uniformity, and storage efficiency. Methods like surge flow irrigation and alternate furrow irrigation were highlighted for their potential in reducing water loss while maintaining crop yields. Additionally, research on the infiltration characteristics and field design adjustments for surface irrigation was included to provide a holistic understanding of the system’s performance.

Limitations

This review is limited by the scope of available studies published in English and may have excluded relevant findings in other languages. Additionally, the focus on arid and semi-arid regions may limit the generalizability of the findings to other climatic zones.

Review of Literature

A substantial body of research has been conducted on surface irrigation, with an emphasis on improving water use efficiency. Several performance metrics such as application efficiency, storage efficiency, and distribution uniformity are commonly used to assess irrigation system. Research has also demonstrated that surface irrigation can become ineffective due to design flaws, soil characteristics, and poor management. Studies have explored various strategies to optimize surface irrigation, from adjusting inflow rates to implementing novel techniques like surge flow irrigation and alternate furrow irrigation.

Surge Flow and Alternate Furrow Irrigation

Mitchell and Stevenson (1993) ^[33] compared surge flow and alternate furrow irrigation to continuous flow on a peppermint field. The results demonstrated water savings and yield maintenance with surge flow, while alternate furrow irrigation also saved water without reducing crop yields. These findings suggest that both techniques can enhance water use efficiency in surface irrigation. Surge flow and alternate furrow irrigation methods are effective techniques in surface irrigation aimed at improving water use efficiency and reducing water loss. These methods have been extensively studied for their impact on water conservation, crop yield, and infiltration characteristics. Sheta *et al.*, 20024 ^[39] found that surge irrigation treatments (with different numbers of surges) saved between 19.83%

and 32.26% more water compared to continuous flow irrigation. Furthermore, it achieved higher crop yields and better soil moisture retention, with the highest maize yield recorded at 3740 kg/feddan using six surge cycles compared to 2756 kg/feddan under continuous flow. The highest WUE was 1.91 kg/m³ for surge irrigation, significantly higher than the 0.94 kg/m³ for continuous flow. Surge irrigation operates by alternating the flow of water between different sections of a field using a surge valve. This pulsing action reduces soil infiltration rates (Clothier and Green, 1994) ^[9], resulting in more efficient use of water. Each pulse of water advances further across the field with less water being lost to deep percolation, particularly in soils prone to high infiltration rates. By adjusting the cycle time and water application rate, farmers can control water delivery to match soil infiltration characteristics, leading to more uniform irrigation and reduced water losses (Goldhammer *et al.*, 1987) ^[23].

1. Surge flow irrigation

Surge flow irrigation involves the intermittent application of water in on-and-off cycles, allowing water to advance more evenly across the field. This method helps to reduce deep percolation losses and soil erosion while increasing the uniformity of water distribution. Mitchell and Stevenson (1993) ^[33] demonstrated that surge flow irrigation could save water and maintain crop yield at levels comparable to continuous flow. The cyclic nature of water application in surge flow allows the soil to partially drain between cycles, improving infiltration and reducing runoff.

2. Alternate Furrow Irrigation (AFI)

Alternate furrow irrigation is a method where water is applied to alternate furrows rather than every furrow. This technique reduces water usage by irrigating only half the furrows during each irrigation event. Studies such as Kang *et al.* (2000) ^[30] showed that AFI could significantly reduce water application without affecting crop yield. Root development was found to be enhanced under AFI and water savings of up to 50% were reported. Moreover, AFI reduces evaporation losses as the non-irrigated furrows act as dry zones, further conserving water.

3. Water Use Efficiency Improvements

One of the primary advantages of surge irrigation is its ability to improve water distribution uniformity, especially in furrow irrigation systems. Studies have demonstrated that intermittent water application helps seal the soil surface, reducing deep percolation and allowing for smaller irrigation applications. This technique has been particularly beneficial in regions with coarse-textured soils, where water infiltration rates are high. Surge irrigation can reduce the amount of water applied by 10-30% compared to traditional continuous-flow irrigation, without negatively impacting crop yields (Evans & Sadler, 2008) ^[16]. In addition to reducing water loss through deep percolation, surge irrigation has been shown to decrease surface runoff, another significant contributor to water wastage in conventional surface irrigation methods. By optimizing the irrigation intervals, farmers can minimize non-beneficial water losses while ensuring that crops receive adequate moisture during critical growth stages. Improved water application efficiency directly correlates with increased WUE, allowing farmers to produce more crop yield per unit of water applied (Irmak *et al.*, 2014).

4. Economic and Environmental Impacts

Surge irrigation not only enhances WUE but also offers economic benefits. By reducing the total volume of water applied, farmers can lower their irrigation-related costs, including energy costs for water pumping. This can result in significant savings in regions where water is scarce or costly. Additionally, better water management reduces soil erosion and nutrient leaching, contributing to long-term soil health and sustainability (Perry *et al.*, 2009) ^[37].

5. Comparison and Performance

Both surge flow and alternate furrow irrigation methods have been shown to enhance water use efficiency and reduce wastage. Surge flow is particularly effective in soils with varying infiltration rates as it promotes better water distribution across the field. In contrast, AFI is more suited for crops with deep-root systems, as it encourages deeper root growth and reduces water stress.

Table 1: Impact of Surge Flow and Alternate Furrow Irrigation on Water Use and Crop Yield

Parameter	Surge flow irrigation	Alternate furrow irrigation (AFI)
Water Application	Intermittent on-off cycles	Water applied to alternate furrows
Water Saving	Significant reduction in deep percolation and runoff	Water savings up to 50%
Effect on Yield	Yield maintained comparable to continuous flow	Yield maintained or enhanced with reduced water input
Infiltration Characteristics	Improved due to cyclic application	Enhanced root development and reduced evaporation
Operational Complexity	Requires timed water application	Requires manual adjustment for each irrigation

6. Challenges and limitations

While surge irrigation offers clear benefits, its implementation can be challenging. The initial setup cost for surge valves and related equipment can be a barrier for small-scale farmers. Additionally, surge irrigation requires careful management to optimize the cycle times and water application rates based on soil type, crop needs, and field conditions. Poorly managed surge irrigation can lead to uneven water distribution, negatively affecting crop yields (Jensen, 2007) ^[29].

Infiltration and Recession Trajectories

Foroud *et al.* (1996) ^[30] developed a technique to assess infiltration rates using border irrigation, revealing that

infiltration characteristics could be predicted using advance and recession functions. Their work underscores the importance of understanding infiltration dynamics for optimizing irrigation scheduling and water application. The study of infiltration and recession trajectories plays a vital role in understanding surface irrigation's efficiency and performance. The infiltration process determines how water moves into the soil, while the recession trajectories relate to the timing of water retreat from the surface, both crucial for designing effective irrigation systems. This review synthesizes findings from various studies on infiltration and recession behaviour, emphasizing their impact on irrigation practices. Infiltration characteristics in surface irrigation systems are often derived using the advance-recession data.

Foroud *et al.* (1996) ^[20] developed a volume-balance technique utilizing these trajectories to assess infiltration parameters in clay loam soil, finding that simulated infiltration data closely matched field data. Similarly, Mohamed and Abbas (2012) ^[35] introduced a mathematical model simulating water movement in furrows, which includes the infiltration and recession trajectory, runoff hydrograph, and irrigation performance indicators.

The relationship between infiltration opportunity time and system efficiency is a key consideration. For example, Sharma and Singh (2009) ^[38] demonstrated that deep percolation losses increase when the infiltration opportunity time is longer than needed, which affects the efficiency of water use. This suggests that proper management of infiltration timing can reduce water losses and enhance system performance. The shape and slope of the field also influence infiltration rates. In their study of furrow irrigation, Holzapfel *et al.* (2004) ^[26] noted that cumulative infiltration varied significantly based on furrow width and measurement methods. Narrow furrows demonstrated more consistent infiltration curves compared to wider ones, highlighting the need for careful field design to improve uniformity in water infiltration.

Further investigation into the recession trajectories has shown that optimizing the inflow rate and irrigation cutoff

time can improve the application efficiency. Darouich *et al.* (2012) proposed multicriteria analysis to rank different surface irrigation alternatives, focusing on both water savings and economic returns. The study found that graded furrow alternatives, which are directly related to recession and infiltration behaviour, are more efficient than non-graded alternatives, though they require land levelling. Kang *et al.* (2000) ^[30] studied the impact of alternate furrow irrigation (AFI) on infiltration and found that AFI reduced water application by up to 50% without compromising yield, suggesting that precise control of infiltration through alternating furrows can optimize water use. Moreover, the initial soil moisture content significantly impacts infiltration rates. Amer and Amer (2010) observed that under wetter initial conditions, smaller irrigation amounts applied more frequently yielded better water use efficiency (WUE) and higher application efficiency. This points to the importance of pre-wetting and irrigation scheduling in managing infiltration and reducing water loss. Incorporating modern technologies, Koech *et al.* (2010) ^[31] proposed a conceptual automatic furrow irrigation system using real-time monitoring of water advance to optimize infiltration and recession timing. This innovation could significantly improve both the accuracy of infiltration management and overall irrigation efficiency.

Table 2: Infiltration Characteristics and Optimization Techniques in Furrow Irrigation

Infiltration/ Recession Focus	Findings	Study
Volume-balance technique for infiltration	Infiltration parameters from advance/recession closely matched field data.	Foroud <i>et al.</i> (1996) ^[20]
Mathematical model for furrow irrigation	Simulated advance-recession trajectories improved performance indicators.	Mohamed & Abbas (2012) ^[35]
Infiltration opportunity time and deep percolation losses	Deep percolation increased with longer opportunity time; proper design can reduce losses.	Sharma & Singh (2009) ^[38]
Furrow width effect on cumulative infiltration	Narrow furrows showed more consistent infiltration compared to wide furrows.	Holzapfel <i>et al.</i> (2004) ^[26]
Alternate furrow irrigation (AFI) impact on water application and yield	AFI reduced water application by 50% without yield loss, showing efficient use of infiltration.	Kang <i>et al.</i> (2000) ^[30]
Effect of initial soil moisture on infiltration	Frequent small irrigation with wet soil gave better efficiency than larger amounts with dry soil.	Amer & Amer (2010)
Automated monitoring of water advance and recession	Real-time monitoring optimized infiltration and recession timing, improving irrigation efficiency.	Koech <i>et al.</i> (2010) ^[31]

General irrigation efficiency

Wang *et al.* (1996) ^[45] introduced the concept of general irrigation efficiency, which incorporates both water use and crop growth effectiveness. Their findings showed that the general irrigation efficiency metric provides a holistic view of the irrigation system's performance. The concept of irrigation efficiency is vital for optimizing water usage in agriculture, particularly as water scarcity becomes a global concern. Irrigation efficiency refers to how well water is applied and utilized in agriculture to maximize crop production with minimal waste. Among the various forms of irrigation, surface irrigation is one of the most common but also one of the least efficient methods.

Performance metrics and challenges

Surface irrigation systems, while simple, pose several challenges in achieving high efficiency. The infiltration rate, soil type, and topography greatly influence water distribution. In fields with uneven terrain or inconsistent soil properties, achieving uniform distribution can be difficult, leading to inefficient water use. One significant problem with surface irrigation is water loss through runoff and deep

percolation. This inefficiency is exacerbated by the slow movement of water across the soil surface, which results in overwatering in some areas while under-watering others. As a result, irrigation performance indices, such as application efficiency and storage efficiency, tend to be lower in surface irrigation systems compared to more advanced methods like sprinkler or drip irrigation.

Improving general irrigation efficiency

The general irrigation efficiency model, proposed by Wang *et al.* (1996) ^[45], integrates these traditional efficiency terms into a comprehensive measure that reflects both water use and crop productivity. This approach highlights the importance of balancing water application and storage to achieve overall efficiency. When general irrigation efficiency is below 100%, it indicates inefficiencies in water use, such as poor application techniques or excessive losses to runoff or percolation. One study showed that alternating furrow irrigation could reduce water application by up to 50% while maintaining crop yield, making it a viable option for improving general irrigation efficiency. Similarly, field experiments using surge flow irrigation revealed substantial

reductions in water consumption without sacrificing crop yield.

Furrow Irrigation Optimization

Horst *et al.* (2005) [27] studied the effect of furrow length, inflow rates, and alternate furrow irrigation on efficiency parameters such as application efficiency and distribution uniformity. Their results indicated that high application efficiencies of up to 80% could be achieved through appropriate adjustments in irrigation design and operation. The optimization of furrow irrigation involves fine-tuning various parameters such as inflow rates, furrow length, irrigation scheduling, and cutoff times to maximize water use efficiency while maintaining crop yield. Researchers have focused on different methods to improve these factors, as furrow irrigation is among the most commonly used surface irrigation techniques, particularly in arid and semi-arid regions.

1. Inflow Rates and Furrow Length: Several studies have examined the impact of inflow rates on furrow irrigation efficiency. Horst *et al.* (2005) [27] found that an inflow rate of 1.8 l/s in long furrows led to 80% application efficiency and 83% distribution uniformity. The study suggested that optimized inflow rates and furrow length can result in significant seasonal water savings. Similarly, Eldeiry *et al.* (2005) [14] observed that furrow length and discharge rate need to be carefully selected for clay soils to maintain high application efficiency (80-90%).

2. Alternate Furrow Irrigation (AFI): Kang *et al.* (2000) [30] introduced AFI as a method where water is applied

alternately between furrows during consecutive irrigations. AFI has been shown to reduce irrigation water by 50% while maintaining comparable yields, as it enhances root development. This approach is particularly valuable in regions where water resources are limited.

3. Automation in Furrow Irrigation: Koech *et al.* (2010) [31] proposed an automatic furrow irrigation system, utilizing a camera and a computer to monitor the advance of water in the furrow. By sending real-time data on water movement, the system adjusts the inflow cutoff time, optimizing water usage without manual labour. This method presents a way forward in the use of technology for furrow irrigation optimization.

4. Irrigation Scheduling and Cutoff Time: Proper scheduling and cutoff times are crucial for minimizing water losses. Azmi *et al.* (2011) [4] demonstrated that reducing the cutoff time by 27 minutes in a 165-meter furrow length improved overall water use efficiency. Similarly, Holzapfel *et al.* (2010) [25] showed that adjusting cutoff times based on furrow design and inflow rates directly affects irrigation efficiency and crop yield.

5. Surge Flow Irrigation: Surge flow, a variant of furrow irrigation, was studied by Mitchell and Stevenson (1993) [33]. In this method, water is applied in intervals rather than continuously, allowing the soil to absorb water more efficiently. The study found that surge flow reduces water runoff and improves application efficiency, especially when compared to conventional continuous flow irrigation.

Table 3: Innovative Approaches to Enhancing Irrigation Efficiency

Study	Methodology	Findings
Horst <i>et al.</i> (2005) [27]	Inflow rate and furrow length	High application efficiency (80%) and water savings (200-300 mm) achieved by optimized inflow and longer furrows.
Kang <i>et al.</i> (2000) [30]	Alternate Furrow Irrigation (AFI)	50% reduction in water use with no significant yield loss, enhancing root development.
Koech <i>et al.</i> (2010) [31]	Automated irrigation system	Real-time monitoring of water advance improved irrigation efficiency by adjusting cutoff times.
Azmi <i>et al.</i> (2011) [4]	Irrigation cutoff time	Reducing cutoff time by 27 minutes in long furrows saved substantial water while maintaining crop yield.
Mitchell and Stevenson (1993) [33]	Surge flow irrigation	Improved water savings and reduced runoff compared to continuous flow irrigation.

Impact of Runoff Collection

Zapata *et al.* (2000) [48] examined the effectiveness of runoff collection systems (RR systems) in basin irrigation,

demonstrating significant improvements in application efficiency and reduced irrigation times compared to conventional methods.

Table 4: Key Findings from Studies on Water-Saving Irrigation Practices

Study	Method	Efficiency Improvement	Key Findings
Mitchell and Stevenson (1993) [33]	Surge Flow, Alternate Furrow	Water savings, maintained crop yields	Surge flow reduced water use with no yield loss
Foroud <i>et al.</i> (1996) [20]	Infiltration Techniques	Accurate infiltration prediction	Advanced techniques enhanced prediction models
Wang <i>et al.</i> (1996) [45]	General Irrigation Efficiency	Holistic performance view	Unified measure of water use and crop growth
Horst <i>et al.</i> (2005) [27]	Furrow Irrigation Optimization	80% application efficiency	High efficiency through design modifications
Zapata <i>et al.</i> (2000) [48]	Runoff Collection	Increased application efficiency by 9%	Runoff collection reduced irrigation losses

Conclusion

Optimizing surface irrigation systems is critical to achieving sustainable water management in agriculture, particularly in

regions where water scarcity threatens productivity. This study highlights the potential of innovative techniques, including surge flow and alternate furrow irrigation, to

significantly enhance water use efficiency while maintaining or improving crop yields. Key findings indicate that adjusting parameters such as inflow rates, furrow length, and irrigation scheduling can reduce water loss and improve application efficiency. Automation and real-time monitoring further streamline these improvements, minimizing human error and optimizing system performance.

While challenges such as cost, operational complexity, and regional variability exist, adopting tailored strategies can address inefficiencies without replacing surface irrigation entirely. Future research should focus on integrating modern technologies, developing cost-effective solutions, and conducting field trials in diverse climatic conditions. By prioritizing such efforts, surface irrigation can continue to play a vital role in global agricultural water management, balancing the need for increased food production with the conservation of precious water resources.

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