Research Article

Evaluating irrigation scheduling and application efficiency: baseline to revitalize Meki-Ziway irrigation scheme, Ethiopia

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Abstract

Irrigation scheduling and application efficiency were evaluated for Meki-Ziway irrigation scheme in an overall effort to revitalize the scheme. The evaluation was done on three furrows in each of the four farm plots. Field capacity, permanent wilting point and bulk density of the four plots were determined in the laboratory. We monitored furrow inflow rate, cutoff time and soil moisture content in the plots over a period of about 4 weeks. This monitoring was done during both periods of water availability and water scarcity. Our results show that on average 58% (range 42–77%) of the applied irrigation water in this scheme can be considered beneficial for crop growth. The results also show that soil moisture content at farm plots at the canal head sections was always between soil saturation level and permanent wilting point. For farm plots along the middle and tail sections of the main canal, soil water content would even fall below the permanent wilting point. This was caused by the absence of a water allocation system to ensure equity, and by large, channel seepage losses along the unlined main canal. To improve irrigation efficiency therefore, rehabilitation of the physical infrastructure of the scheme, more equitable irrigation water distribution in the scheme and improvement in on-farm irrigation water management are needed.

Keywords On-farm water management · Irrigation · Soil moisture · Application efficiency · Lake ziway

1 Introduction

Improving irrigation efficiency can improve economic returns. Bekchanov et al. [4] showed that adequate investments to improve irrigation efficiency could increase basin-wide benefits by 20% under normal water availability and by 40% under dry conditions. At scheme level, baseline information on irrigation efficiency can benefit efforts that aim to rehabilitate an irrigation scheme (e.g., [24]). Considering the complex nature of irrigation efficiency [20], empirical evidence is needed to enhance our understanding of site-specific factors that affect efficiency. This is particularly true for schemes in developing countries for which empirical evidence is not abundant in scientific literature.

Irrigation application efficiency (IAE) often is defined as the ratio of the actual amount of irrigation water that is stored in the root zone to the total irrigation water amount delivered to the crop. Irmak et al. [19] stated that the potential application efficiencies for well-designed and well-managed conventional furrows may vary between 45 and 65%. Bos [9] reported a wider range of IAE (60–90%) for surface irrigation on clay soils. For surface irrigated cotton in Queensland, Australia, application efficiencies were shown to vary widely, from 17 to 100% and on average were 48% [27]. This wide range of

IAE values in the literature calls for site-specific studies to be conducted in order to make efficiency assessments meaningful.

There are few studies in Ethiopia that report on IAE. Beshir and Awulachew [7] showed that IAE ranged between 25 and 50% for surface irrigation schemes. However, higher IAE (56%) is reported by Shonka [26] for a sugar farm in Ethiopia. Causes of differences in IAE are not well explained in the literature. An exception is provided by Bekele and Tilahun [5] who reported that 32–70% of the applied irrigation water is lost due to groundwater percolation in a small-scale irrigation scheme in eastern part of Ethiopia. The reported water loss was largest in tomato and potato fields when compared to that in sorghum and maize fields. Effects of soil texture on IAE are described in Burke et al. [10] who reported lowest efficiencies for soils with high infiltration rates.

The IAE values reported in the literature cover a wide range because of many factors that affect irrigation practices. Bakker et al. [3] integrated field monitoring and a surface irrigation model to show that irrigation interval, inflow rate and furrow shape have a significant effect on IAE. Horst et al. [17] reported that changes in irrigation cut-off times can lead to significant reduction in water losses of up to 150–200 mm/year. Farmers' practices also affect irrigation efficiencies since farmers do not follow consistent irrigation application practices and often prefer to over-irrigate by frequently irrigating with long application durations if water is available [17, 26, 29].

Lankford [22] described that IEA is site, scale and purpose specific, and that a complete and accurate determination of efficiency is rarely conducted, forcing engineers to make assumptions, often using generalized figures from the literature. For most irrigation schemes in Ethiopia, IAE is not well documented. Furthermore, irrigation efficiency estimation and scheduling may benefit from continuous monitoring of soil moisture content in the crop root zone.

Knowledge of soil moisture dynamics and its spatial variability is essential to improve our understanding of root water uptake and soil moisture redistribution [15]. As such, the use of instruments that measure both water fluxes and water storage quantities repeatedly and consistently over time is important to increase confidence of estimated IAE [11]. However, little work has been carried out in Ethiopia to evaluate irrigation practice using monitored soil moisture content. Most of the IAE studies for Ethiopian schemes use once-off measurements that are not repeated overtime making analyses of IAE doubtful. In this study, we monitored soil moisture and water fluxes to estimate IAE for the Meki-Ziway pump irrigation scheme in Ethiopia. Sustainable irrigation is of paramount importance in the scheme due to the arid climate of the area where the scheme is located, poor water retention

capacity of the sandy soil in the area and declining water level in Lake Ziway which is the source of the irrigation water.

Findings of this study are expected to provide useful inputs to support future revitalization of the scheme that is the main supplier of vegetables to the Ethiopian capital city Addis Ababa. Revitalization of existing schemes is important when found feasible since the costs of revitalization could be lower than constructing new systems [20]. The link between IAE and rehabilitation is discussed in Mateos et al. [24] who stated that unreliability, inflexibility and inequity of a newly rehabilitated system will initiate a downward spiral in maintenance resulting in poorer distribution and application efficiency. Wegerich et al. [30] also showed that IAE may be affected after rehabilitation due to misunderstanding and attitude of farmers, which suggests the need to understand current farm practices and farmers attitudes prior to rehabilitation.

2 Materials and methods

2.1 Site description

Meki-Ziway irrigation scheme is situated in Dugeda Bora district of Oromia region, Ethiopia. It is located on the northeastern side of Lake Ziway and about 5 km south east of Meki town as shown in Fig. 1. The scheme is located within 8°06′13″ and 8°08′43″N latitude and 38°47′49″ and 38°50′31″E longitude. The soils in the farm plots are sandy loam and loamy sand.

The mean annual rainfall of the scheme is 650 mm with the maximum rainfall amount occurring in July. The mean daily minimum and maximum temperature vary between 11.3–15.2 °C and 25.4–29.3 °C, respectively. Relative humidity of the study area varies between 68.6 and 79.9%. The wind speed is lowest in October (1.3 m/s) and highest in July (2.2 m/s). The sunshine hour shows large variation (6.1–9.8 h/day).

The reference evapotranspiration (ETo) of the study area is 4.34 mm/day, on average, as estimated using the Penman–Montheith method. ETo is smallest in August (3.81 mm/day) and largest in March (4.83 mm/day). The mean monthly evaporating power of the atmosphere exceeds the total monthly rainfall amount in all months except in July and August. As a result, artificial application of water is required to fulfill the evapotranspiration demand of the atmosphere and grow crops in the study area.

Meki-Ziway pump irrigation scheme was constructed in 1986 with technical and financial support from North Korean government. The target command area of the scheme was 3000 ha (Meki-Ziway irrigation project design
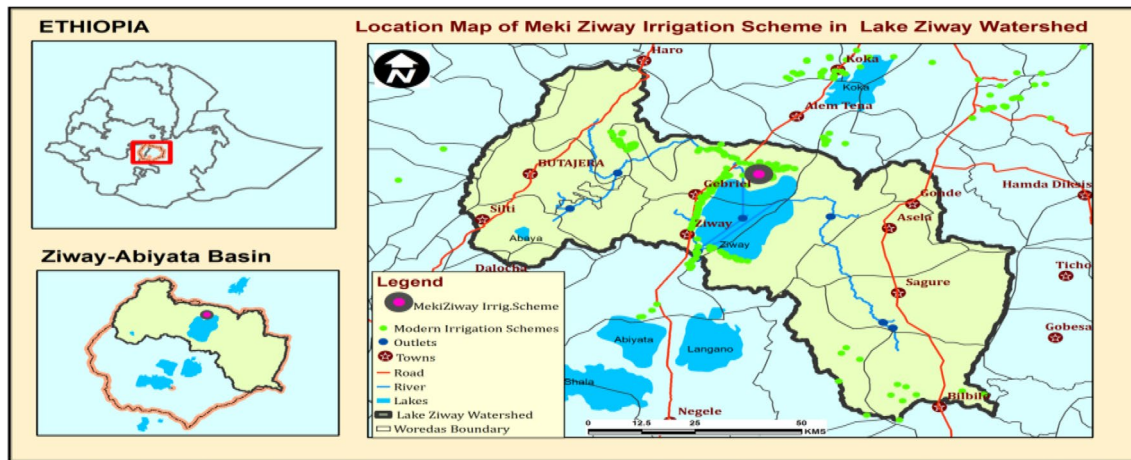
Fig. 1 Location of Meki-Ziway irrigation scheme

document, 1985). Currently, only 222 ha is irrigated. The farm plots are plain, and the main canal is aligned along a ridge. Individual farm hold sizes mostly range from 0.125 to 1 ha with an average farm size of 0.25 ha. Haile and Anteneh [16: unpublished report] indicated that the physical, financial and social performance of the scheme is unsatisfactory. The scheme has significantly deteriorated over the past 30 years not only due to aging but also due to lack of proper scheme management, operation and maintenance which is common in Ethiopia [2]. The number of pumps that serve the scheme with water from Lake Ziway reduced from initially nine to currently two, due to lack of proper maintenance and repair.

2.2 Experimental design and methods

We purposively selected four farm plots (6A, 7A, 9B and 11C coded as per the scheme's design document) in the irrigation scheme to conduct our experiment. The selection was based on a suite of criteria which include farm location relative to the main canal and the level of cooperation, education and communication skill of farmers. The level of access to water for the farms is rated very high, high and medium depending on their location with reference to the main canal (Fig. 2). Farm plot 6A is located nearest to the main canal, followed by 7A, and then 9C. Farm plot 11C is located furthest from the

Fig. 2 Location of the selected plots within the irrigation scheme with the water being diverted from Lake Ziway. Coordinates in UTM with WGS84 as horizontal datum
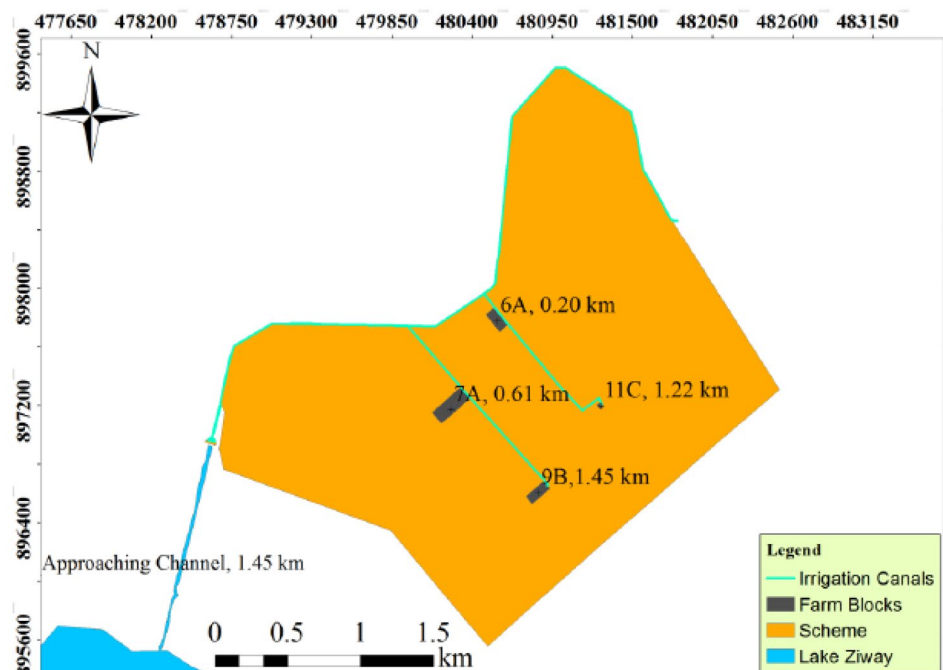
main canal. For field measurements, we had three replicas (experimental furrows) in each farm plot. The field measurements were taken between November 23, 2015, and December 17, 2015, with additional data collection in February 2016 as discussed below.

Soil samples were taken from all four farms, and relevant soil characteristic parameters including field capacity, permanent wilting point and bulk density were analyzed in the laboratory. In each plot, soil samples were taken at 30-cm interval for the top 120 cm depth.

Furrow length, depth, width and slope were measured for each of the replicas of each plot. The furrow inflow rate was measured for three irrigation events at each replica (except for few). It was measured using a bucket of known volume and measuring time it took to fill the bucket. Irrigation cutoff time in each replica was recorded by a stopwatch. The irrigation cutoff times for the replicas were such that there was no outflow from each of the furrows. Measurements were taken once per event for each replica and during a relatively ample water availability period (October 2015) in farm plots 6A and 11C and during water scarcity period (February 2016) in farm plots 7A and 9B. The scarcity was caused by the below average rainfall amounts received in the area during the previous rainfall season which led to reduced water levels of Lake Ziway. As a result, water was pumped from the lake only for few hours during this water scarcity period. The pumping schedule, when enough water is available in the lake, is between 6:00 A.M. and 6:00 P.M. on a daily base.

Volumetric soil moisture content in the crops' root zone was also measured just before and after irrigation. This was done using a soil moisture profiler that measures soil moisture content at 10, 20, 30, 40, 60 and 100 cm of depth. The soil profiler was calibrated with soil moisture contents that were determined in the laboratory by the gravimetric method. Volumetric soil moisture content was measured in the furrows. For each furrow, soil moisture before and immediately after irrigation was measured for three irrigation events. Soil moisture content was also monitored at daily time intervals over a period of 25 days. The moisture content was converted to depth of water in the effective root zone using Eq. 1 below.

In this study, the furrow dimensions depended on mainly the texture of the soil, the slope of land and the type of furrows that the farmers in the area use. Farmers' fields are very flat and thus the very flat furrow slopes shown in Table 2. Farmers in the study area are also using closed-downstream-end furrows. The closed-downstream-end furrows coupled with the very flat field slopes and the sandy soils that have high infiltration rates would require the furrows to have short lengths to facilitate more uniform infiltration of irrigation water into the soil. Thus,

farmers in the study area use short furrows of average lengths of about 5 m (Table 2).

The irrigation water amount was diverted to each experimental plot by field ditches and to the furrows by breaching the field ditches. The amount of the diverted water to each furrow was measured by using a bucket of known volume. We used a stopwatch and a 25-L bucket for the measurement. First, the bucket was inserted into the ground, and then, time elapsed to fill the bucket was recorded. The measurement was undertaken at each of the three furrows per farm plot, and an average of the measurements was used for further analysis. The measurement was taken for three irrigation events at each plot. Farmers simultaneously irrigate multiple furrows during an irrigation event. Thus, water was being applied to the furrows which are on the right and left sides of the experimental furrows, while we are undertaking measurements.

In this study, application efficiency is defined as the ratio of the actual amount of irrigation water which is stored in the root zone to the total irrigation water amount delivered to the crop [18]. Volumetric soil moisture contents (θ_v) in the plots were measured before and after the irrigation events considered in this study in order to estimate changes in water content in the effective root zone. The various crops' effective rooting depths (Z_r) are as shown in Table 2. At each irrigation event and at each plot, depth of water in the effective root zone (W_{rz}) was calculated as shown below:

$$W_{rz} = \theta_{v1}d_1 + \theta_{v2}d_2 + \theta_{v3}d_3 + \theta_{v4}d_4 + \theta_{v5}d_5 + \theta_{v6}d_6 \quad (1)$$

where θ_{v1}, θ_{v2}, θ_{v3}, θ_{v4}, θ_{v5} and θ_{v6} are volumetric soil water content measured at 10, 20, 30, 40, 60 and 100 cm depths, respectively, whereas d_1, d_2, d_3, d_4, d_5 and d_6 are 10, 10, 10, 10, 20 and 40 cm, respectively, i.e., thicknesses of each soil layer at each of the measured depths. For cabbage, green beans and cucumber with effective rooting depths of 60 cm, root zone water content in Eq. 1 was calculated up to 60 cm, whereas for mustard, with effective rooting depth of 100 cm, its root zone water content in Eq. 1 was calculated up to 100 cm. We assumed the root zone to remain the same over the experimental period (25 days) which is significantly shorter than the growing season.

Volumetric soil water content (θ_v) in the effective root zones (z_r) of the crops in each plot for the 25-day-monitoring period as plotted in Figs. 3, 4, 5 and 6 was estimated as follows:

$$\theta_v = \frac{W_{rz}}{Z_r} \quad (2)$$

where volumetric soil water content (θ_v) is expressed in terms of $m^3 \, m^{-3}$, whereas the other terms are in cm. For each irrigation event, the change in depth of water in the

Fig. 3 Temporal variation in soil moisture content (volumetric) for the effective root zone in farm plot 6A (Refer to Table 2 for furrow dimensions and crop type grown)
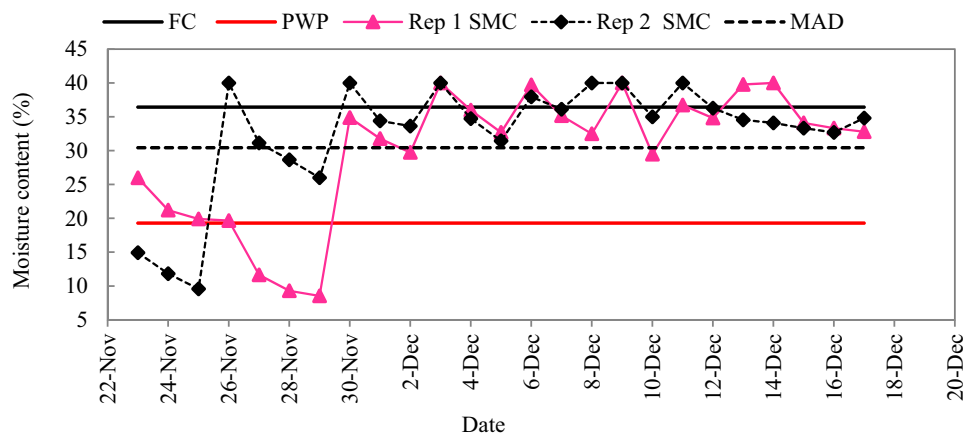
Fig. 4 Temporal variation in moisture content for the effective root zone in farm plot 7A
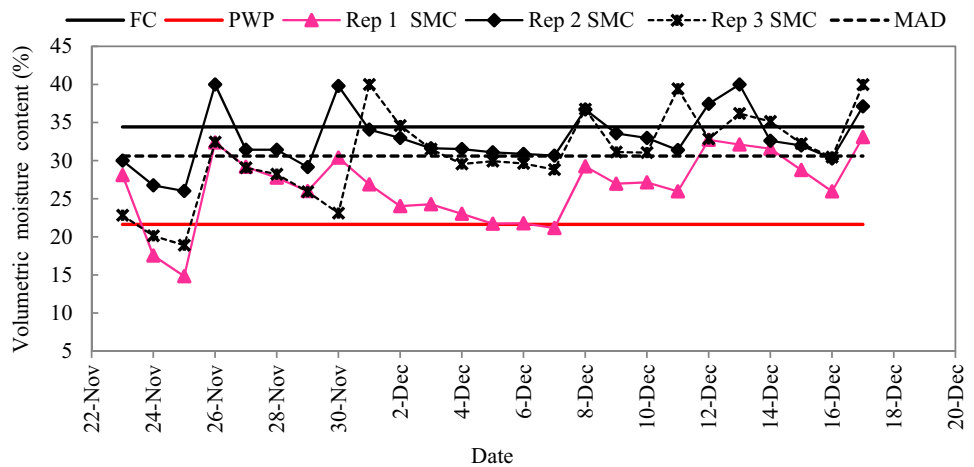
Fig. 5 Temporal variation in soil moisture content (volumetric) for the effective root zone in farm plot 9B
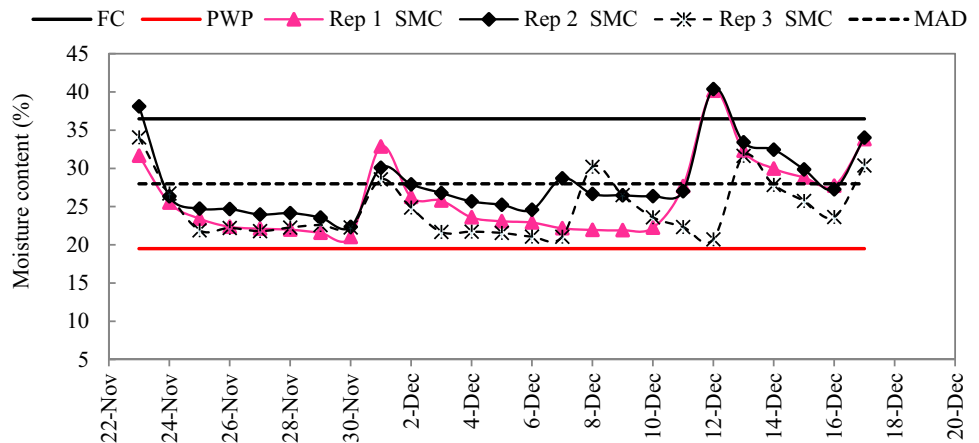
effective root zone was estimated from the change in soil moisture measurements as shown below:

$$\Delta W_{rz} = W_{rz} \text{ after irrigation} - W_{rz} \text{ before irrigation} \quad (3)$$

At each irrigation event, irrigation application depth was estimated as follows:

$$D_n = \frac{(Q \times t_c)}{F_s \times L_f} \quad (4)$$

where D_n is the average depth of water applied (cm), Q is furrow inflow rate (l/s), t_c is cutoff time (s), F_s is furrow spacing (m) and L_f refers to the furrow length (m).
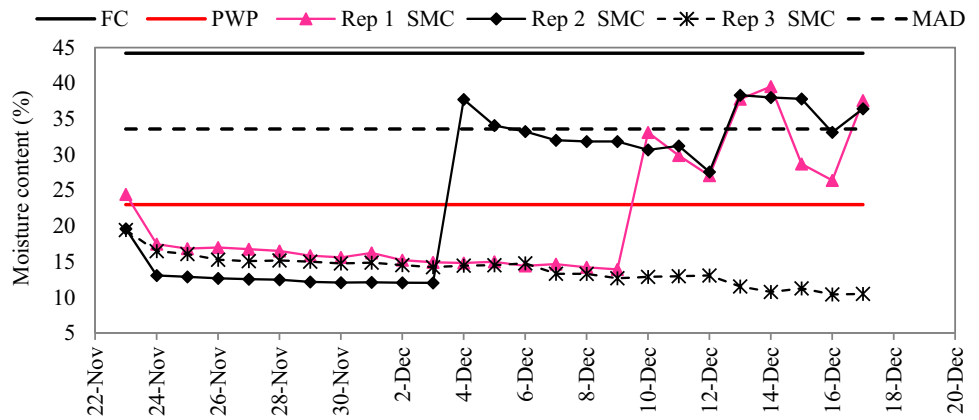
Fig. 6 Soil moisture content (volumetric) pattern for the effective root zone in farm plot 11C

Table 1 Laboratory results of soil water field capacity, permanent wilting point, available water content, bulk density and porosity

Farm plots	6A	7A	9B	11C
Soil type	Loamy sand	Loamy sand	Sandy loam	Sandy loam
Sand (%)	78	81	57	53
Clay (%)	4	1	11	12
Silt (%)	18	18	32	35
FC (volumetric) %	35.0	32.7	36.3	44.1
PWP (volumetric) %	18.7	20.1	19.5	23.0
AWC (volumetric) %	16.2	12.6	16.9	21.1
Bulk density(g/cm^3)	1.63	1.63	1.60	1.70
Porosity (%)	38.5	38.5	39.6	35.8

Values refer to averages over the top 120 cm of the soil

Table 2 Furrow dimensions of the selected farm plots

Farm plot details	Furrow ID	Furrow length (m)	Furrow spacing (m)	Furrow depth (m)	Furrow slope (m/m)
Farm plot: 6A	Rep 1	4.20	0.50	0.130	0.005
Plant: Cabbage	Rep 2	4.80	0.56	0.105	0.006
Effective rooting depth: 0.6 m	Rep 3	4.60	0.56	0.120	0.009
Number of days after planting*: 40	Mean	4.53	0.54	0.118	0.007
Farm plot: 7A	Rep 1	5.04	0.57	0.090	0.004
Plant: green beans	Rep 2	5.00	0.56	0.110	0.009
Effective rooting depth: 0.6 m	Rep 3	5.10	0.54	0.125	0.014
Number of days after planting: 15	Mean	5.05	0.55	0.108	0.009
Farm plot: 9B	Rep 1	4.34	0.43	0.115	0.003
Plant: Cucumber	Rep 2	5.37	0.56	0.085	0.006
Effective rooting depth: 0.6 m	Rep 3	3.93	0.59	0.095	0.002
Number of days after planting: 14	Mean	4.55	0.53	0.098	0.004
Farm plot: 11C	Rep 1	6.45	0.56	0.135	0.005
Plant: Mustard	Rep 2	6.42	0.61	0.125	0.008
Effective rooting depth: 1 m	Rep 3	6.83	0.73	0.150	0.003
Number of days after planting: 32	Mean	6.57	0.63	0.137	0.005

*Refers to the number of days after planting at which the experiment was started

Irrigation application efficiency (IAE) was then estimated in percentages as shown below:

$$IAE = \frac{\Delta W_{rz}}{D_n} \times 100 \qquad (5)$$

Note Eqs. 3 (amount of applied water which is stored in the effective root zone) and 4 (water applied to the crop) can be equal only if all applied water is stored in the effective root zone, which results in IAE = 100%. However, this is not always the case since some of the applied water evaporates, and some percolates below the effective root zone which results in IAE being less than 100%.

All farmers who owned the test plots were informed about the objective of the study. Informed consent was obtained from each farmer to take measurements including soil samples from the plots.

3 Results

3.1 Soil characteristics

Soil characteristics are important inputs to evaluate irrigation performance. Field capacity (FC), permanent wilting point (PWP), available water content (AWC), bulk density and porosity of the top 120 cm soil in the experimental plots are shown in Table 1. Soils in plots 6A and 7A are loamy sand, whereas those in plots 9B and 11C are sandy loam. The FC is 21, 20, 23 and 26% for farm plots 6A, 7A, 9B and 11C, respectively. PWP is 11, 12, 12 and 14% for farm plots 6A, 7A, 9B and 11C, respectively. The estimated PWP of the sandy loam soil agrees with literature reported values, but those of the loamy sand soil are only slightly higher than literature reported values [13, 23]. This may be caused by cropping practice and environmental conditions [23]; however, the deviation is too small to cause difference between the plots.

For the top 120 cm of all the plots, the average bulk density ranges between 1.60 and 1.70 g cm^{-3}. Porosity in

each individual plot shows small variation and ranges from 35.8 to 39.6% for all the plots.

3.2 Furrow dimensions

Table 2 shows that the furrow slope in the study area is very flat (0.002–0.014 m/m). Such slopes provide relatively extended opportunity time for the applied water to infiltrate into the root zone of the crops. The furrow depth varied from 0.09 to 0.15 m which agrees with recommended values in the literature [12].

Due to the high infiltration rates of sandy soils, local farmers use short furrow lengths for better irrigation and crop management. The furrow length of the test plots varied from 3.9 to 6.8 m. The furrow spacing for all the plots was on average 0.56 m and is within the recommended range [14]. However, furrow interconnection problems were observed in some farms which may contribute to irrigation water loss and uneven water distribution. Exceptions are the furrow spacing of replica 1 (0.43 m) and replica 3 (0.59 m) are larger than expected for cucumber crop. Thus, local experts should provide advice to famers to use recommended spacings for cucumber.

3.3 Irrigation application

The mean inflow rate and cutoff time of the scheme are 3.7 l/s and 45.7 s, respectively (Table 3). Both inflow rate and cutoff time varied among plots, irrigation events and replicas. This suggests inconsistency in water application as caused by differences in farmers' skill and furrow characteristics.

The average applied water, which is then average of all irrigation events per plot, varied from 6.6 to 22.7 mm (Table 4). Measurements were undertaken in December 2015 in plots 6A and 11C and in February 2016 in plots 7A and 9B. Water was more abundant in December 2015 than in February 2016, that is, water levels in Lake Ziway were higher in December 2015 than in February 2016. The farmer, whose plot is situated near the main canal

Table 3 Summary of inflow rates and cutoff times in each of the selected farm plots

Farm plots	Min discharge (l/s)	Max discharge (l/s)	Mean discharge (l/s)	Min cutoff time (s)	Max cutoff time (s)	Mean cutoff time (s)
6A	4.08	5.59	4.74	31.09	44.74	37.36
7A	2.37	3.37	2.92	50.09	65.26	59.31
9B	2.37	3.87	2.92	25.30	49.30	40.36
11C	4.30	5.45	5.09	44.22	50.18	46.16
Mean of mean			3.73			45.77
SD			1.16			10.96
CV (%)			31.10			

Table 4 Average applied water (averaged of all irrigation events) in each of the selected farm plots

Farm plot	Applied water depth (mm)			Mean
	Rep 1	Rep 2	Rep 3	
6A	21.9	23.7	22.6	22.7
7A	11.7	10.6	10.7	11.0
9B	9.4	8.7	10.7	9.6
11C	10.4	9.4	0.0	6.6

(6A), applied the largest water amount for all events compared to those at the middle and tail of the main canal. Also, more water was applied when there was relatively abundant water in December 2015 than in February 2016. However, despite the application depths of farm plot 11C being measured during a time when there was better water availability (December 2015) in the scheme, lower amounts of water reached this plot which is at the tail end of the canal. The farmer did not apply water at all to replica 3 of plot 11C due to water scarcity during the time of the experiment. Thus, the applied irrigation depth in this plot was lower when averaged for all events (6.6 mm).

The total applied water is in excess of the required crop water requirement when aggregated over the experimental period. The excess water is largest for plot 6A and smallest for 11C. This excess water is reported for the applied water which is aggregated for all irrigation events. However, adequacy of water for the individual irrigation events is discussed in the following section.

3.4 Temporal variation of soil moisture

The temporal variation in soil moisture content in farm plot 6A is shown in Fig. 3, which also shows PWP, FC and management allowable depletion (MAD) levels. MAD was specified based on FAO recommendations for each group as a threshold to evaluate whether the applied water is adequate or inadequate. The farmers in the study area are not aware of MAD but rely on their experience and water availability to decide the timing of the irrigation events. The difference between FC and PWP indicates the water which is available for the crops. When the moisture level drops below PWP, the soil becomes nearly dry and the crop can no long extract water from the soil.

For the first few consecutive days at the end of November 2015, irrigations had not yet started in the scheme; therefore, the moisture content of plot 6A was below PWP (Fig. 3). When irrigations started, moisture content of the plot was brought above the management allowable depletion (MAD) level. The moisture level was always kept above MAD level after the first irrigation during the monitoring period. The plot was irrigated 7 times during

the 25 days monitoring period. Figure 3 shows that these irrigation applications were done at various soil moisture levels, implying that the farmer applied water to the plot without using a specific or predefined criteria or irrigation scheduling method. The average irrigation interval over the monitored period was 3 days for the initial 7 days. The farmer then started to apply water every other day or daily afterward. However, the farmer did not apply water to replica 2 for the last 7 days, probably due to the late stage of the crop. For each irrigation application, moisture content exceeded the FC level and reached saturation level.

For the farm plot 7A, we noticed differences in soil moisture patterns among the replicas (Fig. 4). Water was applied 6 times over the monitoring period. Irrigation interval was not consistent and varied between 1 and 8 days with the longest interval occurring in the second week. This difference was caused by water never reaching some plots in the scheme on some irrigation events. After the first week, the soil moisture content of replicas 2 and 3 slightly exceeded MAD level and reached FC occasionally during irrigation applications. However, the moisture content in replica 1 was mostly below MAD showing moisture stress, suggesting that the farmer did not apply the water that was available uniformly across the field.

Farm plot 9B received irrigation water four times over the course of the 25 days (Fig. 5). On two of these application occasions, the applied water was not enough to increase the soil moisture content to FC. Irrigation interval was 6 days on average but varied between 4 and 9 days. With exception of few days, the moisture content of this farm plot was below the recommended MAD level. This implies that the plants were under moisture stress which is expected to negatively impact its yield [25]. However, the moisture content did not fall below PWP.

Two replicas of the farm plot 11C were irrigated four times, whereas the third replica was not irrigated at all during the monitoring period (Fig. 6). This suggests that the farmer prioritized the furrows to irrigate during periods of water shortages. Irrigation interval was between 2 and 11 days for replica 2, while it varied between 1 and 16 days for replica 1. The soil moisture content of this plot was significantly lower than the PWP for the first 11 days, as well as for a 16 day period for replicas 1 and 2, and for the entire monitoring period for replica 3. The amounts of water reaching this plot were not sufficient at all to increase the moisture content to FC level; the moisture content was even below MAD. This led to the crop in this field to fail. There was no harvest from this plot.

3.5 Irrigation application efficiency

The overall mean application efficiency of the scheme is estimated at 58.2% (Table 5) and is the ratio of the

Table 5 Plot application efficiency (IAE) of the scheme

Plot	Replica	Irrigation event 1		Irrigation event 2		Irrigation event 3		Mean discharge (l/s)	Mean IAE (%)
		Discharge (l/s)	IAE (%)	Discharge (l/s)	IAE (%)	Discharge (l/s)	IAE (%)		
6A	Rep 1	4.1	77.3	4.8	54.8	4.2	66.6	4.4	66.2
	Rep 2	4.8	51.2	5.6	51.7	4.3	53.1	4.8	52.0
	Mean							4.6	59.1
7A	Rep 1	3.4	53.0	3.0	60.7	2.8	64.4	3.0	59.4
	Rep 2	2.5	67.6	2.5	59.2	2.4	69.1	2.5	65.3
	Rep 3	2.5	53.1	2.4	72.3	2.5	64.9	2.4	63.4
	Mean							2.5	62.7
9B	Rep 1	3.9	46.0	3.1	63.9	3.0	56.0	3.3	55.3
	Rep 2	3.0	50.1	2.7	50.9	2.9	68.3	2.9	56.4
	Rep 3	2.5	42.1	2.4	65.5	2.7	60.2	2.6	55.9
	Mean							2.9	55.9
11C	Rep 1	5.3	52.6	5.4	50.7	4.8	58.6	5.1	53.9
	Rep 2	5.5	64.4	5.4	57.7	4.3	46.2	5.0	56.1
	Mean							5.1	55.0
Mean of mean								3.8	58.2
Std Dev								1.22	3.49
CV (%)								31.92	

The farmer did not apply water to replica 3 of plot 11C due to water scarcity during the time of the experiment

irrigation water amount which is stored in the root zone to the irrigation water amount applied to the crop. The efficiency greatly varies from 42.1 to 77.3% with irrigation events and replicas. The values obtained in this study were close to the lower limit of the literature recommended value of IAE for surface irrigation.

In this study, the reported differences in application efficiencies were possibly caused by the reported variations in inflow rate and cutoff time (generally called decision variables) and furrow parameters mainly soil infiltration characteristics. The application efficiency of the sandy loam soil fields was (plots 6A and 7A) higher than the loam sand soil fields (plots 9B and 11C). It also likely depended on farmer's experience in recognizing flow resistance, required depth of irrigation and soil moisture depletion prior to irrigation.

4 Discussions

The existing literature in Ethiopia is not adequate to be conclusive on the contribution of various factors for reported IAE of schemes. The few available studies reported that application efficiency in most irrigation schemes in Ethiopia is poor. The IAE of Tendaho Sugar state farm is only 56.57% [26]. Bekele and Tilahun [5] reported that 32–70% of the applied irrigation water is lost due to groundwater percolation in a small-scale

irrigation scheme in eastern part of Ethiopia. IAE in the Lake Tana floodplains is also mostly between 40 and 60% [8]. Slightly a wider range of IAE (40 and 85%) is found for a traditional scheme in the central rift valley by Teshome et al. [28] who also reported 50% efficiency in sandy loam soil, which is similar texture as two of our experimental plots. Overall, these studies indicate that irrigation application in Ethiopia is on the lower side of expected ranges as indicated by Bos [9] and Smith et al. [27]. This is further strengthened by the findings of our study.

This study's results show that the current distribution of water to farmers' plots within the Meki-Ziway irrigation scheme is not equitable. The main reason for the poor water distribution in the scheme is the absence of water allocation and management. This favors farmers near the canal head to divert excess water in the expense of those at the canal tail. Repeated failure of the pump and power outbreak also creates water insecurity. This is exacerbated by absence of maintenance of the canal system over the past 4 decades. As observed in the field, there are noticeable water losses along the main canal. Improvements in more equitable allocation of water are therefore needed in order to increase the scheme's irrigation efficiency. Some of these improvements should include:

1. Lining of the scheme's main canal such that seepage losses in the scheme's sandy soils are minimized and

more water is thus available to reach more plots in the middle and tail zones of the scheme.

2. Water allocations decisions should be based on actual crop water requirements rather than on availability of water in the canals as is case in the Meki-Ziway scheme, where farmers with plots in the middle and tail ends of the scheme are forced to access only portions of water that have not been used by upstream farmers. Training farmers in the scheme on when and how much water to apply to specific crops is therefore very much needed. When water is readily available, meeting the crops' water requirements may mean always applying enough water to cover the soil moisture deficit. However, when water is not readily available as seen in the drier parts of the year in this area, water may be proportioned to crops, not to completely cover the soil moisture deficit, but to allow for adequate yields to be realized (i.e., deficit irrigation). Again, farmers need to be trained in deficit irrigation practices such that their yields are not significantly affected.

3. Introducing and strictly enforcing water distribution guidelines/regulations (with government involvement) that reduce the levels of irrigation intensity in the plots near the main canal are needed. Better water distribution in the scheme would therefore require members to come together and cooperatively form a water users' committee and formulate rules for more equitable water management and how conflicts would then be resolved.

4. Considering the water scarcity and the high value crops which are being grown in the scheme, better water application and scheduling is needed for increased efficiency. Many studies have shown the advantages of deficit irrigation in reduce irrigation water loss in Ethiopia [1, 6, 21, 25]. However, the recommendations of these scientific studies have not been translated to farmers practice yet. We therefore recommend that training of especially the upstream farmers on deficit irrigation practices of various crops. Regular maintenance of the scheme canals including the main, secondary and tertiary canals is needed for regular spatial distribution of water throughout the scheme.

5. We suggest additional assessments at diversion areas, conveyance and distributions to provide specific and detailed recommendations for revitalization.

5 Conclusions

Meki-Ziway irrigation scheme has been benefiting smallholder farmers over the last 30 years. Due to lack of major maintenance and rehabilitation of the scheme, available water resources are poorly managed and crop production is affected. Also, there is no water allocation strategy in the scheme that would ensure equity and reliability across the reaches. The unlined main canals cause large transport losses of water through seepage and contribute to uneven distribution of irrigation water. A field survey showed that excess water is applied in the water accessible reaches, while inadequate amounts of water are supplied to many farmers who are located furthest away from the head of the waters, with some agricultural plots not receiving any irrigation water at all. Consequently, farmers have decreased their irrigated area or have shifted to alternative sources of water for irrigation. Also, the inequality to access irrigation water has led to unhappiness and impacted well-being of many households.

The following main conclusions can be drawn based on the experimental results in this study:

• Irrigation water delivery is not reliable and irrigation interval is irregular. There are large variations even within a single plot. Consequently, farmers do not know when they will receive the next irrigation water and often irrigate whenever water is made available in the main canal. Predefined and specific criteria to trigger irrigation application are not available.

• As such, soil moisture content of farm plots at the canal head is always between soil saturation and permanent wilting point. For middle and tail end canal sections, moisture content in farm plots falls below the permanent wilting point for many days.

• The crops in plots whose soil moisture contents falls below the maximum allowable deficit in crop root zones frequently and occasionally even falls below the permanent wilting point face critical water stress to an extent that leads to yield loss or failure. Irrigation application efficiency of the scheme varies over a large range of values (42–77%) with an average of 58%. IAE is within literature reported values for Ethiopia but are at the lower limit as defined in many other countries.

• When soil moisture content in the crop root zone falls below the maximum allowable deficit, it suggests that the crop water demand was not being met during the experimental period. This points to inadequacy of the amount of water delivered to a plot. This was as a result of a number of key scheme

aspects including: (1) temporal water supply to the scheme being inadequate to meet the crop water requirements, (2) inequitable water allocations and distributions throughout the scheme, (3) inefficient water conveyance and delivery systems that are marred by significant water losses for instance the main and secondary canals being unlined and (4) poorly maintained conveyance and delivery systems that lead to irregularities in spatial water distribution within the scheme.

Enhancement of farmer's knowledge on crop yield responses to water application is urgently needed to create awareness on not only ways of maintaining optimum yields in water scarce periods but also improving farm's and overall scheme's irrigation efficiencies. This helps to save water that can be used for other uses including irrigating additional land. Future interventions should therefore provide incentives to farmers to improve the current irrigation efficiency levels.

Compliance with ethical standards

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