# Evaluation of the potentials of supplementary irrigation for improvement of sorghum yield in Wag-Himra, North Eastern, Amhara, Ethiopia.

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## Abstract

*Rainfall variability and drought has been accounted to have a major effect on crop production in Ethiopia. However, supplemental irrigation plays a major role in increasing water use efficiency and yields of rain-fed crops. The experiment was conducted for two cropping seasons (2014 to 2015) at Aybra on far*

*irrigation requirement and schedule of supplementary water application during moisture stress period and to improve crop water productivity of sorghum yield. The design of the experiment was random complete block design and seven treatments (C1, C2, FMSO, S1, S2, S3 and S4) with three replications were tested. The analysis of variance for both years showed that there was significant interaction effect between treatments across years on head weight, grain yield, and water productivity. Supplementing sorghum with the CROPWAT generated depth (100%) (219.4mm) irrigation water during moisture stress at the development and mid-season stage at eight days interval gave better head weight, grain yield, water productivity and stem diameter. Similarly, supplementary application of CROPWAT generated depth (100%) (328.4mm) irrigation water during moisture stress starting from the development stage (development up to harvesting) at eight days interval also gave good sorghum grain yield and yield related parameters. Therefore, this research finding recommended that supplementing rain-fed for sorghum production starting from the development stage (20 days after sowing down to harvesting) based on inidcators. However, if the water is scarce or a limiting factor for crop production, supplementing during development and mid-season stage at eight days interval is recommended.*

**Keywords:** Irrigation requirement, Sorghum, Supplementary irrigation, Wag-himra, Water use efficiency

## Introduction

Agriculture is a fundamental part of rural livelihoods of Ethiopia although there are many instances when farmers in water-scarce areas are unable to succeed in their agricultural scheme due to the unavailability of required quantities of water at the correct time. The Ethiopian economy is based on rain-fed agriculture. Rainfall is the major source of water for agriculture. -fed regions in developing countries is low largely due to low rainwater use efficiency because of non-optimal soil, water, nutrient and pest management options, as well as a shortage of seeds from improved cultivars (Rockström and Barron, 2007; Wani *et al.*, 2008). There are three primary ways to develop rain-fed agricultural production, namely: (i) enhance the effective rainfall use through improved water management; (ii) increase crop yields in rain-fed areas through agricultural research; and (iii) transform policies and improved investment in rain-fed areas.

As the Amhara Regional State Government is emphasizing developing irrigation-based agriculture to attain food security at the household level, it is important that appropriate technologies are available for adoption by farmers. This focuses on the first way, in which supplemental irrigation plays a major role in increasing water use efficiency and yields of rain-fed crops. For instance, a supplemental irrigation study (Rockström *et al.*, 2002) carried out in Burkina Faso (seasonal rainfall of 418-667mm) and Kenya (seasonal rainfall of 196-557mm) reported 37-38% increase in sorghum grain yield by supplemental irrigation alone. However, when supplemental irrigation was combined with a fertilizer application of what nutrient rates, loading rate and timing, the crop yield of irrigated land increased to 70-300% when compared to the rainfed system.

Estimating seasonal rainfall characteristics based on the past records is important to assess drought risk and to improve drought mitigation strategies such as supplementary irrigation.

food production for the last three decades. There have been reported of rainfall variability and drought associated food shortage (Tilahun, 1999; Bewket and Conway, 2007). Unreliable and poor distribution of rainfall is one of the major causes of low yield of sorghum in Ethiopia and it is a staple food crop for millions of people who live in the dry land areas of the country. So, farmers and private sales are now opting for the production of this crop under supplemental and/or full irrigation (Shenkut *et al.*, 2013). In most cases, what determines crop production in semiarid areas of Africa is the distribution of seasonal rainfall rather than the total amount of rainfall because dry wonderful strongly slow down the yield (Barron *et al.*, 2003; Segele and Lamb, 2005). Water scarcity is a feature of Northern Ethiopia; particularly in Wag-himra water scarcity is severe (Bekele, 2006; Araya *et al.*, 2011; Feyisa, 2016). Due to this, moisture stress is the major limiting factor for crop production which highly reduces the crop yield in these areas. Sorghum is an important food cereal crop and the major crop in rain-fed agriculture in Wag-himra.

One of the approaches taken as a countermeasure to the unpredictability of rain and to overcoming such problems is using supplementary irrigation during the growing season. Supplemental irrigation (SI) is a highly efficient option to achieve this strategic goal by providing the crop with the needed amount of water at the required time (Oweis, 1997).

rain-fed crops, when rainfall fails to provide essential moisture for normal plant growth, in order to improve and stabi

supplemental irrigation cannot be determined in advance, because it is supplementary to rainfall, which is variable in amount and distribution and difficult to predict (Oweis *et al.*, 1999). In northern Syria, it was found that applying 50% of full supplemental irrigation requirements would reduce yield by 10-15% while applying the saved water to lands otherwise rain-fed increased the total farm production by 38% (Oweis, 1997; Oweis and Hachum, 2006).

Alleviating soil moisture stress during the critical crop growth stages is the key to improved production. It was concluded by the authors that avoiding drought, through early flowering and maturity, was the main factor underlying higher seed yield under severe drought conditions (Li *et al.*, 2000; Wang *et al.*, 2005; Ghanbari-Malidarreh, 2010). In this area, supplementary irrigation is necessary for the increment of sorghum grain yield and yield components and enhancement of food security. However, the additional amount of water alone may be inadequate for crop production, as irrigation timing relative to critical crop growth stages is critical. Therefore, this research was conducted to compute and set the net irrigation requirement (depth of water) to be Supplemented in the moisture deficit period and the timing of the water application (irrigation interval) and to improve crop and water productivity.

## Material and Methods

### Description of the study area

The experiment was conducted for two cropping seasons (2014 to 2015) at Fikire Selam Kebele -himra, North Eastern Amhara, 12.680N Latitude, and 39.010E Longitude and at an altitude of 1976 m.a.s.l (Fig. 1). The mean maximum and minimum temperatures are 26.5 and 12.1$^{o}$c respectively and the mean annual rainfall in the area was 275.7 mm with a considerable year-to-year variation. But this amount of rainfall
water requirement in the growing season. Such rainfall variation results in a range of conditions under which the use of supplemental irrigation is a useful option to improve and stabilize yields. The soil textural class of the experimental area is clay loam with a pH of 6.7-7.1

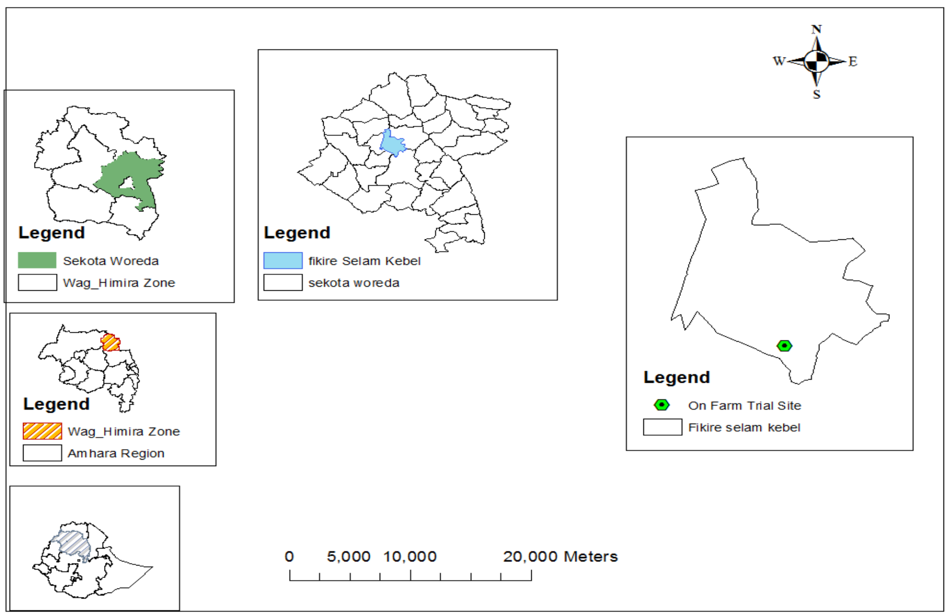


**Figure 1.** Map of the study area

### Soil and Water Sample Collection and Analysis

The collected soil samples were composited into three samples based on the soil depth. The composite soil samples were collected and air dried, thoroughly mixed. The samples were properly labeled, packed and transported to the laboratory. After that, the samples were dispersed after testing and for pH, and soil organic matter (SOM). Soil textures were analyzed at Sekota dry land Agricultural research center Soil Laboratory. The soil pH was measured in the supernatant suspension of a 1: 2.5 using a Standard glass electrode pH meter (Carter and Gregorich, 2008). The soil particle size distribution was determined using the Bouyoucos hydrometer method (Bouyoucos, 1962). The water sample was taken from the site which was used for the irrigation application. The plastic bottle was used to collect the water samples from the experimental site. The sample was labeled carefully and transported to the laboratory and analyzed for their selected chemical composition of pH and ECw. Laboratory analyses were done at Sekota dry land Agricultural research center soil laboratory for selected chemical composition /only for their pH and ECw. ECw of the water samples were measured using conductivity meter. Field capacity and permanent wilting point of the experimental site was done.

**Experimental design and Crop**

The experiment was conducted using a simple r21



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**Table 16.** Length of growing season and other factors of sorghum

| parameters | Crop growth stage | | | | Total growing period |
|---|---|---|---|---|---|
| | initial | development | Mid-season | Late season | |
| Length of growing season (days) | 20 | 35 | 40 | 30 | 125 |
| Crop coefficient (kc) | 0.50 | 0.83 | 1.15 | 0.6 | |
| Rooting depth (cm) | 30 | 50 | 100 | 100 | |
| Depletion level (p) | 0.5 | 0.50 | 0.5 | 0.8 | |
| Yield response factor (ky) | 0.6 | 0.6 | 1.2 | 0.8 | |

Source: FAO CROPWAT model (Smith *et al.*, 2002)

**Determination of reference evapotranspiration**

Reference evapotranspiration (ETo) on a daily basis was calculated by applying the modified FAO Penman-Monteith equation and based on a daily time step (Allen *et al.*, 1998) using FAO CROPWAT software version 8.0. The input data for the CROPWAT software includes location i.e. altitude, latitude, and longitude of the meteorological station, daily values of maximum and minimum air temperatures, air humidity, sunshine duration, and wind speed were used from a 10km meteorological station located on the experimental field.

**Supplementary irrigation water requirement**

The amount of water needed (CWR) to compensate the amount of water lost through evapotranspiration (ETc), requires reference evapotranspiration (ETo) and sorghum crop coefficient (Kc) given by Allen *et al.* (1998) as 0.5 for the initial stage, 0.5 < Kc < 1.15 for the crop development stage, 1.15 for the mid-season stage and 0.6 for the late season stage. Calculation of crop water requirement (ETc) using CROPWAT software over the growing season was from ETo and crop coefficient (Kc) equation 1.1.

$$ETc = ETo*Kc \qquad 1.1$$

Where, ETc = actual evapotranspiration (mm/day), Kc = crop coefficient, and ETo = reference crop evapotranspiration (mm/day). The net irrigation requirement was calculated using the CROPWAT software based on Allen *et al.* (1998) as follows equation 1.2.

$IRn = ETc - Pe$ 1.2

Where, IRn =Net irrigation requirement (mm), ETc in mm and Pe = effective rainfall (mm) which is part of the rainfall that enters into the soil and makes available for crop production. The effective rainfall (pe) was estimated using the method given by Allen *et al.* (1998) as equation 1.3 and 1.4.

$Pe = 0.6 * P \quad 10/3$ for P month <= 70 mm or 1.3

$Pe = 0.8 * P \quad 24/3$ for P month > 70 mm 1.4

Where, Pe (mm) = effective rainfall and P (mm) = total rain fall.

Water productivity, also known as water use efficiency, was determined as the ratio of grain yield per unit area divided by the total seasonal water use of the crop (rainfall + supplemental irrigation) (Irmak *et al.*, 2011). Statistical analysis of the data included analysis of variance (ANOVA), using SAS, to test the effects that season, supplemental irrigation had on grain yield, head weight, stem diameter, and water productivity in the two cropping seasons of 2014 and 2015.

**Table 2.** the treatment setup of supplementary irrigation on the experiment in Wag-himra area.

| | 2014 Year | | | 2015 Year | | | Mean of the two Years | | |
|---|---|---|---|---|---|---|---|---|---|
| Treatment | Total crop water requirement (mm/season) | Measured rainfall (mm/season) | Actual Seasonal irrigation requirements (mm/season) | Total crop water requirement (mm/season) | Measured rainfall (mm/season) | Actual Seasonal irrigation requirements (mm/season) | Total crop water requirement (mm/season) | Measured rainfall (mm/season) | Actual Seasonal irrigation requirements (mm/season) |
| C1 | 351.7 | 351.7 | 0 | 199.7 | 199.7 | 0 | 275.7 | 275.7 | 0 |
| C2 | 351.7 | 351.7 | 0 | 199.7 | 199.7 | 0 | 275.7 | 275.7 | 0 |
| FMSO | 481.7 | 351.7 | 130.0 | 656.3 | 199.7 | 456.6 | 569.0 | 275.7 | 293.3 |
| S1 | 687.7 | 351.7 | 336.0 | 520.6 | 199.7 | 320.9 | 604.1 | 275.7 | 328.4 |
| S2 | 650.3 | 351.7 | 298.6 | 453.7 | 199.7 | 254.0 | 552.0 | 275.7 | 276.3 |
| S3 | 567.0 | 351.7 | 215.3 | 423.2 | 199.7 | 223.5 | 495.1 | 275.7 | 219.4 |
| S4 | 529.6 | 351.7 | 177.9 | 356.3 | 199.7 | 156.6 | 443.0 | 275.7 | 167.3 |

*Where, Treatments, C1=rain-fed without furrow, C2=rain-fed with furrow, FMSO=supplementing farmer estimated depth under field moisture stress observation, S1= Supplementing the CROPWAT generated depth (100%) starting from development stage at eight days interval at moisture stress, S2= Supplementing the CROPWAT generated depth (100%) starting from mid-season stage at eight days interval at moisture stress, S3= Supplemented the CROPWAT generated depth (100%) during development and mid-season stage at eight days interval at moisture stress, S4= Supplementing the CROPWAT generated depth (100%) during mid-season stage at eight days interval at moisture stress.*

## Result and Discussion

### Soil properties of the experimental field

Analysis of soil samples for the major soil physical and chemical properties before planting was carried out at soil laboratories of Sekota Dry-Land Agricultural research center and Mekelle Soil Research Center. Thus, according to the USDA soil textural classification, the percent particle size determination for the experimental site revealed that the soil texture could be classified as clay loam soil. The organic matter (OM) was considered to improve water-holding capacity, nutrient release and soil structure and is rated low as shown in (Table 3). This was in agreement with the findings of Okalebo *et al.* (2002) who reported that soils having OM value in the range of 0.86-2.59% are considered low. Thus, it needs additional materials or nutrients that increase the amount of organic matter in the soils. In agreement with Hazelton and Murphy, (2016), the experimental soils had ECe less than 4dS $m^{-1}$ and are non-saline and suitable for crop production. Moreover, according to the ratings of Chimdi *et al.* (2012), the pH value of the experimental soils is neutral. The topsoil surface had a slightly lower bulk density (1.2g/$cm^3$) than the subsurface (1.26g/$cm^3$) which might be due to the relatively higher organic matter contents in the top soil and the compaction level increased in the lower part. In general, the average soil bulk density (1.24 g/$cm^3$) was suitable for crop root growth. The average soil moisture content values at field capacity of the experimental site were 39.26, 33, and 18% at 0-30, 30-85, and 85- 105cm soil depths, respectively. The moisture content at the permanent wilting point also showed variation with depth and increasing from the surface to the lower depth. The total available water (TAW) that is the amount of water that a crop can extract from its root zone is directly related to variation in FC and PWP and its root depth.

**Table 3.** Soil physical and chemical characteristics of the experimental site

| Depth (cm) | Texture | | | | Bulk density (g/cm3) | Organic matter (%) | pH | EC (ds/m) | FC (%) | PWP (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sand (%) | Clay (%) | Silt (%) | | | | | | | |
| 0-30 | 37.7 | 31.3 | 31.0 | clay loam | 1.2 | 1.55 | 6.9 | 0.15 | 39.26 | 13.12 |
| 30-85 | 51.2 | 25.0 | 23.8 | sandy clay loam | 1.25 | 1.18 | 6.7 | 0.27 | 33 | 13 |
| 85-105 | 35.0 | 36.3 | 28.7 | clay loam | 1.26 | 1.38 | 7.1 | 0.20 | 18 | 7 |

Clear year -to -year variations were seen due to treatment effects. Although the actual rainfall amount which occurred in the second year was less than the long-term mean value, more rainfall was measured at the initial stage of sorghum affecting its growth and resulted in stunted growth. Moreover, the grain yield in the second year was highly affected by the damage of birds during the mid-season stage (at about maturity time).

**Table 4.** Analysis of variance

| Source of variation | Degree of freedom | Mean square | | | |
|---|---|---|---|---|---|
| | | Head weight (kg/ha) | Grain yield (kg/ha) | Stem diameter (cm) | Water productivity (kg/m$^3$) |
| Treatment | 6 | 1999756.88** | 1085183.42** | 0.0509** | 1.2614** |
| Replication | 2 | 11680.88 | 27131.67 | 0.0003 | 0.0108* |
| Year | 1 | 1233387.59** | 1268295.10** | 0.3547** | 0.0288* |
| Treatment*year | 6 | 223083.12** | 50553.40** | 0.0156 | 0.2160** |
| Error | 26 | 21995.56 | 8674.62 | 0.0066 | 0.0026 |

***=Significant at (0.01) level of significance, *=Significant at (0.05) level of significance*

The analysis of variance for both years showed that there was a significant interaction effect between treatments across years on head weight, grain yield, and water productivity (Table 4). The results of 2014 and 2015 indicated that head weight, grain yield, stem diameter, and water

the result supplementing the crop with treatment S3 and S1 application of 219.4mm and 328.4mm of irrigation water respectively at eight days interval at moisture stress obtained better head weight, grain yield, water productivity, and stem diameter as compared to other treatments.

But there was a statistically significant difference in grain yield and water productivity of sorghum. The result was in agreement with the finding of Feyisa (2016) who reported that supplementing the crop with S3 and S1 at eight days interval obtained good sorghum yield and yield related parameters. The result was in line with Ziadat (2015) which reported that full supplementary irrigation of green pepper yield improvement of 32.6 kg/ha compared with the none supplemented irrigation of green pepper in Gumara-Maksegnit watershed. Similar to our result, the research conducted in India indicated that supplementary irrigation early during the vegetative growth stage and early reproductive stage on clay soils contributed to increased yield (Singh and Das, 1987). Sorghum grain yield under rain-fed condition control treatment constantly had a low yield in both experimental seasons 2014 and 2015. The production potential of the crop was particularly affected by rainfall amount and distribution pattern.

The seasonal water use (rainfall and supplemental irrigation) was used to calculate the water productivity of crops. The experimental results in water productivity of sorghum grain yield to improve from 0.75kg/m$^3$ of water for rain-fed and 1.77kg/m$^3$ of water at supplementary irrigation. The result was in line with the finding of Zhang and Oweis (1999) water productivity was about 0.96 kg of wheat grain m $^3$ of water under rain-fed conditions and 1.36 kg of wheat grain m $^3$ under supplemental irrigation. The result also was similarly that the finding of Oweis and Hachum (2009) reported supplemental irrigation caused rainwater productivity in northwest Syria to increase from 0.84kg/m$^3$ of water for rain-fed and 1.06 kg/m$^3$ of water at full supplemental irrigation. From our finding supplementing the crop with S3 at 2194m$^3$/ha irrigation water application at eight days interval at the moisture stress period evaluated to supplementing the 3284m$^3$/ha of water irrigated S1 at eight days interval at moisture stress was achieved 1090m$^3$/ha of water saved. This amount of applying the saved water also 0.49 hectares of additional lands was irrigated.

**Table 5.** Mean separation result of the effects of supplementary irrigation on head weight, grain yield, plant height, stem diameter and water productivity.

| Treatments | 2014 Year | | | | | 2015 Year | | | | | Combined over Year | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Head weight (kg/ha) | Grain yield (kg/ha) | plant height (cm) | Stem diameter(cm) | Water productivity( kg/m$^3$) | Head weight (kg/ha) | Grain yield (kg/ha) | plant height (cm) | Stem diameter(cm) | Water productivity(kg /m$^3$) | Head weight (kg/ha) | Grain yield (kg/ha) | Stem diameter(cm) | Water productivity(kg/m$^3$) |
| C1 | 2084.4d | 1404.4d | 152.4a | 1.21c | 0.43e | | | 139.6a | 1.01b | | 1997.7d | 1404.7d | 0.74e | 1.11d |
| C2 | 2823.7c | 1649.8c | 155.3a | 1.2c | | 1688.9d | 1339.1c | 142.6a | 1.16ab | | | | | |
| FMSO | 2137.8d | 1346.6d | 156.9a | 1.37b | | 2222.2c | 1002.1d | 148.7a | 1.16ab | | | | | |
| S1 | 3383.7ab | 2463.1a | 158.8a | 1.47a | | 3295.8a | 1999.8a | 138.8a | 1.30a | | | | | |
| S2 | 3281.0b | 2229.8b | 156.6a | 1.22c | | 2900.0b | 1896.0a | 140.4a | 1.18ab | | | | | |
| S3 | 3410.4a | 2389.8ab | 151.2a | 1.47a | | 3004.2ab | 1658.0b | 140.4a | 1.16ab | | | | | |
| S4 | 3333.3ab | 2266.0b | 164.0a | 1.46a | | 3033.4ab | 2016.8a | 145.3a | 1.16ab | | | | | |
| CV(%) | 2.36 | 4.67 | 6.94 | 3.32 | | 7.72 | 5.15 | 6.60 | 9.13 | | | | | |
| LSD (0.05) | 122.71 | 163.22 | 19.34 | 0.07 | 0.07 | 354.68 | 148.29 | 16.71 | 0.18 | 0.08 | 177.76 | 104.45 | 0.09 | 0.05 |
| Grand mean | 2922.10 | 1964.26 | 156.50 | 1.34 | | 2579.36 | 1616.71 | 142.30 | 1.16 | | | | | |

*Where; Treatments ,C1=rain-fed without furrow, C2=rain-fed with furrow, FMSO=supplementing farmer estimated depth under field moisture stress observation, S1= Supplementing the CROPWAT generated depth (100%) starting from development stage at eight days interval at moisture stress, S2= Supplementing the CROPWAT generated depth (100%) starting from mid-season stage at eight days interval at moisture stress, S3= Supplemented the CROPWAT generated depth (100%) during development and mid-season stage at eight days interval at moisture stress, S4= Supplementing the CROPWAT generated depth (100%) during mid-season stage at eight days interval at moisture stress.*

## Conclusions and Recommendations

Supplemental irrigation is a viable irrigation management scheme that can be used by farmers in a dry-land area like Wag-himra to enhance and stabilize their rain-fed grain sorghum production. Supplemental irrigation using a limited amount of water, if applied during the critical crop growth stages of vegetative and early reproductive, can result in a substantial improvement on yield and water productivity. The application of supplemental irrigation can also assist the crop to escape critical stages particularly terminal drought or moisture deficit. In rain-fed dry areas, where water is the most limiting factor, the priority should be to maximize yield per unit of water rather than yield per unit of land.

As a result it can be concluded that dry-land areas like wag-himra which has problems of rainfall distribution and amount and having an access to irrigation water can increase their yield advantage 835.2 kg $ha^{-1}$ by supplementary irrigation starting from the crop development stage up to harvesting stage at eight days interval following moisture deficiency indicators like crop physiological indicator and soil moisture stress with amount of 328.4mm seasonal irrigation water requirement for improving variety of sorghum (Miskre) from the analysis of the two year results.

As an option, if water is the restraining factor during the sorghum growing season, applying supplementary irrigation only during development and mid-season stages at eight days intervals on moisture stress or rainfall ceased can give a reasonable good grain yield, head weight and water productivity and it had grain yield improvement of 728.5kg $ha^{-1}$ in 2014 and 2015. Therefore, this research recommended that supplementing rain-fed for sorghum production starting from development stage (20 days after sowing down to harvesting) whenever there is deficit following indicators.

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