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On-farm evaluation of drip irrigation system on coffee production in Western Oromia, Ethiopia

Gudeta Genemo*, Habtamu Bedane and Eshetu Mekonen

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ABSTRACT

Ethiopian coffee production is greatly hampered by frequent droughts.This study aimed to evaluate the performance of a drip irrigation system for coffee production on a farm. Additionally, it estimated the amount of water required for coffee crops. An experiment was conducted on a 5-year-old coffee plant with 2m spacing between lines and 2m between plants. Catch cans were used to evaluate the system performance of the installed drip irrigation system. Based on these, the average hydraulic characteristics of the installed drip irrigation system, distribution uniformity was 93.55%, Christiansen uniformity coefficient was 95.40%, flow variation was 18.52%, and coefficient of variation was 5.59%. Coffee plants grew and produced more when irrigation was used. A fresh cherry yield of 6785 kg ha^{-1} was obtained under irrigated coffee and 2346 kg ha^{-1} under non-irrigated coffee. Compared to non-irrigated coffee, irrigated coffee had the highest crop water use efficiency of 2.5 kg ha^{-1} mm^{-1}, and the lowest was obtained 1.7 kg ha^{-1} mm^{-1}, under non-irrigated coffee. Similarly, irrigated coffee had the highest irrigation water use efficiency (3.6 kg m^{-3}), whereas non-irrigated coffee had the lowest (1.4 kg m^{-3}). These findings show that drip irrigation, compared to non-irrigated coffee plants, enhances yield and water use efficiency by 65% and 60%, respectively. In order to boost production, yield, yield components, and irrigation water use efficiency, drip irrigation is a helpful irrigation technique in locations with limited water resources and extended drought spells.

Keywords: Arabica coffee, Drip irrigation, Irrigation performance, Water use efficiency

Oromia Agricultural Research Institute, Bako Agricultural Engineering Research Center, Ethiopia

*Corresponding author's email: 4genemo@gmail.com (Gudeta Genemo)

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Introduction

One of the most valuable cash crops in the country, highland coffee *(Coffea arabica* L.), is mostly cultivated in Ethiopia.This product, which is the principal agricultural export crop, accounts for 20–25% of the foreign exchange profits (ECFF, 2015). The coffee industry contributes around 4-5% of the country's GDP and provides a great deal of local employment opportunities (EBI, 2014). Tadesse (2019) states that despite the employment of a traditional production method, this system's productivity is negatively influenced by water constraints, particularly during the critical times of blooming and fruit development. Coffee irrigation is a practical way to increase productivity and spread growing coffee in areas thought unsuitable because of frequently occurring water shortages (Silva *et al.*, 2008). The majority of Ethiopia's coffee-growing regions are suffering from drought stress as a result of unevenly distributed and inadequate seasonal rainfall. In the lack of irrigation water during blooming, plants' growth and development during the phonological phases of the coffee crop are often harmed (Abayneh and Masresha , 2014). The ability of drip irrigation to uniformly distribute tiny amounts of water in varied planted configurations is its primary benefit. As a result, compared to other irrigation strategies, this approach is more successful in curbing water logging. Despite the importance of the issues with water scarcity and excessive irrigation water use on farmers' fields, the on-farm evaluation of the drip irrigation system for coffee production was essential to obtaining the data for scientific irrigation scheduling, determining the efficiency of the system, and determining how effectively the equipment can be operated to provide practical recommendations to farmers and extension workers on drip irrigation. The amount of irrigation water required for coffee is not defined in the ecology of the study area. However, the minimum annual crop water needs for coffee are between 1200 and 1600 mm. Therefore, the main objectives of the study were to evaluate the performance of a drip irrigation system for coffee production at the farm level and to determine the crop water requirement of Arabica coffee *(Coffea arabica* L.).

Materials and Methods

The study was carried out in the East Wollega Zone, Wayu Tuka Woreda, and Gute Kebele of the Oromia Regional State, which is situated at an altitude of 1590 meters above sea level and was situated at 9°06' N and 37°09' E, respectively. 13°C and 24°C, respectively, are the lowest and highest average temperatures for the area.

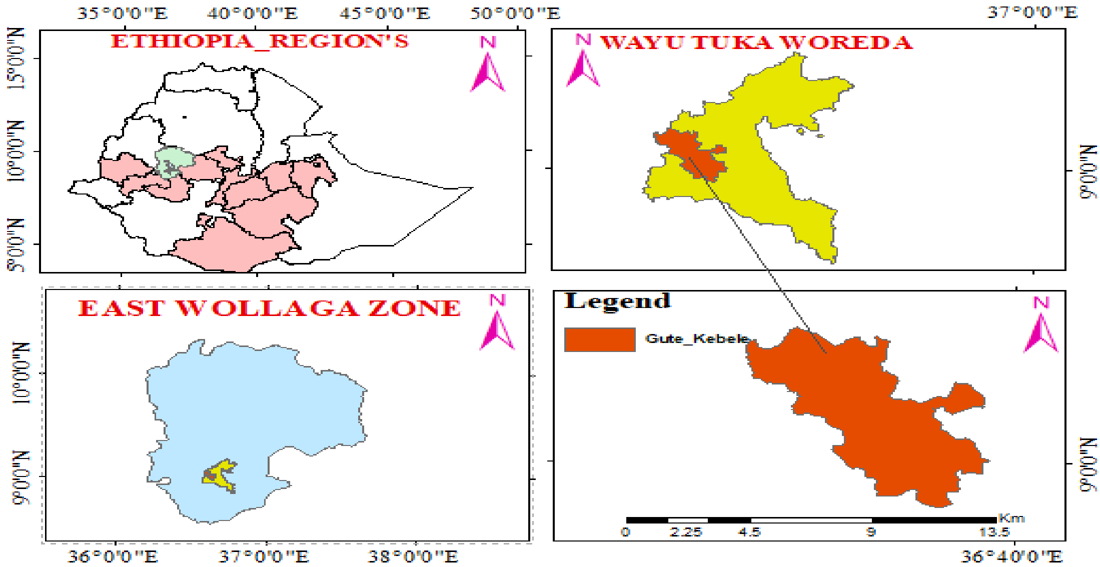

Figure 1. Location map of the study area.

Design and methodology for experiments

In this experiment, coffee plants that were 5 years old, spaced 2 m apart in lines and 2 m apart, were subjected to irrigated and non-irrigated conditions.

Irrigation requirement and crop water requirement of coffee

Meteorological data has been collected from the Nekemte meteorological station to assess the crop water and irrigation needs of coffee. Using the FAO CROPWAT version_8 software, the reference evapotranspiration (ETO) of the experimental site was estimated using a modified FAO Penman-Monteith equation (Allen *et al.*, 1998). Coffee crop Kc values range from 0.9 to 1.1, and reference evapotranspiration (ETo) is required to calculate the quantity of water required to make up for water lost through evapotranspiration (ETc) (Allen *et al.*, 1998). In this study, a 3- to 5-year-old coffee crop with an average crop coefficient of 1.1 was used (Doorenbos and Pruitt, 1977; Silva et al., 2008).

By a crop ground cover factor Kr, the crop water requirements with drip irrigation are lower than the conventional agricultural water requirements. According to Savva and Frenken (2002), a ground cover of 80% was chosen for mature coffee trees. In order to calculate the amount of irrigation water needed for assessment purposes, the value of Kr based on Keller and Karmeli (1975) equal to 0.94 was selected. So, using the following equation (Vermeiren and Jobling, 1980), the amount of water needed for irrigation of the coffee crop was determined.

$$ETC = ETo \times Kc \times Kr$$

Where, ETC= Crop water requirements of coffee (mm/day)
ETo = Reference Evapotranspiration (mm/day)
Kc = coffee crop coefficient of coffee
Kr= factor due to ground cover

The equation was used to determine the maximum net quantity applied during each irrigation (Vermeiren and Jobling, 1980).

$$IR_n = (\theta_{fc} - \theta_{pwp}) \times p \times Z_r \times P_w$$

Where,

IRn = Max amount of water that can be applied (mm)
θ_{fc} = Volumetric moisture content at field capacity (mm/m)
θ_{pwp}= Volumetric moisture content at permanent wilting point (mm/m)
p = Maximum allowable depletion (%)
Zr = Root zone depth (m)
Pw = Percentage wetted area (%)

Installing components of drip irrigation system and work principle

A water tanker with a capacity of 220 L that was built at a head of 1m above the ground feeds a supply line made of HDP Pipe with a 32 mm diameter. Ball valves were installed and used to control the water flow out of the tanker. Screen filters were installed below ball valves to prevent the introduction of sand and other debris. Elbows have been added to connect the main lines to the risers after the screen filters. To prevent water from seeping out of one end of the pipeline, end caps were fitted. The line is attached to a ball valve and a main filter. Using elbows, the main lateral and the extension pipes were connected. Along the mainline, laterals with online emitters spaced at 100 cm began to appear. Elbows were used to connect the extension pipes to the main lateral. Along the mainline, 100 cm-spaced laterals with on line emitters started to appear. Drip holes on HDP Pipe with a diameter of 2 mm were built at a spacing of 2 m based on the distance for growing coffee. The hydraulic parameters of the installed system, including the emitter flow rate, emitter flow rate variation, uniformity coefficient, and emission uniformity, were evaluated.

Emitter flow rate: From plots where catch cans were arbitrarily assigned plots and amounts of flow were captured over time, the average flow rate of the emitters used in the experiment was determined. Thus, the discharge or flow rate from a single output emitter at a given head was calculated as;

$$q = \frac{v}{t}$$

Where,

q = single emitter discharge (litre/hour);
V = volume of water collected from the emitter (litres) and
t = time duration of discharge collection (hour)

Emitter flow rate variation: Variation in emitter flow rate was calculated as;

$$FV(\%) = \frac{q\max - q\min}{q\max} \times 100$$

Where,

FV= emitter flow rate variation (%)
qmax= the maximum emitter flow rate along a lateral(litre/hr) and
qmin = the minimum emitter flow rate along a lateral (litre/hr)

Uniformity coefficient: The uniformity coefficient was computed using the Christiansen coefficient of uniformity formula from Michael (1978).

$$Uc(\%) = 100\left(1 - \frac{\sum X}{qn}\right)$$

Where,

UC (%) = Uniformity coefficient (%)
q = average discharge of the emitters (litre/hour),
n = number of emitters and
Σx = sum of the individual deviations of observed flow from the average discharge (litre/hour).

Emission uniformity

Measurement of application rates using catch cans is the easiest method for assessing the effectiveness of drip irrigation systems. To perform these, a total of 24 observation spots were chosen throughout six lateral lengths, four measurement points at the beginning, one-third, two-thirds, and end of the lateral. Michael (1978) computed the final emission uniformity from measurement locations in the lateral direction.

$$EU(\%) = 100\left\{\frac{qlowquarter}{q}\right)$$

Where,

Eu = Emission uniformity (%)
Qlow quarter = average discharge rate of the low quarter of the number of emitters observed, (litre/hour) and q = average discharge rate of all observed emitters (litre/hour).

Irrigation water use efficiency of coffee

According to Michael (1978), the ratio of the yield of harvested coffee (kg ha^{-1}) to the amount of water the crop consumptively consumed in the field tests is a measure of agricultural water productivity. This ratio was calculated as follows:

$$CWUE = \frac{Y}{ETC}$$

The amount of irrigation water used (gross irrigation water applied and effective rainfall) throughout the trial period was divided by the volume of coffee yield to calculate irrigation water use efficiency (Kang et al., 2001).

Results and Discussion

Analysis of soil data

The average percentages of sand, silt, and clay at the experimental site were 45.33, 38.33, and 16.33%, respectively (Table 1), and these percentages were categorized as sand clay. Field Capacity (FC) and Permanent Wilting Point (PWP) had average moisture contents of 36.27% and 14.68%, respectively.

The total amount of water (TAW) was 215.93 mmm^{-1}.

Table 1. Physical characteristics of selected the experiment site's soil.

Soil Depth (cm)					Particle size Distribution (%)			Textural class
	BD (g/cm3)	FC (%)	PWP (%)	TAW (mm/m)	Sand	clay	silt	
0-20	1.054	38.13	15.83	223.0	52.0	21.0	27.0	Sand Clay loam
20-40	1.098	36.17	15.05	211.2	50.0	37.0	13.0	Sand Clay loam
40-60	1.166	34.52	13.16	213.6	34.0	57.0	9.0	Clay
Average	1.110	36.27	14.68	215.93	45.33	38.33	16.33	Sand Clay

Crop water needs and irrigation requirements for coffee

The monthly weather data were collected from Nekamte meteorological station. Coffee's crop water needs were determined by multiplying the reference ETo by the crop coefficient (Kc) and crop ground cover factor, which was determined to be 1,267.79 mm. By subtracting effective rainfall from ETc, the net coffee water requirement was calculated. The gross water requirement, on the other hand, was calculated using a field application efficiency of 90%, and the results were 1,267.79 mm and 1,408.65 mm, respectively (Table 2).

Table 2. Irrigation water requirement for coffee.

Month	ETo	kc	kr	ETC	ETC	Eff, Rain	NIR	GIR
	mm/day			mm/day)	mm/month	mm	mm	mm
January	3.69	1.1	0.94	3.82	114.46	0	114.46	127.18
February	4.11	1.1	0.94	4.25	127.49	0	127.49	141.66
March	4.23	1.1	0.94	4.37	131.21	0	131.21	145.79
April	4.33	1.1	0.94	4.48	134.32	0	134.32	149.24
May	3.51	1.1	0.94	3.63	108.88	0	108.88	120.98
June	2.82	1.1	0.94	2.92	87.48	0	87.48	97.20
July	2.48	1.1	0.94	2.56	76.93	0	76.93	85.48
August	2.51	1.1	0.94	2.60	77.86	0	77.86	86.51
September	2.84	1.1	0.94	2.94	88.10	0	88.10	97.89
October	3.41	1.1	0.94	3.53	105.78	0	105.78	117.53
November	3.48	1.1	0.94	3.60	107.95	0	107.95	119.94
December	3.46	1.1	0.94	3.58	107.33	0	107.33	119.25
Average	3.41	1.1	0.94	3.52	1,267.79	0	1,267.79	1,408.65

Evaluation of the performance of the installed drip irrigation system

The uniformity of the drip irrigation system is an essential parameter in evaluating the Hydraulic Performance of the system. Uniformity can be expressed in terms of various parameters such as flow variation (qv) coefficient of variation (CV), Distribution (Emission) uniformity (EU), and uniformity coefficient (Uc). The distribution (emission) uniformity (DU), uniformity coefficient (UC), Flow Variation (Qvar), and Coefficient of Variation (CV) of drip irrigation were found to be 93.6%, 95.4%, 8.52%, and 5.6%, respectively. The average emission uniformity (EU) of the system was about 93.55% (Table 3). According to ASAE (1985), as it is shown emission uniformity greater than or equal to 90% generally classified as excellent uniformity.

According to Table 3, the variance in emitter flow rate along laterals was 18.52%. The result is in good agreement with Michael's (1978) results, which suggested that in drip systems, the average variance in the discharge rate of individual emitters across the field shouldn't be more than 20%. The Coefficient of Variation (Cv) Value of 5.59% of discharge also falls within the acceptable limit for micro irrigation systems, if the coefficient of variation is between 5-10%, it is classified as recommended value by ASAE (1994).

Table 3. Hydraulic performance parameters of installed drip Irrigation system.

Observation point	Location of Emmitter	discharge(qi)	Mean=$\frac{\sum qi}{n}$	Rank	Number	$qi-\frac{\sum qi}{n}$	$\left\|qi-\frac{\sum qi}{n}\right\|$	$\sum\left\|qi-\frac{\sum qi}{n}\right\|^2$
1	Beginning	1.29	1.24	1.10	1	0.05	0.05	0.0025
2	1/3 of lateral	1.20	1.24	1.10	2	-0.04	0.04	0.0016
3	2/3 of later	1.29	1.24	1.17	3	0.05	0.05	0.0025
4	End of lateral	1.20	1.24	1.19	4	-0.04	0.04	0.0016
5	Beginning	1.25	1.24	1.20	5	0.01	0.01	0.0001
6	1/3 of lateral	1.20	1.24	1.20	6	-0.04	0.04	0.0016
7	2/3 of later	1.30	1.24	1.20	7	0.06	0.06	0.0036
8	End of lateral	1.10	1.24	1.20	8	-0.14	0.14	0.0196
9	Beginning	1.20	1.24	1.20	9	-0.04	0.04	0.0016
10	1/3 of lateral	1.30	1.24	1.20	10	0.06	0.06	0.0036
11	2/3 of later	1.10	1.24	1.20	11	-0.14	0.14	0.0196
12	End of lateral	1.20	1.24	1.20	12	-0.04	0.04	0.0016
13	Beginning	1.30	1.24	1.25	13	0.06	0.06	0.0036
14	1/3 of lateral	1.25	1.24	1.25	14	0.01	0.01	0.0001
15	2/3 of later	1.17	1.24	1.27	15	-0.07	0.07	0.0049
16	End of lateral	1.20	1.24	1.28	16	-0.04	0.04	0.0016
17	Beginning	1.28	1.24	1.29	17	0.04	0.04	0.0016
18	1/3 of lateral	1.30	1.24	1.29	18	0.06	0.06	0.0036
19	2/3 of later	1.19	1.24	1.30	19	-0.05	0.05	0.0025
20	End of lateral	1.20	1.24	1.30	20	-0.04	0.04	0.0016
21	Beginning	1.30	1.24	1.30	21	0.06	0.06	0.0036
22	1/3 of lateral	1.35	1.24	1.30	22	0.16	0.16	0.0256
23	2/3 of later	1.20	1.24	1.30	23	-0.04	0.04	0.0016
24	End of lateral	1.27	1.24	1.35	24	0.03	0.03	0.0009
		Mean =1.24		Av.ql=1.16			$\sum$ = 1.37	$\sum$ = 0.1107

Maximum rate of discharge (qmax)	*1.35 l/hr*
Minimum rate of discharge (qmin)	*1.10 l/hr*
Avg. discharge rate of the low 25% of sampled emitters	*1.16 l/hr*
Average rate of discharge (qa)	*1.24 l/hr*
Emitter flow variation (qav)	*18.52 %*
Coefficient of variation (CV)	*5.59%*
Distribution (Emission) uniformity (EU)	*93.55%*
Uniformity coefficient (UC)	*95.40%*

Coffee yield, yield component, and water use efficiency under drip irrigation

Drip-irrigated coffee was shown to produce more beans on average per plant and branch than the control treatment.This might reduce the number of beans per plant and bean per branch associated with moisture stress during the dry season. These findings concur with those of Mitchell *et al.* (1984), who noted that moisture stress had a negative impact on the number of blooming branches, the number of fruits per branch, and crop yield. For both irrigated and non-irrigated fields, the total average yield of coffee (fresh cherry) was computed and shown in (Table 5). According to the outcome, the average yield of coffee grown under irrigation and without irrigation was 6785 kg ha^{-1} and 2346 kg ha^{-1}, respectively. This indicated that introducing irrigation during critical periods gave the highest coffee yield compared to non-irrigated coffee plants. Additionally, this outcome is consistent with Tesfaye *et al.* (2013), who studied the effects of partial root-zone drying and deficit irrigation on six-year-old coffee (*Coffea arabica L.*) and found that well-water conditions produced the highest yield and yield component. Compared to non-irrigated coffee plants, irrigation boosts coffee output by 65%. So, irrigation of guarantees that coffee trees produce a lot of fruit (Scalco *et al.*, 2011).

Table 5. Yield, yield component and water use efficiency of coffee.

Treatment	Bean/plant	Bean/branch	Yield (Fresh cherry, kg ha^{-1})	CWUE (kg ha^{-1}.mm)	IWUE (kg m^{-3})
Irrigated	2592.8	87.5	6785	2.5	3.6
Non irrigated	1811.8	58.5	2346	1.7	1.4

The crop water use efficiency findings for irrigated and non-irrigated treatments revealed that the maximum value, 2.5 kg ha^{-1} mm^{-1}, was achieved under irrigated coffee, while the lowest value, 1.7 kg ha^{-1} mm^{-1}, was obtained under non-irrigated coffee (Table 5). In the same way, irrigated coffee yielded the maximum irrigation water use efficiency of 3.6 kg m^{-3}, whereas non-irrigated coffee yielded the lowest, 1.4 kg m^{-3}. These suggest that drip irrigation enhances irrigation water use efficiency by 60% compared to non-irrigated coffee plants. These findings support those by Hassanli *et al.* (2009), who claimed drip irrigation provided the highest irrigation water use efficiency while furrow irrigation provided the lowest.

Conclusion and Recommendation

Knowing how to manage irrigation water properly is a crucial practical factor in irrigated agriculture, controlled through precision irrigation systems to increase water use efficiency. The distribution uniformity, Christiansen uniformity coefficient, flow variation, and coefficient of variation for the installed drip irrigation system's performance were 93.55%, 95.4%, and 5.59%, respectively. For the irrigated and controlled treatments, the total yield (fresh cherry) of coffee was determined; the findings indicate that the average yields were 6875 kg ha^{-1} and 2346 kg ha^{-1}, respectively. A coffee plant that was irrigated had the highest irrigation water use efficiency, at 3.6 kg m^{-3}, compared to a non-irrigated plant's 1.4 kg m^{-3}. The obtained result showed that drip irrigation increases water use efficiency and yield in coffee production by 65% and 60%, respectively, compared to non-irrigated coffee plants. As a result, drip irrigation was recommended as a helpful irrigation technique to boost Arabica coffee's production, yield component, and irrigation water use efficiency in areas with protracted droughts and scarce water supplies.

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