# A participatory and practical irrigation scheduling in semiarid areas: the case of Gumselassa irrigation scheme in Northern Ethiopia

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## Abstract

*Poor irrigation scheduling practices have been quoted as the major challenges for sustainability of small-scale irrigation schemes in Ethiopia due to complexity of scheduling techniques, cost and inaccessibility of soil-water monitoring tools, lack of various local climatic data and soil-water parameters. For local experts to easily schedule irrigation and to promote adoption by farmers, a cheap and simple computation procedure of irrigation scheduling is needed that considers local resources and opinions. So far, there is no such study in the context of Ethiopia. A simple irrigation scheduling method (Practical) was developed based on the FAO procedure (Brouwer et al., 1989),* employing *Hargreaves* $ET_0$ *equation and the opinions of local farmers and extension agents. Then, the method was validated on-farm through participatory and close observation of farmers by comparing with CropWat simulated (Sophisticated) and local (Traditional) scheduling practices for 2015and 2015/16 irrigation seasons considering maize as indicator crop. Data on irrigation depths, yield and yield components and soil salinity were collected and analysed. Furthermore, a farmers' day was arranged to collect opinions on the crop stand and scheduling techniques. In both irrigation seasons, the practical irrigation schedule method resulted in higher grain yield while saving substantial amount of water and in significantly higher water productivity (WP) compared to the other methods. Maximum (0.68 kg* $m^{-3}$ *in 2015) and minimum (0.47 kg* $m^{-3}$ *in 2015/16) WP were found in the practical and sophisticated approaches,* respectively. *The average root zone salinities among the alterative irrigation scheduling methods were not significantly different, in both irrigation seasons. Farmers' and experts' opinions were in favour of the practical scheduling method. The practical irrigation scheduling method is thus recommended for maize, around Gumselassa area. Further, the presented procedure can be adopted for preparation of irrigation calendars of other cops and in other regions.*

**Key words:** Simple irrigation schedule; Hargreaves; CropWat; water productivity; yield and yield component, maize; Tigray

## 1. Introduction

With unreliable and highly erratic rainfall, Ethiopia is characterized by food insecurity due to high risk of annual droughts as well as intraseasonal dry spells (WFP, 2016; FAO, 2014; World Bank, 2014; CIA, 2018). In order to address the problem of water scarcity and food insecurity, promotion and development of small scale irrigation (SSI) has been a priority policy for the Ethiopian Government (FDRE, 2007; MoWR, 2002; MoFED, 2006; MoFED, 2010). As a result of this policy the irrigated area of SSI increased from 853,100 ha in 2009/10 to 1,853,100 ha in 2012/13 (MoFED, 2014).

Despite the huge expansion, the performance of most SSI schemes in the country is far from satisfactory (Amede, 2015; Awulachew and Ayana, 2011; Carter and Danert, 2006; Cofie and Amede, 2015; IFAD, 2005; MoA, 2011; Teshome, 2003; Yohannes et al., 2017). Poor irrigation water management has been among the major reasons quoted for underperformance of the schemes.

Tigray is one of the most degraded and drought prone regions of Ethiopia. Similar to the other schemes in the country, poor water management practices, particularly improper irrigation scheduling is one of the factors for underperformances of most SSI schemes in the region (Eyasu, 2005; Libseka et al., 2015; Yohannes et al., 2017).

Lack of simple and practical scheduling techniques, limited knowledge and inadequate practical skills of farmers and local extension agents on crop water needs, soil types and climatic conditions, in the country (MoA, 2011; Haile and Kasa, 2015; Etissa et al., 2014; Awulachew, 2010) and particularly in Tigray region (Yohannes et al., 2017; Eyasu, 2005) as well in many countries (Hill and Allen, 1996; ICID/FAO, 1996; Maheshwari et al., 2003) have been the major reason for poor on-farm water management practices.

In Tigray region, irrigation scheduling is being decided by a local water committee and/or based on the farmer's intuition, insufficiently accounting for soil, plant and weather conditions (Eyasu, 2005; Mitiku et al., 2002; Mintesinot, 2002). As a result, over or under irrigation of fields is common in the region (Eyasu, 2005) as well as in many irrigation schemes in the country (MoA, 2011).

These poor on-farm water management practices have resulted in low production and water productivity, waterlogging, soil salinization, rise in groundwater levels and decrease in command area (Eyasu, 2005; Mintesinot, 2002). Many studies (Alemayehu et al., 2006; Ayenew, 2007; Fanadzo et al., 2010; Haile and Kasa, 2015) also confirmed that inappropriate irrigation scheduling as among the major factors for poor performance of many irrigation schemes.

Many advanced and novel scientific irrigation scheduling techniques have been developed in the past three decades. However, the adoption by farmers is low, especially in developing countries (Annandale et al., 2011, Fanadazo et al., 2010). The major reasons for low adoption are reported to be lack of soil water parameters and weather conditions (Torres, 1998), and complexity of the techniques such that farmers are confused by choice and do not understand the difference between the different scheduling techniques (Stirzaker, 2006), failure of the scientist to understand the situation of farmers and the constraints under which they operate (Vanclay, 2003; Pleban and Israeli, 1989). Much of the studies are focused on the exact science of irrigation scheduling rather than simple and practical measures that would improve farmers decision (Maheshwari et al., 2003).

Although various researches and attempts were conducted on irrigation scheduling (Demelash, 2013; Mintesinot, 2004; Muktar and Yigezu, 2016; Kifle, et al., 2017; Kifle and Gebretsadikan, 2016) using the CropWat model in Ethiopia, none of these involved the participation of local farmers and extension agents and consequently the outputs didn't serve the end users. Besides, the sophisticated/conventional approach applied by researchers cannot be practiced by the local extension agents. Unavailability of climatic data and absence of simple implementation manuals for farmers were also among the major reasons for failure of the attempts.

In addition to the need of reliable climatic data, the sophisticated method of irrigation scheduling requires computer access, trained professionals and soil-water monitoring tools which are rarely available in most parts of Ethiopia.The choice of the irrigation scheduling method should consider the technology level of the farm (ICID/FAO, 1996).

Past research and practical experience emphasized that irrigation scheduling practices must be simple, useable and understandable by farmers in order for them to be adopted (Hill and Allen, 1996; Hargreaves and Samani, 1987). Though some simple methods of scheduling have been developed (Torres, 1998), the practicality and adoption is still low for several reasons. For example, simple irrigation scheduling calendars (Hill and Allen, 1996) were developed which demand professional and sufficient weather data to apply.

To secure food security in drought-prone regions like Tigray, concrete efforts to improve on-farm water management is required (Hillel, 1997). Thus, improving irrigation scheduling by individual farmers in the region should be a matter of urgency.

Not much has been done on development of simple and practical irrigation scheduling techniques that can be exercised by local extension agents and easily adopted by farmers. Innovations are required for current irrigation management and practices (Pereira et al., 2002) and there is a need to develop simple monitoring tools and conceptual frameworks that enable structured learning (Annandale et al., 2011).

Considering the poor socioeconomic status of the farmers, very low technology level of the farms, inaccessibility of tools and lack of local climatic data and trained professional in Tigray as well as in most rural parts of the country, there is an urgent need to develop more simple and easy to apply irrigation scheduling techniques. The aim of the study is therefore to identify, test and validate practical irrigation scheduling that considers the local conditions, which can be easily practiced by the local extension agents and easily understood and applied by the farmers.

A participatory procedure that included local farmers' and extension agents' opinions in combination with a method published by FAO (Brouwer et al., 1989) and Hargreaves equation (Hargreaves and Samani, 1985) were used for this study. The FAO approach requires limited data and the procedures to be followed are easy for local extension agents. Hargreaves equation is a worldwide accepted simple and reliable method of estimating evapotranspiration that requires only temperature data (Hargreaves and Allen, 2003; Hargreaves, 1994; Allen, 1993; Jensen et al., 1990). In most rural parts of Ethiopia, where computers are not accessible, the other advantage of the Hargreaves approach is that $ET_0$ computation can be done manually using ordinary simple calculating machine.

Local extension agents can benefit from the simple procedures in developing irrigation calendars for other irrigated crops. Finally, this study gives important lesson for local and regional decision makers, on their endeavour to increase the productivity of small scale irrigated agriculture.

This paper is organized as follows: Section 2 describes the study area, practical irrigation schedule development method, alternative irrigation schedules and data collection and analysis methods. Section 3 presents the results. In this section results of the alternative irrigation schedules which included depth of the applied water, yield and yield components, soil salinity and local opinions are presented. Section 4 discusses the results. Section 5 draws conclusions on the main findings of the study and presents policy implications.

## 2. Methodology

### 2.1. Study area description

On-farm experiments were conducted in Hintalo-Wojerat *Woreda*[1], Tigray region, Ethiopia, in 2015 and 2015/16 irrigation seasons, at the Gumselassa SSI scheme located between $13^0$13'to $13^0$15' N and $39^0$30' to $39^0$33' E (Fig.1). More than 60 % of the study area is covered with black clayey soil (Mintesinot et al., 1999). Some physical properties of the soil in the study area are shown in Table 1. The rainfall in the study area is unimodal, and highly erratic in space and time. The annual average rainfall is 500 mm and agro-ecologically, the area is classified as typical semi-arid (Yohannes et al., 2017).

The water source for Gumselassa irrigation scheme is an earthen micro-dam designed to irrigate 110 ha. Review of secondary (past studies) sources and discussions with the local office of Agriculture and Rural Development indicated poor on-farm water management practices as among the major causes for overall poor performance of the irrigation scheme, that resulted in low crop yields and development of soil salinization.

[1] District or an administrative hierarchy below Zonal administration

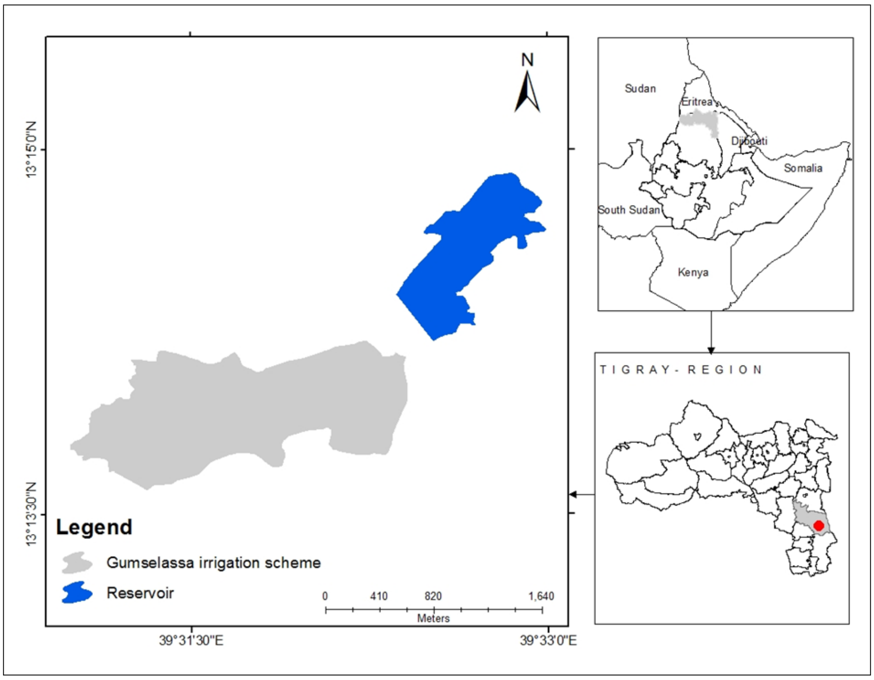


**Figure 1. Location of Gumselassa irrigation scheme (adopted from Yohannes et al., 2017).**

## 2.2. Farmers' and extension agents' participation

### 2.2.1. Participation during pre-implementation

In the first-step, discussions with local extension agents, local leaders, irrigation committee (farmers' representatives) and elder farmers were done individually, regarding irrigation water management related problems, particularly on irrigation scheduling. Then, in the second-step, a meeting was arranged where 25 farmers including the irrigation committee and the *Abomays* (water distribution leaders) and 3 local extension agents were present. Intensive discussion was made on the problem and challenges of irrigation scheduling in the study area.

In the second-step, further discussion was carried out on different techniques of irrigation scheduling. Then we proposed our initiatives on the development of simple and practical irrigation technique, on-farm test and comparison against their scheduling practices and sophisticated scheduling technique (using CropWat). Then intensive discussions were done on the participants' concern, suggestion and comment, regarding the alternative scheduling techniques.

To suit local conditions and to facilitate further adoption, adjustments were done to our first proposed irrigation calendars, based on the vital inputs of the participants. The opinions and suggestions forwarded by the majority of the farmers were based on their local practices and experience, which focused on adjustments for easier understanding, follow up and comparisons of the new scheduling techniques. Beyond on-farm scheduling, they also shared the need of creating convenience for water allocators/distributors at scheme level. Moreover, the crop characteristics and the selection of the experiment plot (which could represent the majority of plots) in the irrigation scheme were determined based on their suggestion. To avoid repetition and for the purpose of clarity, the local inputs are described in relevant steps of the study.

#### 2.2.2. Participation during the experimental period

During the experiment period, more efforts were done to involve farmers from the inception till the end since they are the ultimate beneficiaries. They were participating in installation of Parshall flumes, diversion and distribution of water, cultivation, weeding, harvesting activities and guarding of the experimental plot. Moreover, informal field visits and discussions were common among the local farmers during several irrigation events.The premise was through participation and frequent field observation by which farmers' would acquire practical knowledge on the performance and constraints of the alternative irrigation scheduling approaches. Besides facilitating and improving information feedback (between farmers and researchers), the farmers would be in a position to judge the different irrigation scheduling techniques from their own perspectives.

### 2.3. Development of irrigation schedule

#### 2.3.1. Practical irrigation schedule

The development of the practical irrigation schedule was based on procedures of the "*Simple Calculation Method*" in FAO training manual no. 4 (Brouwer, et. al, 1989) in combination with the Hargreaves equation (Hargreaves & Samani, 1985) and local farmers' and extension agents' inputs. The FAO approach requires limited data and the procedures to be followed are easy. To suite the local conditions and to facilitate adoption, the local farmers' and extension agents' inputs were also used in the development process. The Hargreaves equation was used for estimation of the potential evapotranspiration ($ET_0$). Then a predefined irrigation calendar was prepared following the steps indicated below.

**Step I. Estimation of Reference Evapotranspiration ($ET_0$)**

The Hargreaves equation (Hargreaves and Samani 1985), shown below was used to estimate $ET_0$.

$$\boldsymbol{ET_0 = 0.0023 \times RA \times (T^0C + 17.8) \times TD^{0.5}} \qquad \textbf{(1)}$$

Where:

$ET_0$ is reference evapotranspiration, in mm/day,
RA is extraterrestrial radiation in equivalent mm of water evaporation
T° C is mean monthly temperature $[(T_{mx} + T_{mi})/2]$, in degree Celsius
TD is mean maximum minus mean minimum temperatures in degree Celsius

The monthly mean maximum and mean minimum temperatures were computed (Table 2) from a 35 years temperature data of the nearest (about 43 km far) meteorological station. RA values were used from Doorenbos and Pruitt (1977).

**Step II. Estimation of crop water need ($ET_C$)**

Approximate durations of growth stages 20, 40, 40 and 35 days (Table 3) for the initial, development, mid and late seasons stages, respectively were used for maize from the local farmers and extension agents suggestion. Since there is no location specific crop factor ($K_C$) in the country, the growth stages' based $K_C$ values for maize were adopted from Brouwer and Heibloem (1986). As ETc had to be determined on a monthly basis, for months that do not correspond with the growth stages, the average weighted Kc values were computed to change the growth stages' based Kc to monthly based Kc (Table 3) as indicated in Brouwer and Heibloem (1986). For ease of computation, 30 numbers of days were considered for all months for the computations of the average monthly $K_C$. Then, the monthly ETc (mm/day) was computed using Eq. (2).

$$\boldsymbol{ET_C = ET_0 \times K_C} \qquad \textbf{(2)}$$

Where: $ET_C$= crop evapotranspiration or crop water need (mm/day)

Then the monthly crop water need ETc (mm/month) was obtained, by multiplying the monthly ETc (mm/day) by the respective number of days in each month, as shown in Table 3.

**Step III. Estimation of net and gross irrigation application depths**

The net irrigation depth ($d_{net}$) was adapted from Brouwer et al. (1989), that the net irrigation depth is estimated using only soil type (texture) and crop root depth as inputs. The maize crop (deep rooted) under clayey soil (in the case of the study area) requires $d_{net}$ of 70 mm. Considering short (10m), well graded and closed furrows (no runoff) and controlled discharge, 75% field application efficiency was considered. Then, using Eq. (3) the gross applied depth ($d_{gross}$) of 93.3 mm was computed and rounded to the nearest 5 mm and obtained 95 mm.

$$\boldsymbol{d_{gross} = \frac{d_{net}}{ae} \times 100} \qquad \textbf{(3)}$$

Where: $d_{net}$ and $d_{goss}$, in mm
ea= field application efficiency, in percent

**Step IV. Computation of irrigation water need (IN) over the total growing season.**

The irrigation water need *IN* **(**in mm**)** is calculated as:

$$\boldsymbol{IN = ET_c - P_e} \qquad \textbf{(4)}$$

Where

Pe- effective rainfall, in mm month$^{-1}$ (always equal to or larger than zero) was calculated using the FAO formula shown below:
$P_e = 0.6P - 10$, for P <= 70 mm month$^{-1}$
$P_e = 0.8P - 24$, for P > 70 mm month$^{-1}$
P- Total rainfall, in mm month$^{-1}$

The monthly average rainfall was taken from 39 years (1975-2014) data in Adigudom town rainfall station located about 3 km from the Gumselassa irrigation scheme.

**Step V. Computation of number of irrigation applications and irrigation interval**

The number of irrigation applications ($I_{na}$) was computed as:

$$\boldsymbol{I_{na}} = \frac{\boldsymbol{IN}}{\boldsymbol{d_{net}}} \qquad \textbf{(5)}$$

Where: IN irrigation water need, in mm

Then, the irrigation interval ($I_{int}$) was calculated as:

$$\boldsymbol{I_{int}} = \frac{\boldsymbol{LGS}}{\boldsymbol{I_{na}}} \qquad \textbf{(6)}$$

Where: $I_{int}$, in days
LGS- length of growing season in days

**Step VI. Computation of monthly net irrigation depth ($dm_{net}$)**

The monthly net irrigation depths ($dm_{net}$) in the growing season of maize were calculated using Eq. (7).

$$\boldsymbol{dm_{net}} = \frac{\boldsymbol{ND}}{\boldsymbol{I_{int}}} \times \boldsymbol{d_{net}} \qquad \textbf{(7)}$$

Where: $dm_{net}$, in mm
ND- number of days per month

**Step VII. Checking and adjusting for deficit in the months of peak season**

The monthly calculated $dm_{net}$ were deducted from the estimated monthly IN as shown in Table 6. Positive and negative values of the differences indicate excess and deficit of water, respectively. To avoid crop water stress especially in the months of peak irrigation water need, it is important to refine the scheduling method. Based on the recalculated irrigation interval for the months of peak irrigation water need (Table 7), the $dm_{net}$ values for the entire irrigation season were refined (Table 6) following the procedure indicated by Brouwer et al. (1989) through reiterations to avoid deficits especially in the peak months.

Based on the planting dates and determined irrigation interval, a predefined irrigation calendar was prepared. Considering the shallow crop root depth (early stage) and the farmers' and *Woreda* extension agents' suggestions and local practices the net irrigation depths ($d_{net}$) for the first three irrigation events were reduced to 50 mm, to avoid excess water loss.

**Step VIII. Calendar validation**

The calendar was tested and validated on-farm against CropWat simulated (Sophisticated) and farmers (Traditional) scheduling techniques for 2015 and 2015/16 irrigation seasons as shown in Table 9 and Table 10. In the second irrigation season in 2015/16, due to insufficient rainfall the harvested water in the reservoir was very low. The size of irrigated area in the irrigation scheme is usually decided based on the amount of harvested water. Besides the low amount of harvested water, considering the amount of water that can be saved which otherwise would have been lost by seepage and evaporation from the reservoir, the irrigation committee shifted the irrigation calendar by more than a month earlier from January (2016) to the end of November (2015), so that more farmers could be accommodated. Thus, the practical and sophisticated irrigation calendars for the second season were updated accordingly.

### 2.3.2. Sophisticated (CropWat simulated) irrigation scheduling

The CropWat 8 computer software developed by FAO (Swennenhuis, 2009) was used for determination of the crop and irrigation water requirement and irrigation scheduling. This program helps to calculate the potential evapotranspiration ($ET_0$) using various climatic data (temperature, humidity, wind speed and sunshine hours), based on Penman-Monteith method. Long term climatic data (Table 2) from the nearby (about 43 km far) station were used. The crop factor and length of growing season used were the same as in the practical approach.

Using the CropWat model, several options such as variable irrigation interval and amount (irrigating at critical or fixed depletion), fixed interval per growing stage and variable depth were consulted with the farmers and extension agents. However, for ease of understanding and comparisons of the new scheduling techniques (practical and sophisticated) by the majority farmers, fixed irrigation interval for these two scheduling techniques were suggested by the group. The soil input data for CropWat considered were:

- Texture- clay,
- Total available soil moisture- 160 mm (Table 2),
- Maximum rain infiltration rate- 30 mm/day (adapted from CropWat for clay soil),
- Initial moisture depletion- 80%: The amounts of applied water for all treatments were accounted starting on the first irrigation event (day one) which was done immediately after sowing. 80% depletion was considered based on feel and appearance approach,
- Maximum rooting depth- 2 m.

Then, based on "the fixed irrigation interval" and "refilling to field capacity" option the irrigation schedule was calculated.

### 2.3.3. Traditional irrigation schedule

The traditional method of irrigation schedule represented the farmer’s existing scheduling practice and was considered as a control. The farmer was allowed to irrigate all the replications of the traditional treatment based on his experience without any interference of the researcher for the entire growth period. Yet, the amount of applied water during each irrigation event was simply recorded using a Parshall flume.

## 2.4. Experimental design

Nationally developed maize variety “Melkassa-II” (*Zea mays* L.), which is popular in the study area, was used as indicator crop in this study. Three treatments (irrigation scheduling methods) namely “Traditional”, “Practical” and “Sophisticated (CropWat simulated)” were replicated three times in randomized block design on-farm in 2015 and 2015/16 irrigation seasons.

## 2.5. Data collection and analysis

### 2.5.1. Soil samples

From the experimental field, pre-treatment composite as well as undisturbed soil samples at 20 cm intervals down the profile up to 1 meter were collected from three random locations in 2015. The soil texture, pH and organic matter were analysed from the composite soil samples in a laboratory following the standard procedures. Soil bulk density (BD), field capacity (FC) and permanent wilting point (PWP) were analysed from the undisturbed soil samples. Further at planting and at harvest in both irrigation seasons, soil samples were collected at 20 cm interval up to 1 meter depth from all replications of each treatment and soil salinity of saturated extracts (ECe) were measured at laboratory following a validated procedure.

### 2.5.2. Irrigation water

Pre-plant irrigation is common practice in the study area to soften the soil for ploughing. Since it was done for the entire farm before the experimental lay out, the amount was not included in our study. The irrigation amounts applied to each plot were monitored starting the sowing date. For the traditional scheduling treatment the farmer’s irrigation intervals were recorded and the amount of applied water was monitored using Parshall flume in each irrigation event. For the practical and sophisticated treatments, simple data sheets (displaying instant calculations of the depths of applied water) were prepared and the determined amounts of water were applied using Parshall flumes, at each irrigation events. The salinity (electrical conductivities; ECw) and pH of the irrigation water were monitored using portable and calibrated EC and pH meters.

### 2.5.3. Yield and yield components

Grain yield and yield components (total fresh biomass, plant height, number of ears per plant, ear length, number of kernels per ear and 1000 kernels weight) were measured at harvest (physiological maturity).

### 2.5.4. Water productivity (WP)

The ratio of crop yield to the amount of water applied was calculated using Eq. (8).

$$\boldsymbol{WP = \frac{Y}{I}} \qquad \textbf{(8)}$$

Where: $WP$, in kg $m^{-3}$
Y – Grain yield of maize (kg $ha^{-1}$)
I – Total irrigation water applied ($m^3$ $ha^{-1}$)

### 2.5.5. Farmers' and local experts' opinion

Farmers’ day was arranged at harvest of the maize crop in both irrigation seasons. In the farmers’ day four groups were formed. Three groups were “farmers’ group” consisting of six farmers each and the fourth group was “expert group” formed from four staff members of the

*Woreda* (local) office of Agriculture and Rural Development, which constituted experts from extension, irrigation, crop and natural resources. Then, each group was allowed to rank the crop stand of the three treatments. Moreover, the farmers' and the local experts' opinions and suggestions regarding the conveniences and appropriateness of the different scheduling methods were collected through open discussions.

#### 2.5.6. Statistical analysis

Mean comparison on the effect of irrigation treatments on yield and yield components as well as the soil salinity were done using SPSS-20 statistical software, separately for each irrigation season.

## 3. Results

### 3.1. Potential evapotranspiration ($ET_0$) and crop evapotranspiration ($ET_c$)

As depicted in Table 2, the estimated monthly $ET_0$ for the irrigation season of the study area were higher for Penman-Monteith as compared to the Hargeaves method, except in those three months from July to September, although the climatic data used for both methods were collected from the same station at about 43 km distance.

In both irrigation seasons, lower crop water needs (ETc) were found in the Practical method as compared to the Sophisticated method. The determined ETc using the practical scheduling method were 508 mm and 456 mm in the 1st (2015) and 2nd (2015/16) irrigation seasons, respectively (Table 3). In the sophisticated method, these values were 756.8 mm and 708.9 mm for the former and latter irrigation seasons, respectively (Table 8).

**Table 1. Soil physico-chemical properties of the soil at the experimental plot**

| Soil depth (cm) | Particle size distribution (%) | | | Texture (USDA) | pH | Organic matter (%) | Bulk density ($g/cm^3$) | FC Wt. (%) | PWP Wt. (%) | TAW (mm) |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sand | Silt | Clay | | | | | | | |
| 0-20 | 17 | 32 | 51 | Clay | 8.31 | 2.46 | 1.25 | 35.1 | 20.5 | 36.5 |
| 20-40 | 15 | 31 | 54 | Clay | 8.44 | 2.63 | 1.32 | 35.4 | 22.8 | 33.3 |
| 40-60 | 15 | 29 | 56 | Clay | 8.41 | 2.2 | 1.27 | 37.2 | 24.2 | 33 |
| 60-80 | 14 | 28 | 58 | Clay | 8.37 | 2.14 | 1.33 | 35.5 | 24 | 30.6 |
| 80-100 | 13 | 29 | 58 | Clay | 8.29 | 2.21 | 1.34 | 35.6 | 25.5 | 27.1 |

FC- field capacity, PWP- permanent wilting point and TAW- total available water

**Table 2. Long term climatic data and estimated potential evapotranspiration**

| Month | Rainfall of Adigudom town (mm) | Long term climatic data of Quiha station | | | | | RA (mm/day) | Hargreaves $ET_0$ (mm/day) | CropWat $ET_0$ (mm/day) |
|---|---|---|---|---|---|---|---|---|---|
| | | Min Temp (°C) | Max Temp (°C) | Humidity (%) | Wind (m/s) | Sun (hours) | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 0.7 | 9 | 23.3 | 42 | 3.6 | 9.6 | 12.6 | 3.71 | 5.04 |
| Feb | 2.5 | 9.9 | 24.6 | 39 | 4.3 | 9.8 | 13.7 | 4.24 | 6 |
| Mar | 8.6 | 11.6 | 25.4 | 39 | 4.2 | 9.1 | 15 | 4.64 | 6.29 |
| Apr | 19.6 | 13.3 | 26 | 39 | 4 | 9.3 | 15.7 | 4.81 | 6.53 |
| May | 18.6 | 13.5 | 27.1 | 35 | 3 | 9.8 | 15.8 | 5.09 | 6.33 |
| Jun | 36.7 | 13.3 | 27.5 | 36 | 2.1 | 7.4 | 15.6 | 5.16 | 5.39 |
| Jul | 155.3 | 12.6 | 23.5 | 66 | 2 | 5.2 | 15.6 | 4.25 | 3.84 |
| Aug | 208.4 | 12.5 | 22.6 | 71 | 1.7 | 5.1 | 15.7 | 4.03 | 3.52 |
| Sep | 45.5 | 11.4 | 24.7 | 49 | 1.7 | 7.5 | 15.1 | 4.55 | 4.45 |
| Oct | 3.5 | 10.7 | 23.8 | 41 | 2.9 | 9.5 | 14.2 | 4.14 | 5.25 |
| Nov | 1.9 | 9.9 | 22.8 | 42 | 3.5 | 9.8 | 13 | 3.67 | 5.09 |
| Dec | 0.8 | 8.8 | 22.6 | 42 | 3.7 | 9.9 | 12.2 | 3.5 | 4.94 |
| Average | | 11.4 | 24.5 | 45 | 3 | 8.5 | 14.5 | 4.32 | 5.22 |

### 3.2. Irrigation amount and interval

Following the practical method the first calculated number of irrigation events (7) and the irrigation intervals (19 days) were the same for both irrigation seasons (Table 5). However, for the 1st season experiment, the calculated $dm_{net}$ (using 19 days interval) showed 33 mm and 32 mm water deficit in the months of March and April, respectively (Table 6). Similarly, for the 2nd season a deficit of about 36 mm and 2 mm were shown in the months of February and March, respectively. To avoid crop losses, refinement were done for the entire growing season based on the calculated deficit months $I_{int}$ (15 days) as shown in Table 7. For clarity the refined (recalculated) $dm_{net}$ is placed in Table 6 below 19 days interval column.

Despite the difference in the planting dates of the irrigation seasons, the adjusted irrigation interval appeared to be the same for both irrigation seasons. In our calculation as shown in Table 6, both deficit months (Feb & Mar) were considered. Still, for both irrigation seasons, a small amount of monthly deficits are shown. These deficits would be smaller when partitioned in the two irrigation events; moreover, considering the higher application depth (95 mm) than the determined (93.3 mm), due to rounding, the deficits were ignored.

For the sophisticated method discussed in section 2, the irrigation interval considered (15 days) and the determined irrigation events (9 times) were the same as for the practical method.

The farmer's (traditional) irrigation interval ranged from 13 to 17 days and from 14 to 21 days for the 1st and 2nd season experiments, respectively (Table 10). The minimum intervals were recorded in the 2nd and the maximum in the 3rd, 4th and around the last irrigation events for both irrigation seasons. The same numbers of irrigation events (8) were recorded for the Traditional method for both irrigation seasons, which were lower than the other approaches (9).

**Table 3. Estimated potential and crop evapotranspiration in 2015 and 2015/16 irrigation seasons using the practical approach for the maize crop**

| Year | Growth stages | Days | Dates | Mon | No. of days | Kc per Gr. St. | Kc per mon | ETo (mm/day) | ET crop (mm/day) | ET crop (mm/mon) |
|---|---|---|---|---|---|---|---|---|---|---|
| **2015** | Initial | 20 | Jan 10- 30 | Jan | 20 | 0.4 | 0.40 | 3.71 | 1.49 | 30 |
| | Crop dev. | 40 | Feb 1-Mar 10 | Feb | 30 | 0.8 | 0.80 | 4.25 | 3.40 | 102 |
| | | | | Mar | 10 | | 1.03 | 4.64 | 4.78 | 143 |
| | Mid-season | 40 | Mar 11-Apr 20 | Mar | 20 | 1.15 | | | | |
| | | | | Apr | 20 | | 1.00 | 4.81 | 4.81 | 144 |
| | Late season | 35 | Apr 21-May 25 | Apr | 10 | 0.7 | | | | |
| | | | | May | 25 | | 0.70 | 5.09 | 3.56 | 89 |
| | **Total** | **135** | | | **135** | | | | | **508** |
| **2015/16** | Initial | 20 | Nov 27-Dec 17 | Nov | 3 | 0.4 | 0.40 | 3.67 | 1.47 | 4 |
| | | | | Dec | 17 | | 0.57 | 3.50 | 2.01 | 60 |
| | Crop dev. | 40 | Dec 18-Jan 27 | Dec | 13 | 0.8 | | | | |
| | | | | Jan | 27 | | 0.84 | 3.71 | 3.10 | 93 |
| | Mid-season | 40 | Jan 28-Mar 7 | Jan | 3 | 1.15 | | | | |
| | | | | Feb | 30 | | 1.15 | 4.24 | 4.88 | 146 |
| | | | | Mar | 7 | | 0.81 | 4.64 | 3.74 | 112 |
| | Late season | 35 | Mar 8-Apr 12 | Mar | 23 | 0.7 | | | | |
| | | | | Apr | 12 | | 0.70 | 4.81 | 3.37 | 40 |
| | **Total** | **135** | | | **135** | | | | | **456** |

LGS-length of growing seasons, in days

The total water applied by the Practical approach was 756 mm, which was the same for both irrigation seasons. However, the total applied water in the 1st season experiment were 898.4 mm and 983.8 mm for the Traditional and Sophisticated methods, respectively and during the 2nd season 873.1 mm and 960.9 mm were applied by the former and later approaches, respectively. Higher depths of water were applied by the Sophisticated followed by the Traditional and then by the Practical methods in both irrigation seasons.

The amount of water applied by the Traditional approach depends upon the farmers experience. In the first two irrigations the applied water were lower as compared to the rest of the irrigation events and showed almost an increasing trend except the last in both irrigation seasons.

In the traditional scheduling, maximum depth (>120 mm) per applications were recorded in the 5th, 6th and 7th irrigation events. For the Sophisticated approach, higher application depths (>130 mm) were recorded during the 5th to 8th irrigation events. In both treatments, starting the 3rd (for traditional) and the 4th (for sophisticated) up to the last irrigation events, there were frequent ponding of water on the plots for a considerable time (3-8 hrs.) after irrigation. During these irrigation events, wet soil surface for a couple of days were also observed especially in the sophisticated treatment plots.

**Table 4. Irrigation water need (IN) of maize crop for 2015 and 2015/16 irrigation seasons.**

| **Irrigation season** | **2015** | | | | | | **2015/16** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | Jan | Feb | Mar | Apr | May | **Total** | Nov | Dec | Jan | Feb | Mar | Apr | **Total** |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rainfall (mm/month) | 0.7 | 2.5 | 8.6 | 19.6 | 18.6 | **50.0** | 1.9 | 0.8 | 0.7 | 2.5 | 8.6 | 19.6 | **34.1** |
| Effective rainfall (mm/month) | 0.0 | 0.0 | 0.0 | 1.8 | 1.2 | **2.9** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 1.8 | **1.8** |
| ET crop (mm/month) | 29.7 | 101.8 | 143.4 | 144.3 | 89.0 | **508.2** | 4.4 | 60.2 | 93.0 | 146.3 | 112.1 | 40.4 | **456.3** |
| IN (mm/month) | 29.7 | 101.8 | 143.4 | 142.5 | 87.9 | **505.3** | 4.4 | 60.2 | 93.0 | 146.3 | 112.1 | 38.6 | **454.6** |

**Table 5. Number of irrigation events and irrigation interval ($I_{int}$)**

| **Irrigation season** | **IN (mm/grow. season)** | **No. of irri events ($I_{na}$)** | **$I_{int}$ (days)** |
|---|---|---|---|
| 2015 | 505.3 | 7.2 (7)* | 19.3 (19)* |
| 2015/16 | 454.6 | 6.5 (7)* | 19.3 (19)* |

*Rounded to the nearest whole number

**Table 6. Monthly irrigation requirements, net application depths and deficits (under different irrigation intervals) in 2015 and 2015/16 irrigation seasons**

| **Irrigation interval** | **Irrigation season** | **2015** | | | | | | **2015/16** | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Month** | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Total** | **Nov** | **Dec** | **Jan** | **Feb** | **Mar** | **Apr** | **Total** |
| **19 days** | IN | 30 | 102 | 143 | 143 | 88 | **505** | 4 | 60 | 93 | 146 | 112 | 39 | **455** |
| | $dm_{net}$ | 74 | 111 | 111 | 111 | 92 | **497** | 11 | 111 | 111 | 111 | 111 | 44 | **497** |
| | $dm_{net}$-IN | 44 | 9 | -33 | -32 | 4 | **-8** | 7 | 50 | 18 | -35.8 | -1.5 | 6 | **43** |
| **15 day** (based on Table 7) | IN | 30 | 102 | 143 | 143 | 88 | **505** | 4 | 60 | 93 | 146 | 112 | 39 | **455** |
| | $dm_{net}$ | **67*** | **100*** | 140 | 140 | 117 | **563** | **10*** | **100*** | 140 | 140 | 140 | 56 | **586** |
| | $dm_{net}$-IN | 37 | -2 | -3 | -3 | 29 | **58** | 6 | 40 | 47 | -6 | 28 | 17 | **131** |

*$d_{net}$ for 1st two months reduced from 70 mm to 50 mm

**Table 7. Recalculation of irrigation interval and No. of irrigations based on months of crop water deficits**

| Irrigation season | Deficit months | IN (mm/month) | Sum (mm) (a) | NI (b=a/dnet) (b) | Iint (days) (c=ND/b) (c) | Total $I_{na}$ (d= LGS/c) (d) |
|---|---|---|---|---|---|---|
| 2015 | Mar | 143 | 286 | 4.1 (4)* | 15 | 9 |
| | Apr | 143 | | | | |
| 2015/16 | Feb | 146 | 258 | 3.7 (4)* | 15 | 9 |
| | Mar | 112 | | | | |

NID= no. of irrigation events in the deficit months, NDD= total number of days in the deficit months, *Rounded to the nearest whole number

**Table 8. Crop water requirement ($ET_C$) and irrigation requirements of maize in 2015 and 2015/16 irrigation seasons using Penman-Monteith (CropWat simulated)**

| **Irrigation season** | |
|---|---|
| **2015 (planting date: 10 Jan 2015)** | **2015/16 (planting date: 28 Nov 2015)** |

| Month | Dec | Stage | Kc | ETc (mm/dec) | Eff rain (mm/dec) | Irr. Req. (mm/dec) | Month | Dec | Stage | Kc | ETc (mm/dec) | Eff rain (mm/dec) | Irr. Req. (mm/dec) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Jan | 1 | Init | 0.4 | 2 | 0 | 2 | Nov | 3 | Init | 0.4 | 6 | 0 | 6 |
| Jan | 2 | Init | 0.4 | 20.1 | 0 | 20.1 | Dec | 1 | Init | 0.4 | 20 | 0 | 20 |
| Jan | 3 | Deve | 0.41 | 23.9 | 0 | 23.9 | Dec | 2 | Deve | 0.41 | 20.4 | 0 | 20.4 |
| Feb | 1 | Deve | 0.56 | 31.5 | 0 | 31.5 | Dec | 3 | Deve | 0.59 | 32.3 | 0 | 32.3 |
| Feb | 2 | Deve | 0.76 | 45.7 | 0 | 45.7 | Jan | 1 | Deve | 0.81 | 40.6 | 0 | 40.6 |
| Feb | 3 | Deve | 0.95 | 46.3 | 0 | 46.3 | Jan | 2 | Deve | 1.02 | 51.5 | 0 | 51.5 |
| Mar | 1 | Deve | 1.14 | 70.3 | 0 | 70.3 | Jan | 3 | Mid | 1.22 | 71.7 | 0 | 71.7 |
| Mar | 2 | Mid | 1.23 | 77.3 | 0 | 77.3 | Feb | 1 | Mid | 1.25 | 70.7 | 0 | 70.7 |
| Mar | 3 | Mid | 1.23 | 86.1 | 0.1 | 86 | Feb | 2 | Mid | 1.25 | 74.7 | 0 | 74.7 |
| Apr | 1 | Mid | 1.23 | 79.3 | 0.4 | 78.8 | Feb | 3 | Mid | 1.25 | 60.7 | 0 | 60.7 |
| Apr | 2 | Late | 1.23 | 80.1 | 0.6 | 79.5 | Mar | 1 | Late | 1.23 | 76.5 | 0 | 76.5 |
| Apr | 3 | Late | 1.11 | 71.9 | 0.6 | 71.3 | Mar | 2 | Late | 1.1 | 69 | 0 | 69 |
| May | 1 | Late | 0.93 | 59.6 | 0.2 | 59.5 | Mar | 3 | Late | 0.91 | 63.9 | 0.1 | 63.8 |
| May | 2 | Late | 0.75 | 47.7 | 0 | 47.7 | Apr | 1 | Late | 0.73 | 47 | 0.4 | 46.5 |
| May | 3 | Late | 0.63 | 15.1 | 0.4 | 14.5 | Apr | 2 | Late | 0.63 | 4.1 | 0.1 | 4.1 |
| Total | | | | 756.8 | 2.3 | 754.4 | Total | | | | 708.9 | 0.6 | 708.3 |

**Table 9. Maize irrigation schedule calendar, net and gross irrigation depths (mm) by the Practical and Sophisticated methods in both irrigation seasons**

| **Irrigation event** | **Irrigation season** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **2015** | | | | | | **2015/16** | | | | | |
| | Date | Days after planting | Practical method | | Sophisticated method | | Date | Days after planting | Practical method | | Sophisticated method | |
| | | | dnet | dgross | dnet | dgross | | | dnet | dgross | dnet | dgross |
| 1st | 10/Jan | 1 | 50 | 65 | 9.3 | 12.4 | 28/Nov | 1 | 50 | 65 | 9.3 | 12.5 |
| 2nd | 24/Jan | 15 | 50 | 65 | 42.2 | 56.3 | 12/Dec | 15 | 50 | 65 | 42.1 | 56.2 |
| 3rd | 07/Feb* | 29 | 50 | 65 | 65.2 | 86.9 | 27/Dec | 30 | 50 | 65 | 63.3 | 84.4 |
| 4th | 23/Feb | 45 | 70 | 95 | 92.3 | 123 | 11/Jan | 45 | 70 | 95 | 85.4 | 113.8 |
| 5th | 10/Mar | 60 | 70 | 95 | 118 | 157.2 | 26/Jan | 60 | 70 | 95 | 110 | 147.2 |
| 6th | 25/Mar | 75 | 70 | 95 | 109 | 145.6 | 10/Feb | 75 | 70 | 95 | 102 | 135.9 |
| 7th | 09/Apr | 90 | 70 | 95 | 108 | 144.5 | 25/Feb | 90 | 70 | 95 | 109 | 145 |
| 8th | 24/Apr | 105 | 70 | 95 | 106 | 141 | 11/Mar* | 104 | 70 | 95 | 109 | 145.2 |
| 9th | 09/May | 120 | 70 | 95 | 87.7 | 116.9 | 27/Mar | 120 | 70 | 95 | 90.6 | 120.7 |
| **Total** | | | **570** | **765** | **738** | **983.8** | | | **570** | **765** | **721** | **960.9** |

*Irrigated one day earlier because water gates are not operational on Sunday

**Table 10. Irrigation interval and applied irrigation depth by Traditional irrigation schedule**

| **Irrigation** | **Irrigation season** |
|---|---|

| event | 2015 | | | | | | 2015/16 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Date | Irrigation interval | $d_{gross}$ (mm) | | | | Date | Irrigation interval | $d_{gross}$ (mm) | | | |
| | | | R-I* | R-II | R-III | Average | | | R-I | R-II | R-III | Average |
| 1st | 10/Jan | 1 | 92.6 | 98.7 | 87.7 | 93 | 28/Nov | 1 | 97.6 | 92.2 | 87.9 | 92.6 |
| 2nd | 23/Jan | 13 | 74.1 | 79.3 | 85.3 | 79.6 | 11/Dec | 14 | 77.3 | 86.1 | 77.6 | 80.3 |
| 3rd | 11/Feb | 19 | 122.4 | 120.7 | 129.6 | 124.2 | 01/Jan | 21 | 110.5 | 114.1 | 124.9 | 116.5 |
| 4th | 28/Feb | 17 | 109.5 | 118.5 | 113.7 | 113.9 | 19/Jan | 17 | 104.2 | 109.5 | 116.4 | 110 |
| 5th | 14/Mar | 14 | 127.8 | 130.6 | 125.5 | 128 | 02/Feb | 14 | 120.3 | 124.2 | 125.4 | 123.3 |
| 6th | 30/Mar | 16 | 126.9 | 117.8 | 132.8 | 125.8 | 17/Feb | 15 | 128.6 | 125.6 | 133.6 | 129.3 |
| 7th | 14/Apr | 15 | 125.2 | 125.6 | 128.5 | 126.4 | 05/Mar | 17 | 124.7 | 117.6 | 122.2 | 121.5 |
| 8th | 01/May | 17 | 105.4 | 107.2 | 109.7 | 107.4 | 23/Mar | 18 | 91.1 | 99.6 | 108.1 | 99.6 |
| **Total** | | | **883.9** | **898.4** | **912.8** | **898.4** | | | **854.3** | **868.9** | **896.1** | **873.1** |

*R-replication

## 3.3. Soil salinization

The salinity (electrical conductivity) of the irrigation water varied across the growing seasons from 0.45 dS $m^{-1}$ (pH-7.45) at the beginning of irrigation seasons to 0.68 dS $m^{-1}$ (pH-7.6) at the end.

The distribution of salts (ECe) at 20 cm interval down the soil profile up to 100 cm, at planting and at harvest for both irrigation seasons is depicted in Table 11.

In the 1st season (2015) experiment, the average root zone (100 cm) salinity (ECe) at planting were 1.69, 1.94 and 1.83 dS $m^{-1}$for the sophisticated, traditional and practical treatments, respectively. Statistically, all were similar. In the same season, at harvest, higher surface (0-20 cm) salinity was found in the $I_2$ (2.43 dS $m^{-1}$) followed by $I_1$ (2.34 dS $m^{-1}$) and lower value was found in the $I_3$ (2.03 dS $m^{-1}$) treatment. In contrast, the ECe in the preceding profile (20-40 cm) was higher in the $I_3$ (1.88 dS $m^{-1}$) as compared to the other treatments. Lower soil salinity below 50 cm down the soil profile, was found in the $I_1$ compared to the other treatments. In all treatments as shown in Table 11, starting the second layer (20-40 cm) the ECe showed an increasing trend downward of the soil profile, except the last profile in the $I_2$. In 2015, although variations on the profile salt distributions were observed among the different treatments, statistically only the surface (0-20 cm) ECe was significantly ($P<0.05$) higher in the $I_2$ as compared to the $I_3$.

In the same season the average ECe at harvest were 2.41, 2.57 and 2.46 dS $m^{-1}$ for the $I_1$, $I_2$ and $I_3$, respectively. Although a significant increment in soil salinities were observed at harvest as compared to planting in all treatment, the average root zone salinities at harvest among all the treatments were not significantly different.

In 2015/16 at harvest, the ECe of $I_1$was higher (2.22 dS $m^{-1}$) at the surface (0-20 cm) and lower at the preceding profiles as compared to the other treatments. In contrast, except in the surface (0-20 cm), higher ECe was found in all layers in the $I_3$ compared to the other treatments. The average ECe across the entire profile were 2.04 dS $m^{-1}$, 2.19 dS $m^{-1}$ and 2.3 dS $m^{-1}$ in the $I_1$, $I_2$ and $I_3$, respectively. At harvest, the soil salinity only in the 60-80 cm depth were significantly ($P<0.05$) higher in $I_3$ (2.68 dS $m^{-1}$) as compared to both $I_1$ (2.12 dS $m^{-1}$) and

$I_3$ (2.21 dS $m^{-1}$). However, the average root zone salinities between all treatments were not significantly different.

In both irrigation seasons, although the severity varied between irrigation events, after the soil dried, a white efflorescence appeared on the surfaces of all treatments. At harvest, in both irrigation seasons lowest surface ECe were found in the practical treatment and the lowest average root zone ECe was found in the Sophisticated treatment.

**Table 11. Effects of irrigation schedule on distribution of salts (dS/m) in the soil profile**

| **Irrigation season** | | **2015** | | | | | | **2015/16** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sampling time | Treatment | Sample depth (cm) | | | | | | | | | | | |
| | | 0-20 | 20-40 | 40-60 | 60-80 | 80-100 | Ave | 0-20 | 20-40 | 40-60 | 60-80 | 80-100 | Ave |
| Planting | $I_1$=Sophisticated | 1.44 | 1.62 | 1.5 | 2 | 1.89 | 1.69 | 1.32 | 1.34 | 1.62 | 2.01 | 2.09 | 1.67 |
| | $I_2$=Traditional | 1.5 | 1.56 | 2.06 | 2.36 | 2.24 | 1.94 | 1.43 | 1.41 | 1.88 | 1.98 | 2.19 | 1.78 |
| | $I_3$=Practical | 1.45 | 1.38 | 1.62 | 2.28 | 2.43 | 1.83 | 1.46 | 1.37 | 1.98 | 2.08 | 2.04 | 1.79 |
| Harvest | $I_1$=Sophisticated | 2.34ab | 1.8 | 2.63 | 2.53 | 2.77 | 2.41 | 2.22 | 1.69 | 2.01 | 2.12a | 2.14 | 2.04 |
| | $I_2$=Traditional | 2.43a | 1.61 | 2.91 | 2.99 | 2.93 | 2.57 | 1.96 | 1.9 | 2.32 | 2.21a | 2.54 | 2.19 |
| | $I_3$=Practical | 2.03b | 1.88 | 2.51 | 2.82 | 3.04 | 2.45 | 1.76 | 1.95 | 2.46 | 2.68b | 2.63 | 2.29 |

* Note: Means followed by the same letters in column are not statistically different at P<0.05.

### 3.4. Yield and yield components

The effect of different irrigation scheduling treatments showed significant results of maize biomass in both irrigation seasons (Table 12). In 2015, the $I_3$ (practical) treatment significantly increased (at $P < 0.05$) the biomass as compared to other treatments ($I_1$ and $I_2$). However, in 2015/16 the results showed non-significant differences in biomass between the $I_3$ and other treatments. Maximum and minimum biomass of 25.8 t $ha^{-1}$ (2015) and 20.4 t $ha^{-1}$ (2015/16) were recorded in $I_3$ and $I_1$ treatments, respectively. In 2015 the biomass in both the $I_1$ and $I_2$ treatments showed non-significant results, although significant differences were found in 2015/16.

As shown in Table 12, the effect of different irrigation scheduling treatments showed non-significant results in grain yield among all treatments in 2015. However in 2015/16, the $I_3$ treatment gave significantly higher grain yield than all treatments. In both irrigation seasons, the $I_2$ and $I_3$ treatments were, however, statistically not significant in grain yield. In 2015, average grain yield results were 4.78, 4.83 and 5.22 t $ha^{-1}$ in $I_1$, $I_2$ and $I_3$ treatments, respectively. The corresponding grain yield in 2015/16 was 4.5, 4.41 and 5.05 t $ha^{-1}$, respectively.

The plant height was significantly higher for $I_3$ as compared to $I_1$ in 2015. However, no significant differences on plant height were observed in 2015/16. The effect of irrigation scheduling on ear length showed no significant differences among all treatments in both irrigation seasons.The number of ears per plant and the number of kernels per ear in 2015/16 were significantly higher for $I_3$ as compared to $I_1$, though all the treatments failed to show any significant differences in 2015 in the number of ears per plant and the number of kernels per ear. In both years, the $I_3$ treatment significantly enhanced 1000-kernel weight as compared to other treatments, though no significant differences in 1000-kernels weights were found between the $I_1$ and $I_2$ treatments in both years.

**Table 12. Effect of irrigation schedule on yield and yield components and water productivity of maize**

| Irrigation season | Treatments | Biomass (t ha$^{-1}$) | Grain yield (t ha$^{-1}$) | Plant height (cm) | Number of ears per plant | Ear length (cm) | Number of kernel per ear | 1000 kernel wt. (gm) | WP (kgm$^{-3}$) |
|---|---|---|---|---|---|---|---|---|---|
| 2015 | $I_1$=Sophisticated | 22.9a | 4.78a | 170.7a | 1.04a | 15.9a | 373.3a | 285.3a | 0.49a |
| | $I_2$=Traditional | 23.0a | 4.83a | 172.6ab | 1.05a | 15.7a | 371.9a | 309.8a | 0.54a |
| | $I_3$=Practical | 25.8b | 5.22a | 174.9b | 1.18a | 16.7a | 397.2a | 359b | 0.68b |
| 2015/16 | $I_1$=Sophisticated | 20.4a | 4.5a | 169.7a | 1.07ab | 15.5a | 364a | 294.8a | 0.47a |
| | $I_2$=Traditional | 24.4b | 4.41a | 171.2a | 1.04a | 15.8a | 373.7a | 300a | 0.50b |
| | $I_3$=Practical | 24.1ab | 5.05b | 173.6a | 1.2b | 16.7a | 424.7b | 363b | 0.66c |

Note: Means followed by the same letters in column are not statistically different at $P<0.05$.

### 3.5. Water productivity (WP)

The average water productivity of the different irrigation scheduling treatments is presented in Table 12. The WP was significantly influenced by the different irrigation schedules in both irrigation seasons. Maximum WP (0.68 kg m$^{-3}$ in 2015 and 0.66 kg m$^{-3}$ in 2015/16) was found in $I_3$ in both irrigation seasons. The $I_1$ treatment resulted in lower WP (0.49 kg m$^{-3}$ in 2015 and 0.47 kg m$^{-3}$ in 2015/16) in both irrigation seasons. The $I_3$ treatment significantly increased the WP as compared to the other ($I_1$ and $I_2$) treatments, in both irrigation seasons. The WP for both $I_1$ and $I_2$ were not statistically significant in 2015, though the WP for $I_2$ in 2015/16 was significantly higher than $I_1$. The simple linear regression between WP and yield (Fig. 2) showed that an increase in WP with yield increment and water decrement.

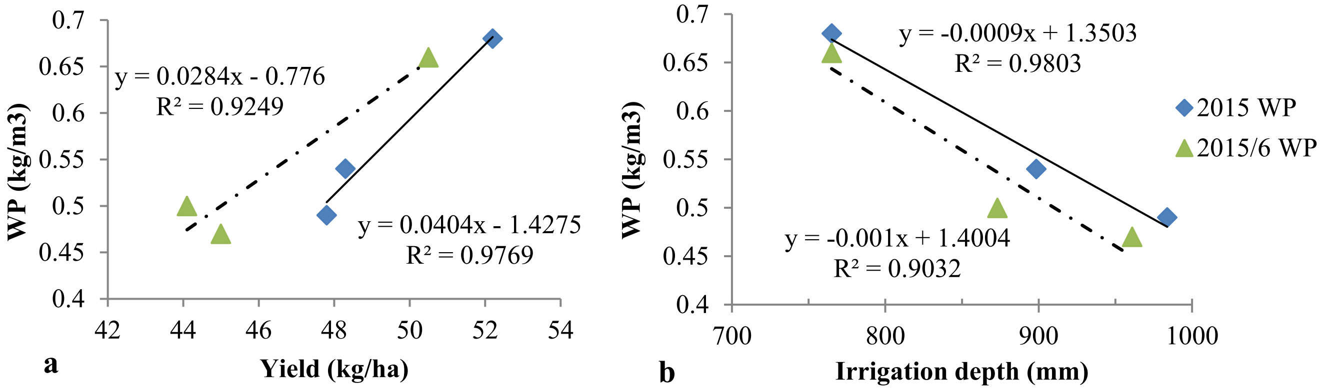


**Figure 2. Relationships of water productivity (WP) with grain yield and irrigation depth for 2015 and 2015/16 irrigation seasons**

### 3.6. Farmers' and local experts'(extension agents') opinion

#### 3.6.1. Ranking of crop stand

The farmers' and extension agents' groups mean rank (according to their own criteria) of the treatments are depicted in Table 13. Each group was invited to present their ranking results as well as major justifications.

In 2015, the $I_3$ treatment was ranked the best by all of the groups, although statistically similar as compared to $I_2$ in the farmer group II. The treatment mean rank in $I_1$ and $I_2$ were the same for farmers' group I and III. Although, the mean rank of $I_1$ was the least for the experts and the farmers group-II, compared to $I_2$, it was significant only for the latter group.

In the second season (2015/16) similarly, the $I_3$ treatment was given the best rank by all except for farmers' group-II, which they gave same rank as $I_2$ treatment. The mean rank variation between $I_1$ and $I_2$ were significant for farmers group I and group II.

In both irrigation seasons, the farmer groups' overall mean rank variation for $I_3$ were significantly different (best) as compared to both $I_1$ and $I_2$. However, the overall mean rank between $I_1$ and $I_2$ were statistically similar for both irrigation season. From the groups' presentation, the farmers major criterion of ranking of the crop stand were the expected grain yield and total biomass, which were judged from observation of the plant height, stem thickness (diameter) and number of ears. These criterions were similar for all groups except for the inclusion of visible surface salt (white salt efflorescence) by the experts' group.

**Table 13. Farmers and expert group mean rank of crop stand**

| Irrigation season | Treatment | Farmer groups | | | | Expert group |
|---|---|---|---|---|---|---|
| | | G-I | G-II | G-III | Mean | |
| 2015 | $I_1$=Sophisticated | 2.33a | 2.67a | 2.33a | 2.44a | 2.33a |
| | $I_2$=Traditional | 2.33a | 1.67b | 2.33a | 2.11a | 2a |
| | $I_3$=Practical | 1b | 1b | 1b | 1b | 1b |
| 2015/16 | $I_1$=Sophisticated | 2a | 2.33a | 2.67a | 2.33a | 2.67a |
| | $I_2$=Traditional | 2.67b | 1b | 2.33a | 2a | 2.33a |
| | $I_3$=Practical | 1c | 1b | 1b | 1b | 1b |

Note: Means followed by the same letters in column are not statistically different at $P<0.05$. The smaller the number, the best the rank

### 3.6.2. Scheduling technique opinions

All the participants appreciated the water saved by the $I_3$ (practical technique). While comparing the irrigation intervals, most of the participants were in favor of the fixed irrigation interval ($I_1$ and $I_3$). The major reasons raised were its convenience and easiness for individual farmers and scheme water distributors in such a way that they both will know ahead whose turn is next. Important concern raised by the farmers was the capacity and skill of the Water Users Association, on providing fixed interval-based irrigation scheduling at scheme level.

The second major point raised by the experts was on the technical feasibility of measuring water by individual farmer. Water is not metered on-farm in most irrigation scheme in Ethiopia. However, during the experimental seasons the farmers were surprisingly able to classify the irrigation scheduling techniques qualitatively in their own local language, based on their observation of the applied water to each treatment. "Ablek leck" means too much water for $I_1$, "Limud" means usual for $I_2$ and "Chebreck-chebreck" means little by little for $I_3$.

# 4. Discussions

## 4.1. Effect of irrigation scheduling on potential evapotranspiration ($ET_0$) and irrigation amount

The determined crop water needs (ETc) using the practical scheduling method were, about 33% and 36% lower than that of the Sophisticated method for the 1st (2015) and 2nd (2015/16) irrigation seasons, respectively. The obtained results also showed that the gross amount of applied water by the sophisticated method was higher by 28.6% (2015) and 25.6% (2015/16) than the Practical method. Similarly, the gross applied depths by the Traditional method were higher by 17.4 % and 14.1 % as compared to the practical method, for the corresponding irrigation seasons.

The big difference between the Practical and Sophisticated methods were entirely attributed to the methods used for estimating the potential evapotranspiration ($ET_0$) by Hargreaves and the Penman-Monteith equations based on various climatic factors acquired from a meteorology station located at about 43 km distance, respectively. The Penman-Monteith (PM) estimated monthly $ET_0$ were higher in all months except for the months of July to September, as compared to Hargreaves (Table 2).

Frequent field observations confirmed surface water-pond and saturated soil for a significant time after irrigation, in both the Sophisticated and Traditional treatments. Regarding the traditional practices, this is in line with the finding of Yohannes et al. (2017), that reported qualitatively over-watering practices of the farmers in the same irrigation scheme, from their scheme level survey conducted in 2015/16.

The Penman-Monteith is worldwide recommended methodology under availability of representative and accurate weather data gathered from large and well-watered area (Droogers & Allen, 2002).

Although the station where the climatic data adopted and the study area have similar elevation, Ethiopia in general and the region in particular is characterized with a complex variation in local topography. Yet, Dinku et al. (2014) found strong dependence of temperature on elevation in Ethiopia. Another study conducted in the country by Boke (2017), generally indicated large errors in predicting or interpolating wind speed as compared to temperature, sunshine fraction and rainfall.

Although further robust researches on local climate and $ET_0$ are required, considering the irrigation depth applied by the alternative approaches versus field observations, the obtained crop performances and the observation by Dinku et al. (2014) and Boke (2017) the findings of this research indicates that the overestimation of the Penman-Monteith $ET_0$ was probably due to poor representation of most of the climatic data acquired from 43 km far station. On the other hand, the better performance of the Hargreaves could be due to relatively better representation of temperature data.

The higher ETc values in the 1st irrigation season as compared to the 2nd irrigation season, in both scheduling methods, were due to change in the irrigation calendar (start of irrigation) of the irrigation scheme, which was relatively cooler for the 2nd season experiment.

### 4.2. Effect of irrigation scheduling on crop performance and water productivity

Higher grain yields were recorded in the Practical method in both irrigation seasons, although, it was significant only in 2015/16. A significant biomass increase was also obtained in 2015 for the practical as compared to the other treatments. Over all, the practical method resulted in better crop performance as compared to the other treatments. Since land preparation, fertilizer application and other agronomic practices were the same for all treatments, it can be concluded that, the combined effect of the applied amount of irrigation water and interval created a favorable soil water environment for production of a greater amount of grain yield and overall better crop performance.

Besides to lower grain yields, the Sophisticated and Traditional methods resulted in applying more water than the Practical method. Especially in the sophisticated method, about 218 mm (in 2015) and 196 mm (in 2015/16) in excess of the practical method were applied. The practical method significantly increased the water productivity in both irrigation seasons compared to the other methods (Table 12). The finding of this study showed that, higher water productivities are associated with higher grain yields (Fig. 2a) as well as lower total irrigation depths (Fig. 2b) in both irrigation seasons. These also confirms that there were over-irrigation in both the sophisticated and traditional methods. The higher amounts of applied water (especially in $I_1$ treatment) were mainly responsible for lower photosynthetic performance, through creation of aeration problem and other nutritional factors.

According to Sakamoto et al. (2011), peak development stage of the corn is more sensitive to over-irrigation. And, over-irrigation could essentially prevent the plants from retaining nutrition required for its development. In a research conducted to quantify the impact of over-irrigation on maize yield in Nebraska, United States (Irmak, 2008) over-irrigation of maize to 125 percent of $ET_c$ resulted in yield reduction as compared with fully irrigated (100 percent ETc). Another study conducted in Limpopo, South Africa reported excessive irrigation water is among the factors for poor maize yields on farmer’s fields (Machethe et al., 2004).

### 4.3. Effect of irrigation schedules on soil salinization

In both irrigation seasons at harvest (Table 11), lower surface (0-20 cm) soil salinity and in the succeeding profile (20-40 cm) higher soil salinity was observed in the practical compared to the other treatments. During harvest the salinity values presented in Table 11, generally indicated capillary salinization dominates compared to any potential leaching in the upper soil profiles of all treatments except for the practical treatment in 2015/16.

As discussed in section 3, surface water ponds were common in both the sophisticated and traditional treatments due to the higher application depths (in most of the irrigation events) and poor internal drainage of the clayey soil (Table 1).Thus, evaporative concentration of salts at the surface and capillary movement from the succeeding soil profile are among the likely major reasons for relatively higher surface salt concentration in both the sophisticated and traditional treatments. Due to similar reasons, Akhand and Al Araj (2013) found higher salts in the upper (0-25 cm) relative to the lower (25-50 cm) depth, which is in line with the finding of this research. According to a survey conducted in 2015/16 (in similar seasons) in the study area, Yohannes et al. (2017), also revealed that, farmers believed over-irrigation as the major cause for soil salinization in the irrigation scheme. On the other hand, in both irrigation seasons, the average root zone salinity was slightly lower in the sophisticated treatment. This indicates that despite the clayey textured soil, leaching seem to be relatively better in the sophisticated treatment.

At planting of both irrigation seasons, the salt concentrations were lower in all treatments. This indicates that the effect of the rainy season decreases the salt concentration. Difference in salt concentration was also found between the irrigation seasons, which was over all lower in the 2$^{nd}$ season. This is attributed to the change in the planting date of the 2$^{nd}$ (a month earlier) experiment, which reduced the capillary movement of soluble salts, owing to relatively colder periods.

Although a wide salinity tolerance exist among different maize cultivars (genotypes), as a general indication the yield potential under increasing salinity of water (ECi) and soil (ECe) is: 100% at ECi= 1.1 dS $m^{-1}$ and ECe= 1.7 dS $m^{-1}$, 90% at ECi= 1.7 dS $m^{-1}$ and ECe= 2.5 dS $m^{-1}$, and so on. During harvest the average root zone salinity found in all treatments were lower than 2.5 dS $m^{-1}$ (the threshold for 90% yield potential), except in 2015 where slightly higher (2.57 dS $m^{-1}$) salinity was found in the traditional treatment. According to various literatures (Maas and Hoffman, 1976; Maas et al., 1983; Farooq et al., 2015), maize is more sensitive to salinity at early stage (emergence and vegetative) than later growth stages (development of grain yield and yield components).

Considering the good quality (0.45-0.67 dS $m^{-1}$) of the irrigation water utilized and the obtained average root zone salinities which were lower at planting and higher at harvest (which is expected to be the maximum during the growing period due to gradual buildup of salts), the average root zone salinity in all treatments, will not generally significantly decrease the yield of maize, in both irrigation seasons.

### 4.4. Farmers' and experts' opinion

While conducting the field experiments, many farmers had followed the entire progress cautiously in both irrigation seasons. Allowing farmers participation in on-farm research encourages information feedback between farmers and researches. It helps in identification of the limitations and requirements by the farmers in the selection of appropriate irrigation scheduling methods.

The local farmers and extension agents were in favor of the practical approach. This result is more or less in agreement with the obtained results in section 3. In addition to water saving and better crop performance advantages, the major reason for selection of the practical approach was its convenience for farmers and water distributors due to the fixed interval and constant application. Local extension agents need easy scheduling methodology while farmers also demand for simple, practical and convenient calendars to achieve improved irrigation management at farm level (Clyma, 1996). Under low technology situations ICID/FAO (1996), simple and operational rules with fixed interval and constant water application are recommended.

Other main concerns raised by the farmers were, skill and capacity of the WUA to provide such schedule. The WUAs in many countries need capacity building in technical and institutional issues to improve the performance of irrigation schemes (World Bank, 2006; Kazbekov et al., 2009; Thiruchelvam, 2010; Ghazouani et al., 2012; Mutambara et al., 2016).Thus, building institutional capacity and technical skill of the WUA should be considered to arrange and enforce predetermined scheduling calendars.

Based on continuous field observation, the farmers' classification of the alternative irrigation scheduling techniques qualitatively and in their own local language in this study indicated that they are more or less capable of applying the desired amount of water roughly if allowed or participated in scheduling practices.

## 5. Conclusions

Despite the availability of various scientific irrigation scheduling techniques, the adoption by farmers is poor mainly due the complexity of techniques, inaccessibility of soil-water monitoring tools, lack of local climatic and soil water data and absence of stakeholders' participation. Using Hargreaves equation (which requires only temperature data for estimation of $ET_0$) and based on the simple procedures for irrigation scheduling in Brouwer et al. (1989) as well as the local farmers' and extension agents' inputs, a simple scheduling calendar (Practical) for maize was tested and validated on-farm against CropWat (Sophisticated) simulated and farmers (Traditional) scheduling methods for two years (2015 and 2015/16) at Gumselassa irrigation scheme, North Ethiopia.

The result of the study showed that, the practical approach resulted in higher grain yield, substantial saving in irrigation water amount and subsequently in significant improvement in water productivity as compared to the other approaches in both years.

Although most of the farmers in the study area are illiterate or completed an elementary school level, they were surprisingly able to classify the alternative irrigation scheduling approaches based on the amount of applied water, qualitatively in their own local language. This leads to the conclusion that, if allowed/participated in scheduling practices, farmers are more or less capable of applying the desired amount of water roughly based on their observations. Overall, from results of the crop-stand ranking and opinions of the alternative approaches, the local farmers and experts were in favor of the practical approach. This also gives important information that if the beneficiaries are allowed/participated, they can be equipped with practical facts to judge alternative technologies from their own perspectives.

For successful implementation of such simple irrigation calendar in a community managed irrigation schemes like Gumselassa, technical support and capacity building of the Water Users Associations, is required urgently, especially on arranging and synchronizing schedules at scheme level.

In most rural areas of Ethiopia as well as in other similar countries, where climatic data are lacking or unreliable and the technology level of the farm is low, this technique can significantly improve the irrigation water management practices. Furthermore, local extension agents can practice and easily prepare irrigation calendars for different crops and planting dates following based on the Practical procedure. Moreover, researchers should build on and rectify on such simple procedures in different agro-hydrological environments, for wider use. This study also recommended the need for local climate studies as well as observations facilities in the vicinity of irrigation schemes of the rural areas so that they can have their own representative meteorological data and accurate scheduling.

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