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

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## Abstract

*Water is the most limiting factor for agricultural production in dry land areas of Wag-Himra. Supplying of adequate water is very crucial in stabilizing crop yields and increasing their production and productivity of sorghum. Therefore, the experiment was conducted for two cropping seasons (2014 to 2015) at Aybra on a farmer's plot in Sekota, Wag-Himra, North Eastern Amhara. The study aims to evaluate different supplementary irrigation potentials on Sorghum yield and water productivity. The design of the experiment was Randomized Complete Block Design (RCBD) and seven treatments (C1, C2, FMSO, S1, S2, S3, and S4) with three replications were tested. The statistical analysis indicated that there was a significant difference in head weight, grain yield, stem diameter, and water productivity of sorghum among treatments. 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. Supplementing the sorghum crop with S3 and S1 treatments with an application of 219.4mm and 328.4mm of irrigation water respectively at eight days interval during moisture stress time better head weight, grain yield, water productivity, and stem diameter was obtained. Therefore, this study recommended that supplementing rain-fed for sorghum production starting from the development stage (20 days after sowing down to harvesting) with an application of 328.4mm irrigation water at eight days interval. However, water is a limiting factor for crop production supplementing during development and mid-season stage only 219.4mm application of irrigation water at eight days interval at moisture stress or rainfall is ceased.*

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

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 study was conducted to evaluate different supplementary irrigation potentials on Sorghum yield and water productivity.

## Materials and methods

### Description of the study area

The experiment was conducted for two cropping seasons (2014 to 2015) at Fikire Selam Kebele on a farmer's plot in Sekota woreda, Wag-himra, North Eastern Amhara, 12.680N Latitude, 39.010 E Longitude and at an altitude of 1976 m.a.s.l. The mean maximum and minimum temperatures are 26.5 and 12.1oc respectively and the mean annual rainfall in the area was 275.7mm with a considerable year-to-year variation. But this amount of rainfall didn't fulfill the crop 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.

Analysis of soil samples for the major soil physical and chemical properties was done at Sekota Dry-Land Agricultural research center soil laboratory and soil moisture content at Mekelle Soil Research Center. The result of the soil analysis from the study area showed that the average composition of sand, silt, and clay percentages were determined. 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 content of the soil is taken as a basic measure of fertility status. Organic Matter (OM) is considered to improve water-holding capacity, nutrient release, and soil structure. The composite soil sample contributed soil OM which is rated as low shown in table 1. This was in agreement with 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.

As described in the table below, the salinity of soil (ECe) of the experimental site was determined. According to (Hazelton and Murphy, 2007) soils having the ECe less than 4dS m-1 are considered as non-saline and suitable for crop production. Moreover, the pH value of the experimental site was secure. According to (Chimdi et al., 2012), soils having pH value in the ranges are considered neutral soils. The topsoil surface had a slightly lower bulk density (1.2g/cm3) than the subsurface (1.26g/cm3) which might be due to high organic matter contents in the topsoil surface and the compaction level increased in the lower part. But in general, the average soil bulk density (1.24 g/cm3) and which was suitable for crop root growth.

The average soil moisture content values at the 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 watcThe . The . ct57(w)-i( )-62h. Th4( .mo26.26 Tm[( )] TJETBT47low

## Experimental design and Crop

The experimental design was a Randomized Complete Block Design (RCBD) replicated three times. The experimental Plots were 3m x 5m. The experimental treatments were seven with two control treatments (C1 and C2) (no supplementary irrigation). The experimental treatments were C1=rain-fed without a 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 the 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 the mid-season stage at eight days interval at moisture stress.

Irrigation water was applied using hand-held watering can having a fixed volume of water Conveyed to the furrow. Sorghum (Miskre variety), which has a relative maturity of 125 days was used as a test crop. Fertilizer was applied at the rate of 100kg/ha for Di Ammonium phosphate (DAP) at planting and 50kg/ha of urea (applied in two splits, half at planting and a half at 45 days after sowing). The crop data, crop type, planting date, growth stage in the day, maximum rooting depth, Kc values, depletion fraction, and yield reduction coefficient were used as inputs to the CROPWAT computer model.

**Table 2.** Length of the growing season and other factors of sorghum

| Parameters | Crop growth stage | | | | Total growing period |
|---|---|---|---|---|---|
| | Initial | Development | Mid-season | Late season | |
| Length of growing (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) daily 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).

$$ETc = ETo*Kc \text{-----------------------------------------------------------------equation (1.1)}$$

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:

$$IRn = ETc - Pe \text{--------------------------------------------------------------------equation (1.2)}$$

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).

$$Pe = 0.6 * P – 10/3 \text{ for P month} <= 70 \text{ mm or-----------------------------equation (1.3)}$$

$$Pe = 0.8 * P – 24/3 \text{ for P month} > 70 \text{ mm----------------------------------equation (1.4)}$$

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, (ANOVA) was used with SAS, to test the effects of seasonal supplemental irrigation water on grain yield, head weight, stem diameter, and water productivity during the two cropping seasons ( 2014 and 2015).

## Soil and Water Sample Collection and Analysis

The soil samples were collected from the field experiment three sample 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. The samples were dispersed after testing 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 harvested rainwater which was used for the irrigation application. The plastic bottle was used to collect the water samples from the harvested rainwater. The water 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 was measured using a conductivity meter. Field capacity and permanent wilting point of the experimental site was done.

**Table 3.** the treatment setup of supplementary irrigation on the experiment in the Wag-himra area.

| | The 2014 Year | | | The 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 a 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 the 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 the mid-season stage at eight days interval at moisture stress.*

## Result and discussion

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)

The combined analysis showed that there was a highly significant difference among treatments in head weight, grain yield, and stem diameter and water productivity. Moreover, the treatments over year interaction result indicated that there was a highly significant difference in head weight, grain yield, and water productivity (Table 4). Table 5 indicated that in both 2014 and 2015 there was a statistically significant difference among experimental treatments in head weight, grain yield, stem diameter, and water productivity. However, there was no significant difference among treatments in plant height.

According to 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 32.6kg/ha compared with the unsupplementary 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 season to season.

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 0.30kg/m3 of water for rain-fed and 0.78kg/m3 of water at supplementary irrigation. The result was in line with the finding of (Zhang and Oweis, 1999) water productivity was about 0.96kg of wheat grain m−3 of water under rain-fed conditions and 1.36kg 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/m3 of water for rain-fed and 1.06 kg/m3 of water at full supplemental irrigation. From our finding supplementing the crop with S3 at 2194m3/ha irrigation water application at eight days interval at moisture stress period evaluated to supplementing the 3284m3/ha of water irrigated S1 at eight days interval at moisture stress was achieved 1090m3/ha of water saved. This amount of applying the saved water also 0.49 hectares of additional lands was irrigated.

**Table 22.** 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 | 14205114.55** | 10533905.99** | 0.05089** | 0.33844** |
| Replication | 2 | 28359.76 | 27152.19 | 0.00032 | 0.00195 |
| Year | 1 | 1560638.93 ** | 800253.77** | 0.3564** | 0.1060** |
| Treatment* year | 6 | 99171.05** | 58965.94** | 0.0157 | 0.0113** |
| Error | 26 | 21166.52 | 8676.45 | 0.0066 | 0.0005 |

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

**Table 23.** Mean separation result of the effects of supplementary irrigation on head weight, grain yield, plant height, stem diameter, and water productivity

| | The 2014 Year | | | | | The 2015 Year | | | | | Combined over Year | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Treatment | 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 | 1484.4e | 804.4cd | 152.4a | 1.21c | 0.23$^e$ | 1311.1c | 805.1d | 139.6a | 1.01b | 0.40e | 1397.8cd | 804.8c | 1.11c | 0.32d |
| C2 | 2123.7d | 949.8c | 155.3a | 1.2c | 0.27d | 1188.9c | 639.1e | 142.6a | 1.16ab | 0.32f | 1656.3c | 794.5c | 1.20bc | 0.30d |
| FMSO | 1437.8e | 646.6d | 156.9a | 1.37b | 0.13f | 1022.2c | 602.1e | 148.7a | 1.16ab | 0.09g | 1230d | 624.4c | 1.27abc | 0.11e |
| S1 | 3983.7c | 3063.1b | 158.8a | 1.31b | 0.44c | 3695.8b | 2599.8c | 138.8a | 1.30a | 0.50d | 3839.8b | 2831.5b | 1.31ab | 0.47c |
| S2 | 4081.0c | 3029.8b | 156.6a | 1.22c | 0.47c | 3700b | 2696c | 140.4a | 1.18ab | 0.60c | 3890.5b | 2862.9b | 1.21bc | 0.53c |
| S3 | 5110.4a | 4089.8a | 151.2a | 1.47a | 0.72a | 4904.2a | 3558.1a | 140.4a | 1.16ab | 0.84a | 5007.3a | 3824a | 1.32ab | 0.78a |
| S4 | | | | | | | | | | | | | | |

## Conclusion and recommendation

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 in 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 have access to irrigation water can increase their yield advantage 835.2 kg/ha 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 the variety of sorghum (Miskre) from the analysis of the two-year results.

As an option, if the 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 can give good grain yield, head weight, and water productivity and it had grain yield improvement of 728.5 kg/ha. Therefore, it is possible to recommend supplementary irrigation for sorghum production starting from the development stage (20 days after sowing down to harvesting) (328.4 mm) at eight days interval. However, if still water is highly scarce supplementing during development and mid-season stages only (219.4 mm) every eight days interval at moisture stress is recommended.

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