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Research Article

Boosting Coffee Yields and Water Productivity: A Review of Drip Irrigation in Ethiopia

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Abstract

This review evaluates the effects of different irrigation methods on coffee yield and water productivity (WP) in Ethiopia's Jimma and Wollega zones, aligning with global trends. Drip irrigation consistently results in the highest coffee yields, producing 3870 kg ha^{-1} in Jimma at Melko, a 48% increase over surface irrigation and a 142% increase over rainfed conditions. In East Wollega at Wayu, drip irrigation yields 2035 kg ha^{-1}, 45% higher than surface irrigation and 213% higher than rainfed farming. Surface irrigation, although less efficient than drip, still offers significant improvements over rainfed methods, with cheery yields of 3000 kg ha^{-1} in Jimma at Melko, 2330 kg ha^{-1} in Jimma at Gera district, and 1402 kg ha^{-1} in West Wollega at Haru district, demonstrating increases of 63%, 48%, and 115%, respectively, over rainfed conditions. Rainfed agriculture consistently delivers the lowest yields, highlighting its vulnerability to water scarcity, with only 1600 kg ha^{-1} in Jimma at Melko and 650 kg ha^{-1} in West Wollega at Haru district. The review emphasizes the need for better irrigation and agronomic practices to boost productivity and climate resilience in Ethiopian coffee production. Drip irrigation also achieves the highest WP, with 0.38 kg m^{-3}in Jimma (Melko) and 0.17 kg m- ³in East Wollega (Wayu), surpassing the lower WP values of surface irrigation and rainfed methods. The findings advocate for more efficient irrigation techniques to enhance coffee yield and WP, in line with global practices.

Keywords

Drip Irrigation, Coffee Yield, Water Productivity

1. Introduction

Ethiopia is Africa's largest coffee producer and the world's fifth-largest exporter of Arabica coffee, contributing 30-35 percent of the country's export earnings. The coffee industry is vital to Ethiopia's economy and culture, supporting 25 percent of the population [1]. However, the reliance on rain-fed agriculture makes coffee production highly susceptible to the vagaries of climate, including droughts and erratic rainfall patterns [2].

Irrigation is a vital strategy for mitigating the impacts of climate variability and ensuring food security [3]. Drip irrigation, characterized by its precision and efficiency, has been widely promoted as a means to enhance water productivity and crop yields [4]. This method minimizes water loss through evaporation and deep percolation, providing a steady supply of water directly to the plant roots [5]. In contrast, furrow irrigation, while less efficient in water use, is a more traditional and accessible method for many smallholder farmers in Ethiopia [6].

Compared to traditional furrow irrigation methods, drip fer-

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tigation can also reduce crop evapotranspiration and irrigation water use and reduce weeding frequency and development [7], and plays an important role in protecting the environment and preventing soil and water pollution [8]. In addition, several studies have highlighted the benefits of drip irrigation in improving water use efficiency and crop yields. For example, Zhang et al. [9] found that drip irrigation increased water use efficiency by 30-50% compared to furrow irrigation in wheat production. Similarly, Choudhary et al. [10] reported higher yields and water use efficiency for cotton crops under drip irrigation. Mitku [11] extensively reviewed the evolution and development status of drip irrigation in Ethiopia. The study reported that drip irrigation systems were demonstrated and promoted, and their effectiveness in enhancing crop yield was evaluated. In southern Ethiopia, specifically in Gedeo, about 12.5% of coffee-producing farmers use supplemental or full irrigation. The water is applied using methods such as can irrigation and drip irrigation [12]. In the Jimma zone, the performance of drip and furrow irrigation was evaluated on potato and coffee crops. The results showed that drip irrigation improved yield and water productivity compared to surface irrigation [7, 13]. These findings suggest that drip irrigation could play a crucial role in enhancing crop production including coffee. In addition, the current suitable coffee-growing areas are located in sloping regions with erratic rainfall distribution, a situation exacerbated by climate change. Future coffee production should be supplemented with drip irrigation, as these areas are less suitable for surface irrigation and to reduce dependence on rainfed farming. The Ethiopian coffee forest area is shrinking over time, largely due to various factors. As a result, open sun cultivation is becoming more common, including around homesteads, and large-scale coffee plantations are emerging [14]. This situation requires the adoption of water-efficient irrigation technologies, such as drip and sprinkler irrigation.

However, the adoption of drip irrigation in Ethiopia faces several challenges, including high initial investment costs, lack of technical expertise, and limited access to irrigation infrastructure [15, 16]. Furrow irrigation, despite its lower efficiency, remains a viable option for many farmers due to its simplicity and lower costs [17]. The experience of Brazil shows that farmers have improved the yield and water productivity of coffee through the use of efficient technologies such as drip irrigation and sprinkler irrigation [18]. However, some farmers are still reluctant to adopt these technologies. The same applies to Ethiopia. Enhancing coffee productivity in terms of yield and water efficiency requires national and regional policy support, including credit services, training, demonstrations, the establishment of demo sites, and the application of improved drip irrigation technologies.

This review aims to provide a comprehensive analysis of the comparative impacts of drip irrigation and furrow irrigation on coffee yield and water productivity in Ethiopia. By synthesizing existing research and evaluating the advantages and limitations of each method, this study seeks to contribute to the development of sustainable and efficient irrigation practices that can support Ethiopia's coffee sector.

2. Review

2.1. Evolution and Development of Coffee Drip Irrigation Technology in Ethiopia

The development of drip irrigation in Ethiopia has been a gradual process influenced by the need for efficient water management and improved agricultural productivity. This technology was introduced in the late 20th century in response to water scarcity and the desire to optimize crop yields. Initially, adoption was slow due to high costs, limited awareness, and technical challenges [19]. Over time, the Ethiopian government and various international organizations have promoted drip irrigation through pilot projects, subsidies, and training programs. These efforts aimed to demonstrate the benefits of drip irrigation, such as water conservation, increased crop yields, and reduced labor costs [20]. In recent years, there has been a noticeable increase in the adoption of drip irrigation, particularly among smallholder farmers and commercial farms. This growth is supported by improved access to affordable equipment, better technical support, and favorable policies. The expansion of drip irrigation is also driven by the growing demand for efficient water use in the face of climate change and increasing water scarcity [21].

The Ethiopian government has emphasized increasing the adoption of drip irrigation technologies by expanding research focused on small-scale family drip irrigation. The Ethiopian Institute of Agricultural Research (EIAR) has studied the impact of drip irrigation on the yield of various horticultural crops, including coffee, at several centers throughout the country. These studies have shown that drip irrigation improves both yield and water productivity [22]. These centers have demonstrated small-scale and low-cost family drip irrigation technologies to smallholder farmers. For example, the Jimma Agricultural Research Center evaluated the impact of drip irrigation on the yields of potato, cabbage, and coffee both at research stations and on farmers' fields. They reported that drip irrigation increased potato yields by 50% compared to furrow irrigation. The centers demonstrated drip irrigation for potatoes and coffee to farmers from the Jimma zone, along with experts from the zone and district. The participants appreciated the technology's performance in improving yields and expressed willingness to adopt it on their farms. The Coffee yield also improved by 65% compared to rain-fed conditions [13]. Additionally, some private coffee plantations, such as Southwest Babaka Coffee Plantation and Limmu Plantation, have started using drip irrigation. New coffee-growing areas, including the Amhara and Sidama regions, have also begun cultivating coffee with drip irrigation. Today, drip irrigation is recognized as a crucial technology for sustainable agriculture in Ethiopia, contributing to higher

productivity and resilience in the agricultural sector. However, challenges remain, including the need for further training, financial support, and infrastructure development to ensure broader access and adoption [23].

2.2. Impact of Drip Irrigation and Surface Irrigation on Coffee Yield

The results of the Jimma and Wollega zones in Ethiopia show significant variations in coffee yield across different irrigation methods and locations. These findings are consistent with global trends in coffee production, where irrigation plays a crucial role in enhancing yield. Under the same farming condition, the highest yields were consistently observed under drip irrigation. For instance, in Jimma (Melko), drip irrigation resulted in yields of 3870 kg ha^{-1}[7]. Similarly, in East Wollega, drip irrigation yielded 2035 kg ha^{-1} [24]. These results are consistent with global findings that drip irrigation (5316 kg ha^{-1}; brazil) is more efficient than other methods, as it minimizes water loss through evaporation and deep percolation [25] (Table 1 and Figure 2).

Surface irrigation generally resulted in lower yields compared to drip irrigation but higher than rainfed conditions. In Jimma, surface irrigation yielded 3000 kg ha^{-1}[26], while in Jimma (Gera), it yielded 2330 kg ha^{-1}[27]. In West Wollega (Haru), surface irrigation resulted in a yield of 1400 kg ha^{-1}[7]. These findings are consistent with global studies showing that surface irrigation is less efficient than drip irrigation but can still significantly improve yields compared to rainfed conditions [28]. Rainfed conditions resulted in the lowest yields. In Jimma, the rainfed yields were 1600 kg ha^{-1}[26] and 1100 kg ha^{-1}. In West Wollega, the rainfed yield was 650 kg ha^{-1}[7]. These results highlight the vulnerability of rainfed agriculture to water scarcity and the need for improved irrigation practices to enhance productivity [29]. The yield under farmer practice in Jimma zone was 700 kg ha^{-1}[30, 31] (Table 1 and Figure 2). This indicates that there is a significant potential to improve coffee production through the adoption of more efficient irrigation methods and better agronomic practices. Global studies have shown that improving irrigation efficiency and management can significantly enhance crop yields [32, 33]. In addition, Previous studies have demonstrated that using drip irrigation improves coffee yields compared to surface irrigation and rainfed [34]. Researchers in China have reported that drip irrigation enhances both coffee yield and water productivity [35].

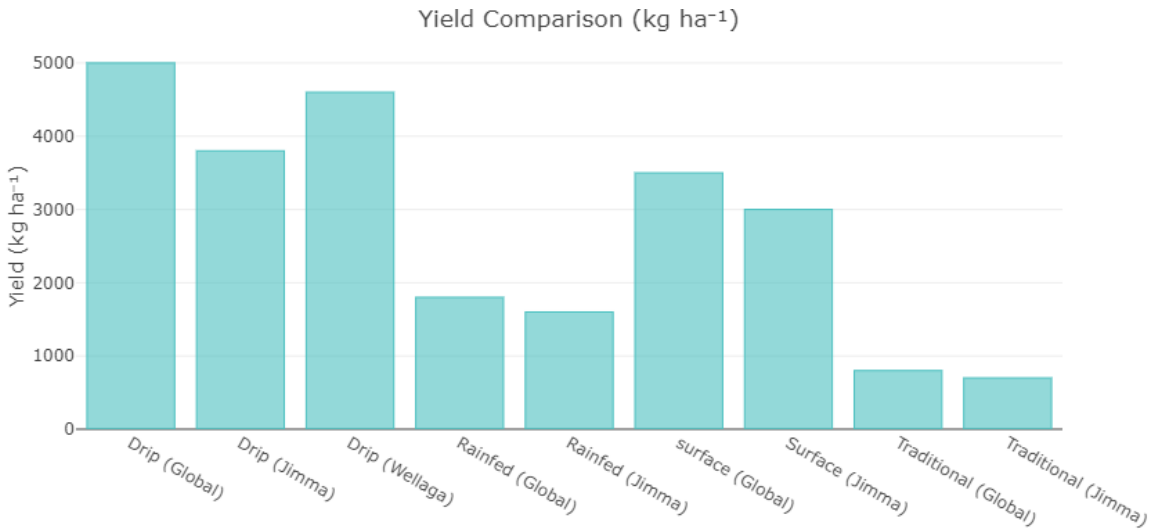

Figure 1. *A comparison of drip irrigation with surface irrigation on coffee yield in Ethiopia with global practices.*

Table 1. *Impact of drip irrigation on coffee yield and water productivity in west Ethiopia.*

Location	Irrigation Method	Yield (kg ha^{-1})	WPc (kg m^{-3})	Reference
Jimma (Melko)	Drip irrigation	3870	0.32	JARC, 2024
Jimma (Melko)	Surface irrigation	2051	0.17	Tesfaye et al., 2013
Jimma (Melko)	Rainfed	1051	0.09	Tesfaye et al., 2013
Jimma (Melko)	Drip irrigation	3870	3.78	JARC, 2021
Jimma (Gera)	Surface irrigation	2330	0.19	Etafa et al., 2021

Location	Irrigation Method	Yield (kg ha^{-1})	WPc (kg m^{-3})	Reference
Jimma (Melko)	Rainfed	1100	0.09	JARC, 2021
Jimma Zone	Farmer practice	700	0.06	CSS, 2023
East Wollega (Wayu)	Drip irrigation	4663	3.68	Genemo et al., 202
West wellega (Haru)	Surface irrigation	1402	0.11	JARC, 2024
West wellega (Haru)	Rainfed	550	0.05	JARC, 2024

Note: For the yield obtained from drip irrigation as reported by Genemo et al. [24], the fresh cherry yield was converted to a clean coffee yield, reducing from 6785 kg/ha to 4663.95 kg/ha. The yield obtained from Tesfaye et al. [26] was converted from kg/tree to kg/ha

2.3. Water Productivity

Water productivity (WP) is a critical metric for assessing the efficiency of water use in agriculture. The results from the Jimma and Wollega zones show variations in the WP between different irrigation methods and locations. Drip irrigation resulted in the highest WP values. In Jimma, drip irrigation had a WP of 0.38 kg m^{-3}and 3.78 kg m^{-3}[7]. In East Wollega, drip irrigation had a WP of 0.17 kg m^{-3}[24] (Table 1 and Figure 1). These results are consistent with global findings that drip irrigation is more water-efficient than other methods [18].

Surface irrigation had lower WP values compared to drip irrigation but higher than rainfed conditions. In Jimma, surface irrigation had a WP of 0.25 kg m^{-3}[26], while in Jimma (Gera), it had a WP of 0.19 kg m^{-3}[27]. In West Wollega, surface irrigation had a WP of 0.11 kg m^{-3}[7]. These findings align with global studies that show surface irrigation is less water-efficient than drip irrigation but still improves WP compared to rainfed conditions [36, 37]. Rainfed conditions had the lowest WP values. In Jimma, rainfed WP was 0.13 kg m^{-3}[26] and 0.09 kg m^{-3} In West Wollega, rainfed WP was 0.05 kg m^{-3}[7]. These results emphasize the importance of irrigation in improving water use efficiency in agriculture. The WP under farmer practice in Jimma zone was 0.06 kg m^{-3} [30]. This indicates that there is a significant potential for improving water use efficiency through the adoption of more efficient irrigation methods and better agronomic practices. Global studies have shown that improving irrigation efficiency can significantly enhance WP (Table 1 and Figure 1).

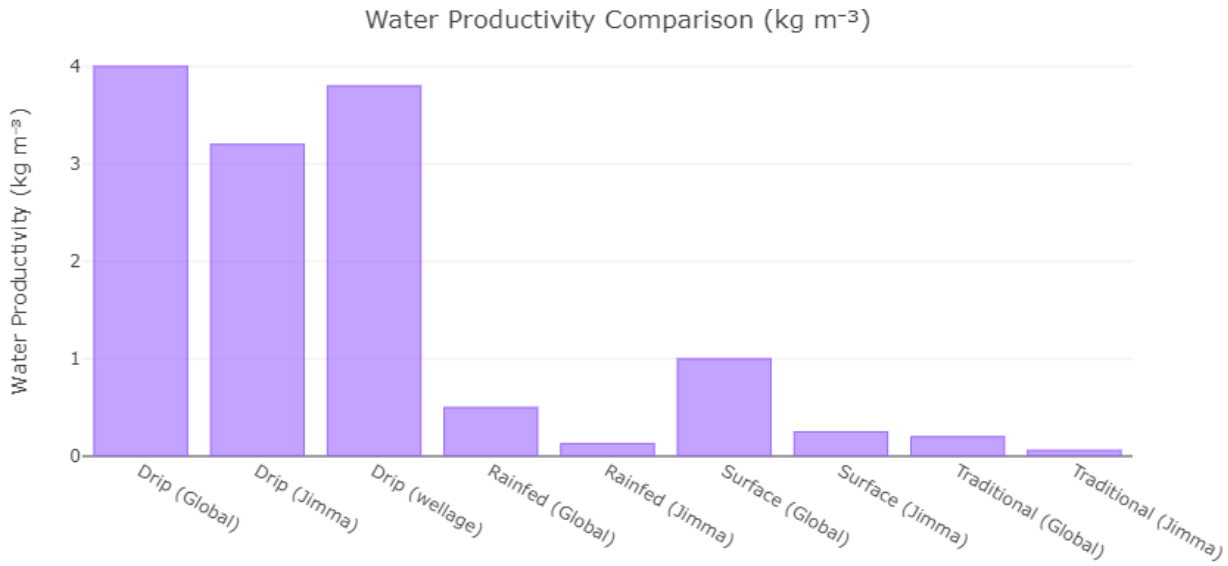

Figure 2. *A comparison of drip irrigation with surface irrigation on coffee water productivity (WPc) in Ethiopia with global practices.*

2.4. Global Experience

In Brazil, one of the world's leading coffee producers, similar trends in yield and WP have been observed. Drip irrigation has been shown to significantly increase coffee yields and WP compared to rainfed and surface irrigation methods [38]. For example, drip irrigation in Brazil has re-

sulted in yields of over 5000 kg ha^{-1} and WP values of up to 2.0 kg m^{-3} [37, 39-41]. These results are comparable to the findings from Jimma and Wollega zones in Ethiopia, highlighting the potential for improving coffee production through efficient irrigation practices.

In other countries, such as Colombia and Vietnam, the adoption of drip irrigation has also led to significant improvements in coffee yield and WP. In Colombia, drip irrigation has been shown to increase yields by up to 20% and improve WP by 30% compared to conventional irrigation methods [42]. Similarly, in Vietnam, drip irrigation has resulted in yield increases of up to 30% and WP improvements of up to 50% [43, 44]. Many researchers from Africa and Vietnam have reported that drip irrigation improves coffee yield and water productivity [45].

3. Conclusions

The development of drip irrigation in Ethiopia has gradually evolved, driven by the need for better water management and increased agricultural productivity. Initially slow due to high costs and technical challenges, the adoption of drip irrigation has accelerated with the support of the government and various organizations through pilot projects and training programs. Research has shown that drip irrigation significantly enhances crop yields and water efficiency, especially for coffee. Studies from different regions in Ethiopia confirm that drip irrigation yields higher results compared to surface and rainfed methods. Despite progress, challenges such as the need for additional training, financial support, and infrastructure development remain.

However, the growing use of drip irrigation, particularly in new coffee growing areas, highlights its potential to transform agricultural practices and improve productivity. International experiences also support the benefits of drip irrigation, reinforcing its value for sustainable agriculture in Ethiopia. The results of the Jimma and Wollega zones in Ethiopia demonstrate the critical role of irrigation in enhancing coffee yield and water productivity. Drip irrigation consistently outperformed other methods, highlighting its potential to improve agricultural sustainability in water-scarce regions. These findings are in line with global trends and underscore the need to promote efficient irrigation practices and improved agronomic management to enhance coffee production in Ethiopia and other countries.

Abbreviations

WPc Crop Water Productivity

Conflicts of Interest

The authors declare no conflicts of interest.

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