Evaluating On-Farm Water Management in Small-Scale Irrigation Schemes in Southern Ethiopia

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Abstract

Ethiopia's agricultural sector is predominantly dependent on rain-fed farming, with irrigation systems becoming increasingly essential to enhance productivity and ensure food security. This study assesses on-farm water management practices within small-scale irrigation schemes in southern Ethiopia, focusing on two irrigation schemes, Wosha and Werka, which are located at wondo genet district sidama region. Soil physical characteristics, crop water and irrigation requirements, irrigation scheduling, and application efficiency were evaluated. The findings revealed that Werka exhibited better soil water-holding capacity and higher application efficiency (59%) compared to Wosha (48.2%). Sugarcane and chat were the dominant crops in both schemes, with irrigation scheduling showing gaps between farmers' practices and optimal water intervals, particularly in Wosha. Overall, Werka's irrigation system demonstrated better performance, highlighting the need for improvements in Wosha's irrigation management practices. Farmers in both schemes, especially in Wosha, should adopt scientifically calculated irrigation intervals to reduce water wastage and enhance crop yields. Strengthening technical proficiency in water management and providing training on modern irrigation techniques is essential for farmers to optimize water use.

Keywords: water management, irrigation, schemes, performance, assessment

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Introduction

Ethiopia's agricultural sector significantly depends on rain-fed farming, with over 85% of the population involved in subsistence agriculture (FAO, 2016). Implementing irrigation systems is vital for enhancing agricultural productivity, particularly in a country where the majority of the population depends on agriculture for their livelihood (World Bank, 2021). Nevertheless, recurrent drought episodes, predominantly affecting the southern and eastern regions, have critically undermined food security and the livelihoods of smallholder farmers. These drought occurrences intensify the challenges faced by an already precarious agricultural framework, constraining productivity and increasing the likelihood of crop failures and livestock losses (Maltou & Bahta, 2019; Zeleke et al, 2023).

Ethiopia possesses substantial water resources, characterized by an estimated annual surface runoff of approximately 122 billion cubic meters (Seleshi, 2010). The annual groundwater recharge is estimated at approximately 40 billion cubic meters, primarily designated for domestic and industrial water supply (Makombe et al., 2011; Mengistu et al., 2022). Despite these resources, only a modest fraction has been effectively harnessed for productive utilization. Irrigation schemes are strategically designed to address water scarcity and agricultural challenges, ensuring a reliable and sustainable water supply for farming and enhancing the livelihoods of local farmers (Gebremedhin, 2015). These irrigation schemes generally encompass both surface and groundwater resources, employing traditional water harvesting techniques such as river diversions, ponds, and small dams (Teshome, 2018).

Global climatic change, water scarcity, and variability exert significant influences on pivotal sectoral outputs and the comprehensive economies of numerous African nations (WWAP, 2016). The escalating competition for finite water resources, propelled by the surging food demand from the highly water-dependent agricultural sector, aggravates water shortages, thereby diminishing availability for crop cultivation (Ingle et al., 2015; Pereira et al., 2009). The FAO (2011) posits that irrigated agriculture represents the most substantial and least efficient consumer of water, constituting approximately 70% of global water withdrawals. In Ethiopia, numerous farmers depend on traditional irrigation techniques such as furrow irrigation. This often results in over-irrigation, waterlogging, and uneven water distribution across agricultural fields (Woldegeorgis et al., 2021). Principal obstacles to the optimization of irrigation systems encompass inefficient water management practices, a deficiency in technical proficiency, and insufficient maintenance of irrigation infrastructure, all of which inhibit the full realization of irrigation system potential (Desalegn et al., 2020).

The performance of irrigation systems in developing nations has frequently been due to less-than-optimal results. To enhance performance, it is crucial to augment the capabilities of stakeholders in developing sustainable infrastructure, providing assistance to irrigation users, and strengthening their competencies in system management. (Hagos et al., 2009; Seleshi & Mekonnen, 2011). Evaluating the existing condition of irrigation systems, implementing contemporary methodologies, and proficiently managing water resources are paramount for augmenting the efficiency, sustainability, and productivity of irrigated agriculture (McCornick et al., 2003). Consequently, this study aims to assess on-farm water management practices within small-scale irrigation schemes in southern Ethiopia, with the objective of identifying deficiencies and proposing optimization strategies.

Material and Methods

Description of the Study Area

The irrigation schemes studied are in Wondo Genet, Sidama region of Ethiopia, geographically positioned between 6°54′0″ to 7°7′45″ N and 38°31′33″ to 38°41′20″ E. The area covers an altitudinal range of 1600 to 1950 meters above sea level. The Wosha small-scale irrigation scheme taps into the Wosha River through a gravitynsystem, designed to irrigate approximately 180 hectares of arable land, primarily in the Wosha Soyama Kebele.

Similarly, the Werka irrigation scheme, which abstracts water from the Werka River, utilizes a modern weir and a masonry-embanked reservoir to feed a gravity-driven system. Initially designed to irrigate 200 hectares of land in Wetera Kechem Kebele, the scheme expanded to cover 292.2 hectares by the 2017/18 irrigation season. The infrastructure includes a 1.5 km main unlined earthen canal, alongside secondary and tertiary canals. At the intake, the average water discharge rate is 75 liters per second, although the metal sheet gate remains non-operational.

Long-term climatic data (1986–2015) from the Wondo Genet College of Forestry and Natural Resources Meteorological Station indicate that the area receives an average annual rainfall of 1069.2 mm, with over 70% of the precipitation occurring between April and September. The highest monthly rainfall occurs in August (147.0 mm), while the lowest is in December (18.3 mm). The mean annual maximum and minimum temperatures are 22.6°C and 13.4°C, respectively.

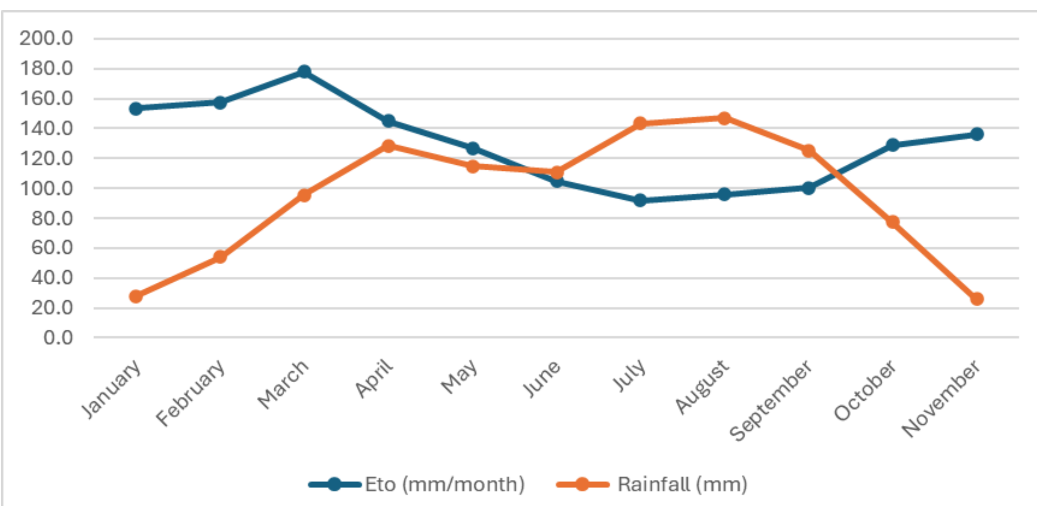


Figure 1: - Long-term Evapotranspiration vs rainfall data

Data Collection

Primary and secondary data were collected during the 2017/18 irrigation season. To assess the effectiveness of the irrigation scheme for water management, three representative reaches were selected from the head, middle, and tail-end sections of the water distribution system. These selected reaches were chosen based on their proximity to the water source and their coverage of the dominant crop, which constitutes the majority of the irrigated area within the scheme.

Soil physical analysis

For this specific study soil sample were collected from the depths 0-30cm, 30-60 cm, 60-90 cm, and 90-120 cm from each selected reach of the schemes. The collected samples were used to analyses the texture, bulk density, soil moisture content, field capacity and permanent wilting point.

No	Data type	Soil type	Method
1	Texture	Disturbed soil	Hydrometer
2	Bulk density	Undisturbed	Core sampling
3	Soil moisture content	Disturbed soil	Gravimetric
4	Field capacity and permanent wilting point	Disturbed soil	Pressure plate

Table 1: - Determination of Irrigation and Crop Water Requirement

The crop water requirements (CWR) for the primary irrigated crops within the irrigation schemes were estimated using the CROPWAT 8.0 software. The CWR determination relies on calculating the reference evapotranspiration (ETo) value, which is derived from five climatic variables. The CROPWAT model computes ETo using the FAO Penman-Monteith equation (FAO, 2009)

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T+273}\right)u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (1)$$

Where: -

ET_o: - reference evapotranspiration (mm/day)
R_n: - net radiation at the crop surface (MJ/m^2/day)
G: - soil heat flux density (MJ/m^2/day)
T: - mean daily air temperature at 2 m height (°C)
e_s:- saturation vapor pressure (kPa)
e_a:- actual vapor pressure (kPa)
$e_s - e_a$: - saturation vapor pressure deficit (kPa)
Δ: - slope vapor pressure curve (kPa/°C)
γ: - psychrometric constant (kPa/°C)

The evapotranspiration of the crop was determined by multiplying the crop coefficient (K_C) of the crop by reference evapotranspiration (ET_O).

$$ET_C = K_C \times ET_O \qquad (2)$$

Where: -

ET_C: - crop evapotranspiration (mm/day),
K_C: - crop coefficient, which is a function of crop type and stage of growth (decimal),
ET_O: - reference evapotranspiration (mm/day)

The net irrigation water requirement (IR_n) was computed by the CROPWAT model using the water budget equation.

$$IR_n - [(F_C - PWP) \times P \times \rho_d \times R_d] - R_e \quad (3)$$

Where: -

IR_n: - net irrigation water requirement (mm)
F_C: - Mass base moisture content at field capacity (decimal)
PWP: - Mass base moisture content at permanent wilting point (decimal)
P: - Allowable soil moisture depletion level for each crop (decimal)
ρ_d:- Soil bulk density (g/m^3)
R_d: - Root depth (mm)
R_e: - Effective rainfall (mm)

Irrigation scheduling

The irrigation schedule for sugarcane was determined to compare the differences between farmers' irrigation practices and the calculated irrigation intervals. The intervals were computed using the equation provided by Michael (2008).

$$I = \frac{RAW}{ETc} \quad (4)$$

Where: -

I: -Irrigation interval [day]
RAW: - Readily Available Water [mm]
ETc:- Evapotranspiration of the crop [mm/day]

Flow Measurement

A two-inch Parshall flume was used to measure the volume of water applied to the farmers' fields at the head, middle, and tail during irrigation events. The flume was installed at the entrance of each selected field, ensuring a straight and uniform approach. The relationship between the head of irrigation water and its discharge is described by the equation provided by the USBR (2014).

$$Q = C * H^n \quad (5)$$

Where:
H: - is water depth measured at one third from in late of converging,
C and n are constant to be determined for flume with two-inch throat

The flow velocity at main and secondary canals were measured using floating methods. Then discharge of the flow was determined by the continuity equation as follows.

$$Q = AV \quad (6)$$

Where: -

Q: - Discharge of the flow (m^3/s)

A: - cross-sectional area (m^2)

V: - Velocity of the flow (m/s)

The discharge then adjusted to $V_{flow} = 0.85\ V_{surface}$

Application Efficiency (Ea)

The application efficiency was computed as the ratio of moisture stored in the soil profile due to irrigation to the total irrigation water applied to the field. (Michael, 2008):

$$Ea = \frac{W_s}{W_f} * 100 \quad (7)$$

Where: -

Ea: - application efficiency
W_s: - average depth water stored in the root zone of the plant
W_f: - average water delivered to the field (water depth applied to the field)

Results and Discussion

Soil Physical Characteristics of Study Schemes

The soil textural class of the schemes revealed that clay, sandy loam, and sand at the head, middle and tail, respectively was dominant soil textural class at Wosha Irrigation Scheme (Table 2). Whereas, at Werka Irrigation Schemes textural class varied from clay-to-clay loam at the head, middle and tail reach of the scheme (Table 3). The result indicates that the soils of both schemes are quite different textural classes.

Table 3. Selected soil physical characteristics of Wosha irrigation scheme.

Reach	Soil depth (cm)	Particle size distribution (%)			Textural class	Bd (g/cm^3)	FC (%)	PWP (%)	TAW (mm)
		Sand	Clay	Silt					
Head	0-30	29	55	16	Clay	1.01	36.2	25.1	34
	30-60	23	60	17	Clay	1.01	37.6	23.4	43
	60-90	23	68	9	Clay	1.05	37.7	24.0	43
	90-120	17	73	10	Clay	1.09	37.4	24.8	41
	Average					1.04	37.2	24.3	161
Middle	0-30	56	19	25	Sandy Loam	1.16	26.2	14.0	42
	30-60	77	10	13	Sandy Loam	1.23	24.1	13.5	39
	60-90	65	18	17	Sandy Loam	1.24	24.1	12.3	44
	90-120	67	19	14	Sandy Loam	1.24	23.1	10.7	46
	Average					1.22	24.4	12.6	172
Tail	0-30	63	18	19	Sandy Loam	1.23	19.0	9.7	34
	30-60	89	7	4	Sand	1.24	13.4	8.4	19
	60-90	95	3	2	Sand	1.27	10.2	6.2	15
	90-120	97	1	2	Sand	1.27	9.9	5.3	18
	Average					1.25	13.1	7.4	86

Physical soil analysis of Wosha Irrigation Scheme showed that average moisture content on a mass base at field capacity (FC) was 37.2, 24.4 and 13.1% at the head, middle and tail reach, respectively. Whereas, at Werka irrigation schemes 43.7, 43.9 and 44.5% were recorded at the head, middle and tail reach, respectively (Table 1). On the other hand, the mass base moisture content at the permanent wilting point (PWP) at Wosha was 24.3, 12.6 and 7.4% at the head, middle and tail reach, respectively. At Werka 24.2, 22.3 and 23.5% were observed at the head, middle and tail reach of the scheme, respectively (Table 3).

The bulk density values ranged from 1.01 to 1.27 g/cm^3 and 1.03 to 1.16 g/cm^3 at Wosha and Werka irrigation schemes, respectively. The soil bulk density of both irrigation schemes indicates that as the depth goes down the bulk density increased, which implies the soil compactness increased as goes down to deep.

The volumetric total available water content (TAW) at 120 cm of soil depth for both irrigation schemes ranged from 86 to 172 mm and 253 to 288 mm in Wosha and Werka Irrigation Schemes, respectively. TAWs of these schemes are within the range of FAO (1985) recommendation for the soil type. The soil physical analysis result revealed that soil at Werka Irrigation Scheme had higher water holding capacity than the sandy dominant soil type of Wosha Irrigation scheme. This is an important condition for the Werka Irrigation Scheme that longer irrigation intervals were practiced in an area where there is high competition for irrigation water.

Table 4. Selected soil physical characteristics of Werka irrigation scheme.

Reach	Soil depth (cm)	Particle size distribution (%)			Textural class	Bd (g/cm^3)	FC (%)	PWP (%)	TAW (mm)
		Sand	Clay	Silt					
Head	0-30	39	26	35	Loam	1.03	37.0	23.3	42
	30-60	36	33	31	Clay Loam	1.09	44.6	21.8	75
	60-90	37	24	39	Loam	1.07	44.7	24.5	65
	90-120	25	48	27	Clay	1.11	48.3	27.0	71
		Average				1.08	43.7	24.2	253
Middle	0-30	43	27	30	Loam	1.08	38.8	21.7	55
	30-60	42	22	36	Loam	1.12	39.9	18.9	71
	60-90	36	30	34	Clay Loam	1.10	47.4	23.6	79
	90-120	38	29	33	Clay Loam	1.13	49.4	24.8	83
		Average				1.11	43.9	22.3	288
Tail	0-30	41	26	33	Loam	1.05	40.5	20.9	62
	30-60	39	26	35	Loam	1.07	41.7	22.7	61
	60-90	43	32	25	Clay Loam	1.14	47.0	25.7	73
	90-120	32	41	27	Clay	1.16	48.8	24.7	84
		Average				1.11	44.5	23.5	279

Irrigated Crop Coverage

Sugarcane is the most dominant crop based on area coverage at both Wosha and Werka irrigation schemes which account for 55 and 41% at Wosha and Werka, respectively. It was followed by Chat which accounts for 40% of Wosha and 27% of Werka irrigation scheme (Table 4). Due to the perennial nature of the crop, both crops required more irrigation water than the other crops. Horticultural crops in the Wosha irrigation scheme account for only 5% of the total area coverage of the scheme. However, at the Werka irrigation scheme, 32% of the total area was covered with carrot, potato, cabbage, and tomato crops. The study revealed that more emphasis on horticultural crops was given at Werka than the Wosha irrigation scheme. On the other hand, farmers in the Wosha irrigation scheme are more dependent on perennial crops than horticultural crops.

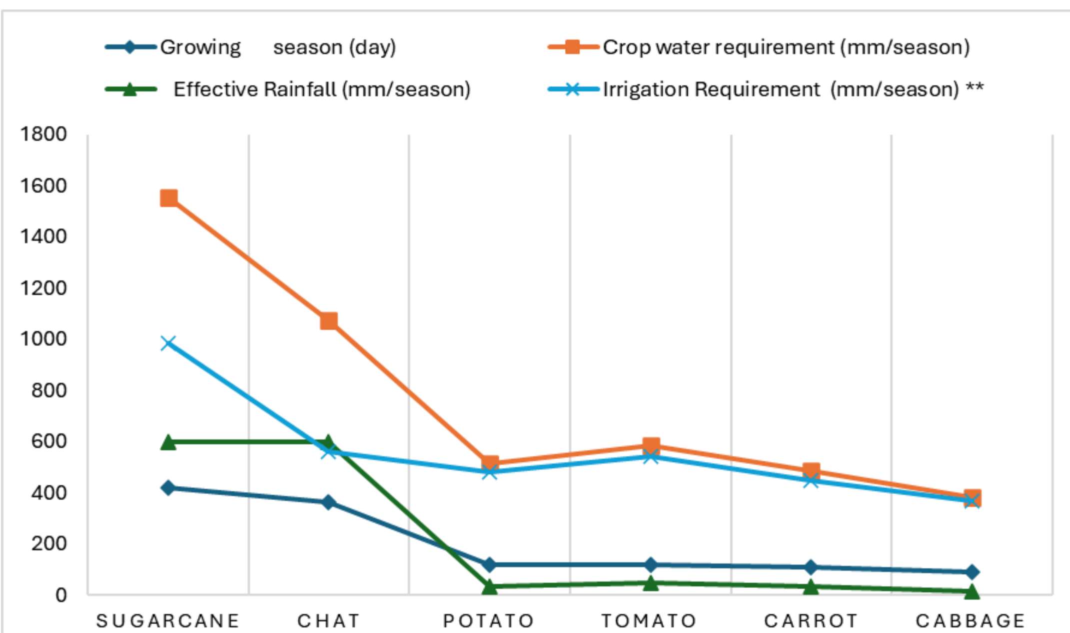
Table 4. Major crop and area coverage of Wosha and Werka irrigation scheme

Crop Type	Wosha Irrigation Scheme		Werka Irrigation Scheme	
	Area Coverage (ha)	Percentage of the total area (%)	Area Coverage (ha)	Percentage of the total area (%)
Sugar cane	205	55	118.25	41
Chat	149	40	78.5	27
Carrot	5	1	3.5	1
Potato	4	1	68.5	23
Cabbage	7	2	17.5	6
Tomato	3	1	6	2
Total	373	100	292.25	100

Crop Water and Irrigation Requirement

From the computation of the CROPWAT model, the maximum water-demanding crop was sugar cane (ratoon), which is 1551.6 mm/season, followed by chat 1071.9 mm/season. A similar trend was also observed in irrigation requirements. Due to the perennial nature of sugar cane and chat crops about 56 and 39 % of the total crop water requirement meets from rainfall, respectively. On the other hand, the lowest crop water requirement and irrigation requirement was obtained from cabbage as its growing season is shorter than all the rest (Figure 2).

Figure 2. Crop water and irrigation requirement of the selected irrigation scheme



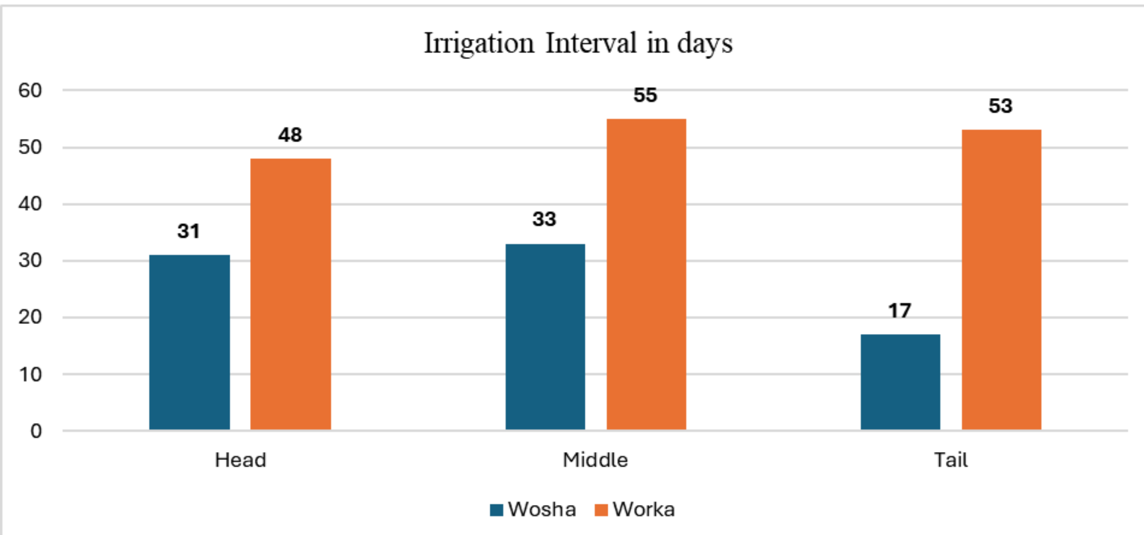
Irrigation Scheduling

In Wosha Irrigation Scheme, farmers used 15 to 30 days interval to irrigate sugarcane. Computed irrigation intervals using soil and crop data revealed that it is 31 and 33 days at the head and middle of the scheme, respectively. This indicates similar irrigation interval was practiced at Wosha irrigation schemes at the head and middle reach of the scheme. However, in the case of the tail part of the scheme, the computed interval was 17 days, which implies the sugarcane did not obtain appropriate irrigation scheduling as compared with an irrigation interval of 30 days, which farmers practice.

Farmers in Werka irrigation scheme was practice irrigation interval of 45 to 60 days but as computed, irrigation interval ranged from 48 to 55 days (Table 6). The application interval similar but it is longer to the irrigation interval near to 60 days and more.

The study revealed that longer irrigation intervals were obtained at Werka than Wosha irrigation scheme both with estimation using soil and crop data and the current farmer practice.

Figure 3. Irrigation scheduling of sugarcane for Werka Irrigation Scheme



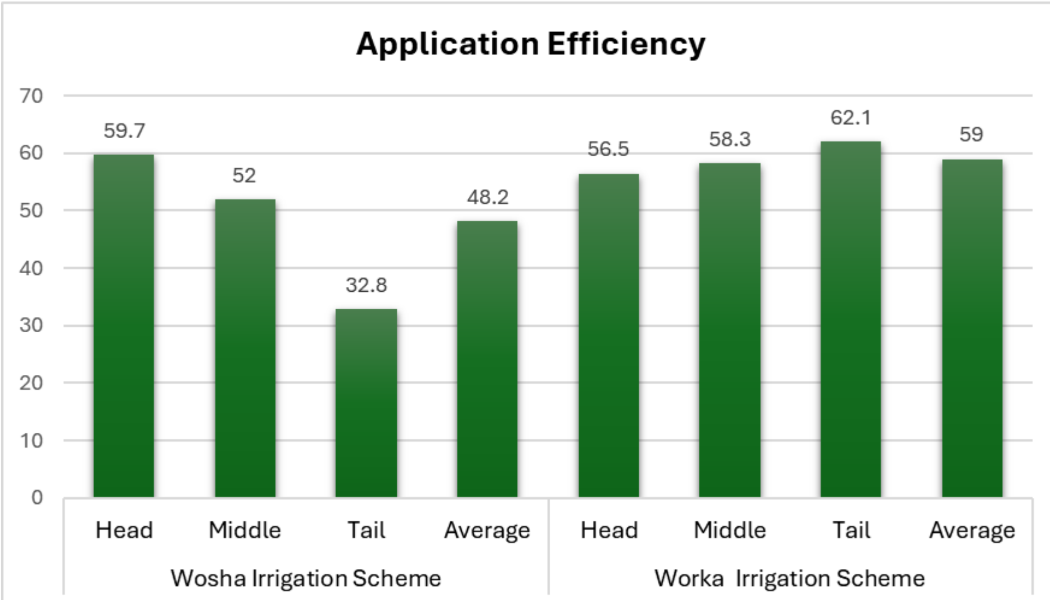
Application Efficiency

The average application efficiency was 48.2% for the Wosha irrigation scheme and 59% for the Werka irrigation scheme (Table 9). In the Wosha scheme, application efficiency exhibited a decreasing trend from the head to the tail of the scheme. This decline may be attributed to soil properties, as the water-holding capacity at the head is superior compared to the middle and tail sections. According to FAO (2002), the application efficiency for furrow irrigation typically ranges from 50% to 70%. However, the Wosha irrigation scheme falls below this range.

The lower application efficiency observed at the tail reach of the Wosha scheme can be linked to its sandy soil texture, which is prone to high deep percolation losses. In comparison, the Werka irrigation scheme demonstrated consistent application efficiency across the entire field, with an average value of 59%, which aligns with the FAO (2002) range. This efficiency is likely due to the advantageous soil properties, which include a greater water-holding capacity and a more uniform water distribution throughout the head, middle, and tail sections of the scheme.

Overall, the Werka irrigation scheme exhibits better application efficiency compared to the Wosha scheme. Similar findings were reported by Worku (2013), who observed an application efficiency of 58.4% in the clay soils of the Midhegdu small-scale irrigation scheme. Furthermore, Dessalew et al. (2016) found that the application efficiency in the Bedene Alemtena small-scale irrigation scheme ranged from 53.6% at the head to 57.2% at the tail, with soil types varying from silty clay loam at the head to clay loam at the tail. These results are consistent with Dinka (2017), who reported application efficiencies ranging from 57.2% to 65.5% in the clay loam soils of the Ketar medium-scale irrigation scheme.

Figure 4. Application efficiency of Wosha and Worka Irrigation Schemes



Conclusion and Recommendation

The performance study of the Wosha and Werka irrigation schemes in southern Ethiopia regarding to irrigation water management revealed significant differences in soil types, water-holding capacity, and irrigation efficiency. Werka irrigation scheme demonstrated higher application efficiency and better irrigation scheduling compared to Wosha, which suffered from inefficient water distribution, particularly at its tail-end, due to sandy soils. Both schemes are significantly reliant on perennial crops like sugarcane and chat, which demand higher irrigation water. These differences underscore the need for better irrigation management practices, particularly in the Wosha scheme, to enhance water usage efficiency, reduce water loss, and improve agricultural productivity. Farmers in both schemes, especially in Wosha, should adopt scientifically calculated irrigation intervals to reduce water wastage and enhance crop yields. Strengthening technical proficiency in water management and providing training on modern irrigation techniques is essential for farmers to optimize water use.

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