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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, and irrigation systems are becoming increasingly essential for enhancing productivity and ensuring 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, located in the Wondo Genet District Sidama Region. The physical characteristics of the soil, 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%) than Wosha (48.2%). Sugarcane and chat were the dominant crops in both schemes, with irrigation scheduling showing gaps between farmer practices and optimal water intervals, particularly in Wosha. Overall, Werka's irrigation system demonstrated a 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 yield. Strengthening technical proficiency in water management and providing training on modern irrigation techniques are essential for farmers to optimize water use.

KEY WORDS

Water management, irrigation, schemes, performance, assessment.

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

Global climatic change, water scarcity, and variability significantly influence the pivotal sectoral outputs and comprehensive economies of numerous African nations (WWAP, 2016). The escalating competition for finite water resources, propelled by the increasing food demand from the highly water-dependent agricultural sector, aggravates water shortages, thereby diminishing the 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 withdrawal. In

Ethiopia, numerous farmers depend on traditional irrigation techniques such as furrow irrigation. This often results in overirrigation, waterlogging, and uneven water distribution across agricultural fields (Woldegeorgis et al., 2021). The principal obstacles to the optimization of irrigation systems include 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 attributed to less-than-optimal results. To enhance performance, it is crucial to augment the capabilities of stakeholders in developing sustainable infrastructure, provide assistance to irrigation users, and strengthen their competencies in system management. (Hagos et al., 2009; Seleshi & Mekonnen, 2011). Evaluating the existing conditions 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.

MATERIALS AND METHODS OF RESEARCH

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 1600–1950 m above the sea level. The Wosha small-scale irrigation scheme taps into the Wosha River through a gravity system designed to irrigate approximately 180 ha of arable land, primarily in the Wosha Soyama Kebele.

Similarly, the Werka irrigation scheme, which extracts 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 was 75 L/s, although the metal sheet gate remained non-operational.

Long-term climatic data (1986–2015) from the Wondo Genet College of Forestry and Natural Resources Meteorological Station indicated 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 occurred in August (147.0 mm), whereas the lowest was in December (18.3 mm). The mean annual maximum and minimum temperatures were 22.6°C and 13.4°C, respectively.

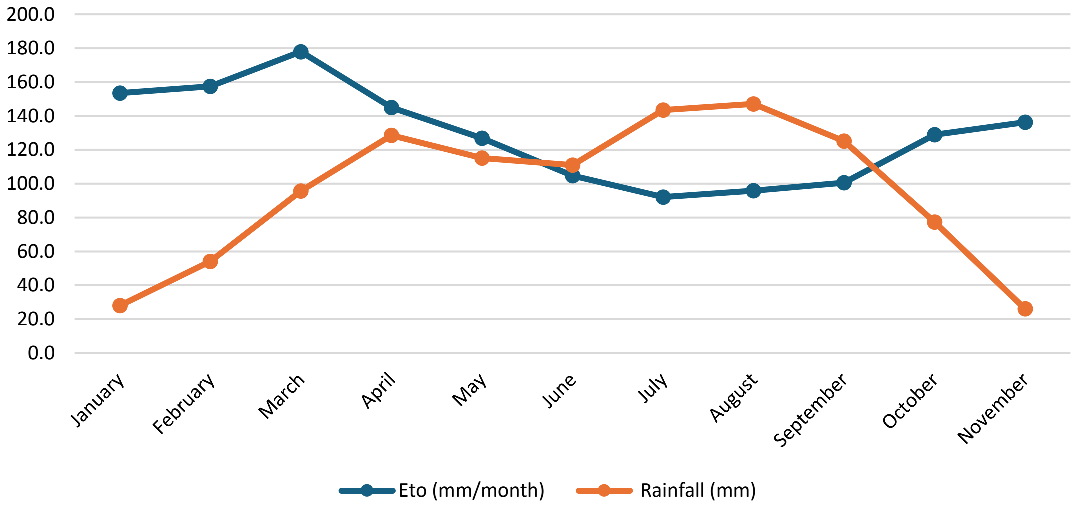

Figure 1 – Long-term Evapotranspiration vs rainfall data

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 coverage of the dominant crop, which constitutes the majority of the irrigated area within the scheme.

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

Table 1 – Determination of Irrigation and Crop Water Requirement

N	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

The crop water requirements (CWR) for the primary irrigated crops within the irrigation schemes were estimated using CROPWAT 8.0. 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 (^{o}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/^{o}C); γ: - psychrometric constant (kPa/^{o}C).

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

$$ET_C = K_C \text{ x } ET_O \qquad (2)$$

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 using the CROPWAT model and the water budget equation.

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

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).

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

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

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

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. A flume was installed at the entrance of each selected field to ensure a straight and uniform approach. The relationship between the head of irrigation water and its discharge is described by the equation provided by USBR (2014).

$$Q = C * \ H^{n} \tag{5}$$

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 a two-inch throat
The flow velocities in the main and secondary canals were measured using the floating method. The discharge of the flow was determined using the continuity equation, as follows:

$$Q = AV \tag{6}$$

Where: Q: - Discharge of the flow (m^3/s); A: - cross-sectional area (m^2); V: - Velocity of the flow (m/s); The discharge was then adjusted to $V_{flow} = 0.85 \ V_{surface}$.

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):

$$Ea = \frac{W_s}{W_f} * 100 \tag{7}$$

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

The soil textural classes of the schemes revealed that clay, sandy loam, and sand at the head, middle, and tail, respectively, were the dominant soil textural classes in the Wosha Irrigation Scheme (Table 2). However, the textural class of the Werka Irrigation Schemes varied from clay-to-clay loam at the head, middle, and tail reaches of the scheme (Table 3). The results indicated that the soils of both schemes had different textural classes.

Table 1 – Selected soil physical characteristics of the 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 the Wosha Irrigation Scheme showed that the average moisture content on a mass basis at field capacity (FC) was 37.2, 24.4, and 13.1% at the head, middle, and tail reaches, respectively. In Werka irrigation schemes, 43.7, 43.9%, and 44.5% were recorded at the head, middle, and tailreachesh, respectively (Table 1). In contrast, the mass base moisture content at the permanent wilting point (PWP) in Wosha was 24.3, 12.6, and 7.4% at the head, middle, and tail reaches, respectively. At Werka, 24.2, 22.3%, and 23.5% were observed in the head, middle, and tail reaches 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 the Wosha and Werka irrigation schemes, respectively. The soil bulk density of both irrigation schemes indicates that as the depth decreases, the bulk density increases, which implies that the soil compactness increases as decreases.

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. The TAWs of these schemes were within the range recommended by the FAO (1985) for the soil type. The soil physical analysis results revealed that the soil in the Werka Irrigation Scheme had a higher water-holding capacity than the sandy dominant soil type of the Wosha Irrigation scheme. This is an important condition for the Werka Irrigation Scheme in that longer irrigation intervals are practiced in an area where there is high competition for irrigation water.

Table 2 – Selected soil physical characteristics of the 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

Sugarcane is the most dominant crop based on area coverage in both Wosha and Werka irrigation schemes, accounting for 55 and 41% at Wosha and Werka, respectively. This was followed by Chat, which accounted for 40% of Wosha and 27% of the Werka irrigation scheme (Table 4). Owing to the perennial nature of the crop, both crops require more irrigation water than the other crops. Horticultural crops in the Wosha irrigation scheme accounted for only 5% of the total area covered by the scheme. However, in the Werka irrigation scheme, 32% of the total area is covered with carrot, potato, cabbage, and tomato crops. The study revealed that more emphasis was placed on horticultural crops in Werka than in Wosha. However, 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

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 observed for the irrigation requirements. Due to the perennial nature of sugarcane and chat crops, approximately 56 and 39 % of the total crop water requirements meet from rainfall, respectively. On the other hand, the lowest crop water and irrigation requirements were obtained from cabbage, as its growing season was shorter than the rest (Figure 2).

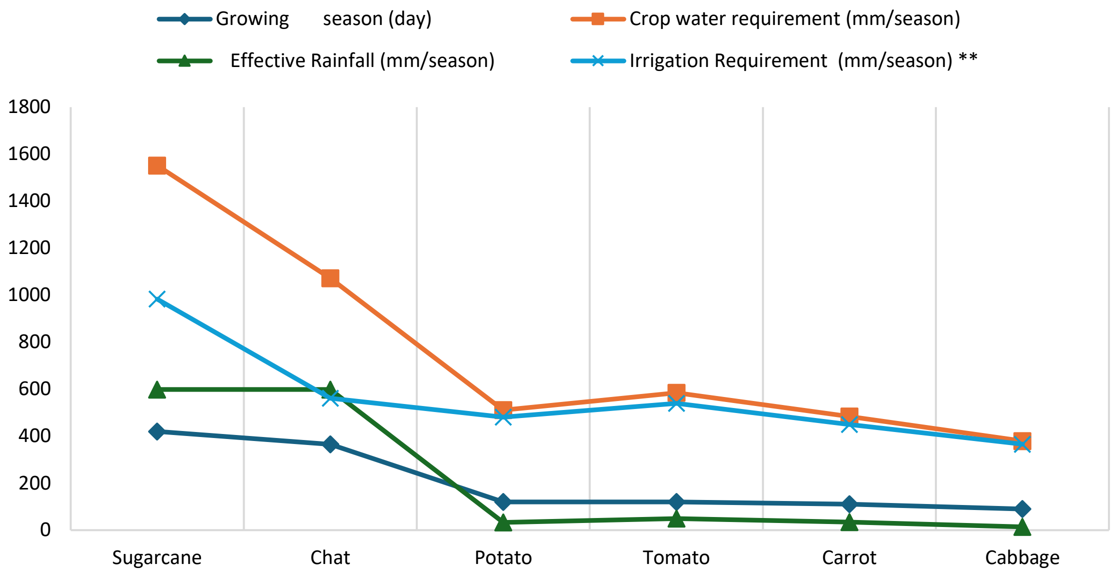

Figure 2. Crop water and irrigation requirement of the selected irrigation scheme

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

Farmers in the Werka irrigation scheme practiced irrigation intervals of 45–60 days, but as computed, the irrigation interval ranged from 48 to 55 days (Table 6). The application interval was similar, but it was longer than the irrigation interval of 60 days or more.

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

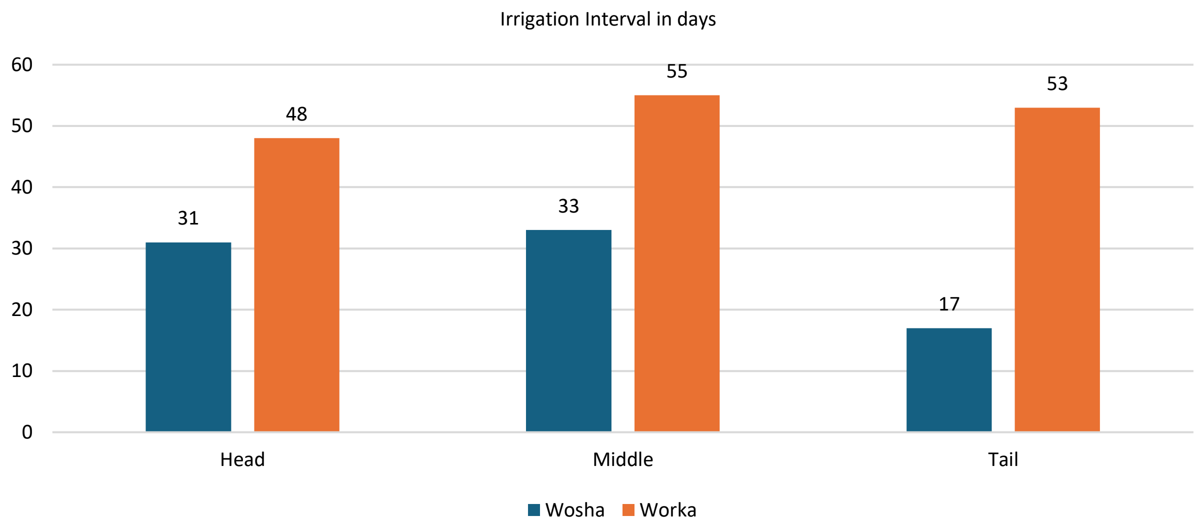

Figure 3 – Irrigation scheduling of sugarcane for Werka Irrigation Scheme

The average application efficiency was 48.2% and 59% for the Wosha and Werka irrigation schemes, respectively (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 to that at 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 deep percolation losses. In comparison, the Werka irrigation scheme demonstrated a 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 more uniform water distribution throughout the head, middle, and tail sections of the scheme.

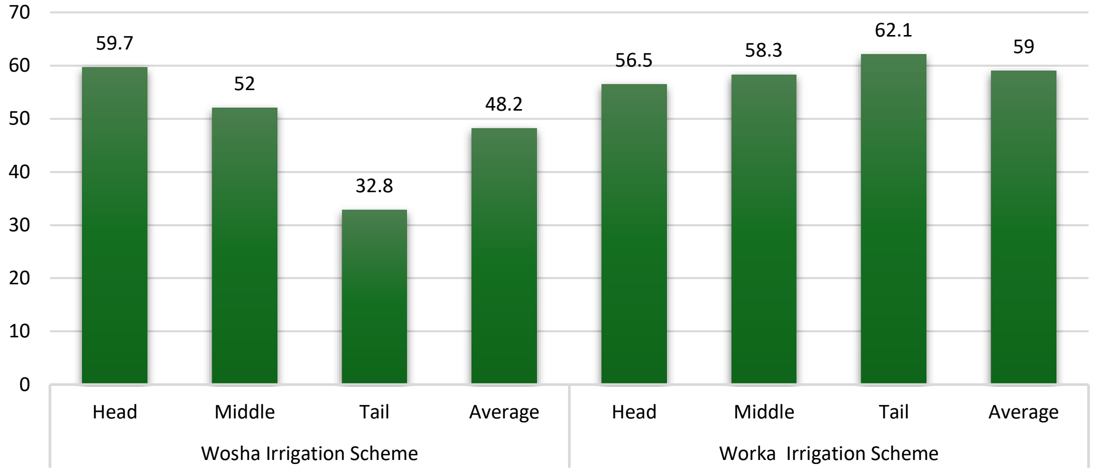

Figure 4 – Application Efficiency of Wosha and Worka Irrigation Schemes

Overall, the Werka irrigation scheme exhibits better application efficiency than the Wosha scheme. Similar findings were reported by Worku (2013), who observed an application efficiency of 58.4% in 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 those of Dinka (2017), who reported application efficiencies ranging from 57.2% to 65.5% in clay loam soils of the Ketar medium-scale irrigation scheme.

CONCLUSION

A performance study of the Wosha and Werka irrigation schemes in southern Ethiopia regarding irrigation water management revealed significant differences in soil type, water-holding capacity, and irrigation efficiency. The Werka irrigation scheme demonstrated higher application efficiency and better irrigation scheduling than Wosha, which suffered from inefficient water distribution, particularly at its tail end, due to sandy soils. Both schemes are significantly reliant on perennial crops such as 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 yield. Strengthening technical proficiency in water management and providing training on modern irrigation techniques are essential for farmers to optimize water use.

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