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Determination of supplementary irrigation water requirement and schedule for Sorghum in Kobo-Girana Valley, Ethiopia

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Abstract Rain-fed is the main season agriculture shares the largest crop production system in Amhara region. However, due to erratic nature of rainfall, crop production is always at a risk. For this reason, crop production in the arid and semi-arid regions of Ethiopia including Kobo-Girana Valley usually requires supplemental irrigation. Supplemental irrigation is the application of a limited amount of water to the crop when rainfall fails to provide sufficient water for plant growth to increase and stabilize yields. There was a significant difference among treatments in stalk biomass, grain yield and water productivity. As observed data in the experimental years, the grain yield widely ranged from 5.397t ha^{-1} to 1.53t ha^{-1}. Complementing of the crop at optimal depth of application (100%) and optimal time of application starting from development stage gave the highest stalk biomass of 11t ha^{-1} and grain yield 5.397 t ha^{-1}. It had a maximum yield advantage of 2.874 t ha^{-1} compared with the controlled system in 2011 cropping season. In the second year (2012) complemented the optimal generated depth (100%) at optimal time of application starting from development stage, seasonal irrigation water of 330.6 mm which had a yield advantage of 1.607 t ha^{-1} compared with supplementing of the optimum depth of application (100%) at mid-stage in 8 days irrigation interval. Finally supplementing of irrigation water starting from development stage to mid stage at 8 days interval was vital for sorghum production in Kobo-Girana valley area.

Keywords: Irrigation requirement, Irrigation schedule, Rain-fed and Supplementary Irrigation

Introduction

In sub-Saharan Africa 95% of farm land is rain-fed (Rockström *et al*., 2007). Ethiopian economy is highly dominated by the agricultural sector; relative to manufacturing, construction, and tourism and hospitality sectors. Agriculture contributes approximately 45% of the national Gross Domestic Product (GDP), more than 80% of employment opportunities and over 90% of the foreign exchange earnings of the country (MOA, 2010). Rain-fed farming has always been the main livelihood for most Ethiopian people. Natural rainfall is the major source of water for agriculture. Almost all food crops (97 percent)

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in Ethiopia come from rain-fed agriculture, with the irrigation sub-sector accounting for only about 3 percent of the food crops (Bacha *et al*., 2011).

Ethiopia is the center of origin and diversity for many crops including sorghum (Vavilov, 1951 and Mekibeb, 2008). Sorghum is the second most important cereal after maize with 22% of total cereal area which is 23,142, 595ha with total yield of 230,350,064t in Africa (FAOSTAT, 2015). The area covered by sorghum showed an oscillating pattern over the last 15 years, but production showed an increasing trend (CSA, 2012). Sorghum took a share of 34% of the area covered by cereals in commercial farms in 2010/2011; 14% of the area covered by grain crops; and 10% of the land that was covered by all kinds of crops produced by commercial farms. The national average sorghum productivity in Ethiopia is 2.0t ha^{-1} (CSA, 2012) which is far below the global average of 3.2t ha^{-1} (FAO, 2005). Amhara region ranked in the second more producer regions in the country and it covers 32.9% of the country (Kinfe, 2018).

Sorghum is a stable crop of particularly subsistence farmers, increasing productivity and production is often considered a means of improving incomes and food security of the poor sorghum growing farmers. However, in developing countries farmers' yield gain in rain-fed agriculture is very low. This might be directly or indirectly related to attributes of low rainwater use efficiency (because of inappropriate soil, water, nutrient and pest management options), lack of seeds of improved cultivars, poor crop establishment, and also socio-economic and policy factors (Rockström *et al.,* 2007, Wani *et al*., 2008 and Kinfe, 2018). Sorghum is usually grown in arid and semi-arid parts of the tropics and sub-tropics. Drought is one of the major yield limiting factors which affecting during various growth stages of the crop (Ali *et al*., 2009). Most of the time, in semiarid areas of Africa the main determinant is the distribution rather than the total amount of rainfall; the reason behind is that dry spells strongly reduced the yield (Barron *et al*., 2003; Meze-Hausken, 2004; Segele and Lamb, 2005).

Particularly, the research was conducted in Northern Ethiopia year- to-year with rainfall variability (Meze-Hausken, 2004).The variability is characterized by delay in onset, dry spell after sowing, and drought during critical crop stage and too early stop (Agnew and Chappell, 1999). Over 80% of sorghum in Ethiopia is produced under severe to moderate drought stress conditions (EIAR, 2014). wale *et al.* (2019) indicated that the rainfall variability has been affecting country`s economy and food production for the preceding three decades. Furthermore, similar research results pointed out that rainfall variability and drought associated food shortages problems (Tilahun, 1999; Bewket and Conway, 2007). Therefore, understanding the rainfall characteristics of the given area i.e., daily or decadal, seasonal and annual variability; based on the long term past records is very relevant to estimate drought risk and to develop cope-up strategies.

In North Eastern Amhara, particularly in Kobo-Girana Valley rain water scarcity or moisture stress is a critical problem for rain fed agriculture. It highly diminishes the crop yield. Sorghum is an important food cereal crop used and the major production crop in rain fed agriculture in the Eastern Amhara particularly in Kobo Girana valley, where rainfall is not only low or not enough for production but also variable. It begins later and ceases earlier. It stops for certain days in the growing period as major contributor for yield reduction. As a result of such problems, farmers have been continuously affecting with sever grain yield shortage through their traditional agricultural practices. Oweis and Hachum (2012) indicated that rain-fed agriculture can be enhanced through three main ways: (i) increase rainwater productivity through improved water management; (ii) to increase crop yields in rain fed areas through agricultural research; and (iii) through reformed policies and increased investment in rain fed areas. As a result, this research mainly targets on the first approaches i.e. supplementary irrigation (SI). It has a great role in increasing water use efficiency and yield of rain-fed crops. Thus, the government of Ethiopia has been emphasized on water center based agricultural development approaches. The approach helps to use each irrigation water alternative sources which drives to sustain food security at house hold and state levels. Ground water exploration is the major irrigation water sources in the region. Kobo-Girrana Valley Development Program (KGVDP) has already established about 5,500ha under irrigation and planned to reach about 17,000ha.

As a result, these irrigation infrastructures help to increase the production and productivity of the rain-fed agriculture systems in the valley through applying supplementary irrigation practices. According to Oweis and Hachum (2012). This technique is the worthy alternative to acquire a significant yield because it can provide the required amount of water at the required time. The term supplemental irrigation is "the addition of a limited amount of water to rain-fed crops, when rainfall fails to provide essential moisture for normal plant growth, in order to improve and stabilize productivity". Avoiding or reducing of moisture stress during critical growth periods at early flowering, the maturity is the key determinant factors to improve crop production. In Kobo-Girrana valley practicing of supplementary irrigation is very crucial to enhance the performance of irrigation schemes in general and for the increment of sorghum grain yield in particular. So it helps to enhances farmers` food security. Therefore, the research was proposed to quantify and set both the required amount of net depth of supplemental irrigation water and application time during the rain-fed agriculture and to increase water value and crop productivity.

Materials and methods

A field experiment was conducted during July- December in two consecutive cropping seasons (2011 to 2012) at Kobo agricultural irrigation research main station at Kobo district. As showed in figure 1; the area is located in North Eastern Amhara at latitude 12.08^0 N and longitudes 39.28^0E. The altitude of experimental area is 147**0**ma.s.l. The mean annual rainfall in the study area is 630 mm, with considerable year-to-year variations. The soil type in the experimental site is Silty-Clay loam with average FC and PWP of 27.57% and 12.3% on volume basis accordingly. The site is characterized by average infiltration rate of 8 mm/hr and pH value of 7.8.

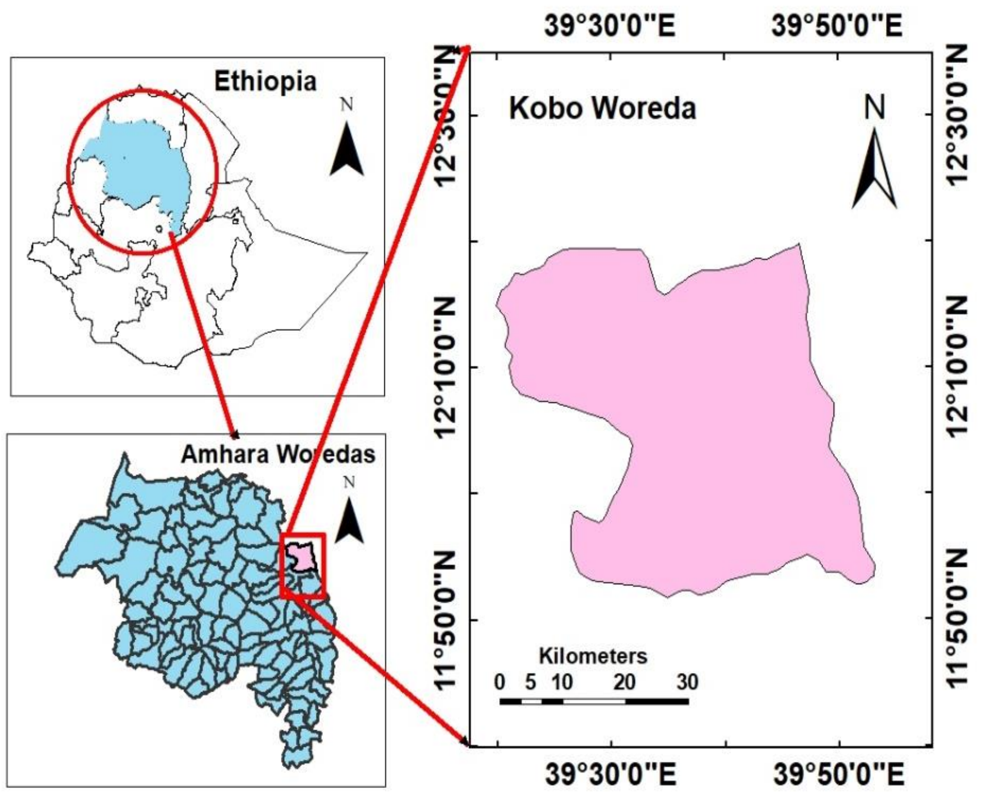

Figure 1. Location map of the study district

Sorghum *'Teshale'* variety requires 120 days of total length of growing period, and was used as a test crop. Fertilizers DAP 100 kg ha^{-1}applied at planting and urea 111 kg ha^{-1}applied in two splits i.e. 36 kg at planting and 75 kg at knee height. The experiment was laid out in Randomized Completely Block Design (RCBD) with three replications and experimental plot size of 3m by 6m. Totally six treatments were tested in the 1st year. While in the second year, one treatment (user adjustment) was added and seven treatments were examined. The treatments include**:** Controlled (**C**- treatment under rain-fed condition no supplementary irrigation). Five supplementary irrigation levels **(S1-S5)** in different growing stages (Table 1) were determined using CROPWAT 8 software program and daily user adjusted treatment (**U).** The daily user adjustment treatment was included in the second year to adjust the rainfall event during irrigation.

Table 1. Experimental treatments with their total crop water requirements, effective rainfall and seasonal irrigation requirements

S.no	Treatments	Total crop water requirement (mm/season)	Effective rain fall (mm/season)	Seasonal irrigation requirements (mm/season)
1.	Controlled (rain fed farming) **(C)**	232.4	232.4	0
2.	Applying 100%) CROPWAT depth with 8 days interval starting from DSt with CROPWAT interval **(S_1)**	563	232.4	330.6
3.	Applying 100% CROPWAT depth with 8 days interval starting from DSt **(S_2)**	658.7	232.4	426.3
4.	Applying 100% CROPWAT depth with 8 days interval starting from MSt **(S_3)**	548.6	232.4	316.2
5.	Applying 100% CROPWAT depth with 8 days interval during DSt & MSt **(S_4)**	536.6	232.4	304.2
6.	Applying 100% CROPWAT depth with 8 days interval at only MSt **(S_5)**	458	232.4	226.5
7	User adjustment **(U)**	417.7	206	211.7

The irrigation water was supplemented when the available soil moisture is below the allowable depletion. Irrigation water was applied to the furrow through using siphon tubes. The time duration was computed the amount of applied irrigation water. Water productivity, also known as water use efficiency, was determined as the ratio of crop yield per unit area, in terms of grain, to crop evapotranspiration (mm), and was expressed as kg of grain or biomass per m^3 of consumed (evapotranspiration) water. Statistical analysis of the data were included analysis of variance (ANOVA) using SAS software as to test the effects of SI on grain yield, stalk biomass, and water productivity.

Results

Rainfall analysis

The study area has a bimodal type of rainfall pattern. The research was conducted in such challenging climate variability, for the experimental year 2011 late onset and early offset with relatively highest amount than 2012 experimental year. In the second year, rainfall distribution and variability was very high and observed with late onset and long dry spell in the month of July and having highest rainfall recorded in August, September and October compared to the first experimental year (2011) as shown in Figure 2. The first four months was the critical period for worthy growth of the crop and the second growing season (2012) had 40.2 mm much more rainfall amount than the first year. There was an average effective rainfall of 232.4mm in the growing season. However, this amount of total rainfall could not satisfy the total crop water demand in the growing season.

Agronomic yield and water productivity

There was no significant ($p<0.05$) interaction effects among treatments across years on grain yield, stalk biomass and water productivity (Table 2). As shown in the ANOVA table, the combined result of the two experimental years, treatment effects were not significant ($p<0.05$) in grain yield. On the other hand stalk biomass ($p<0.05$) and water productivity ($p<0.01$) showed a significant treatment effects.

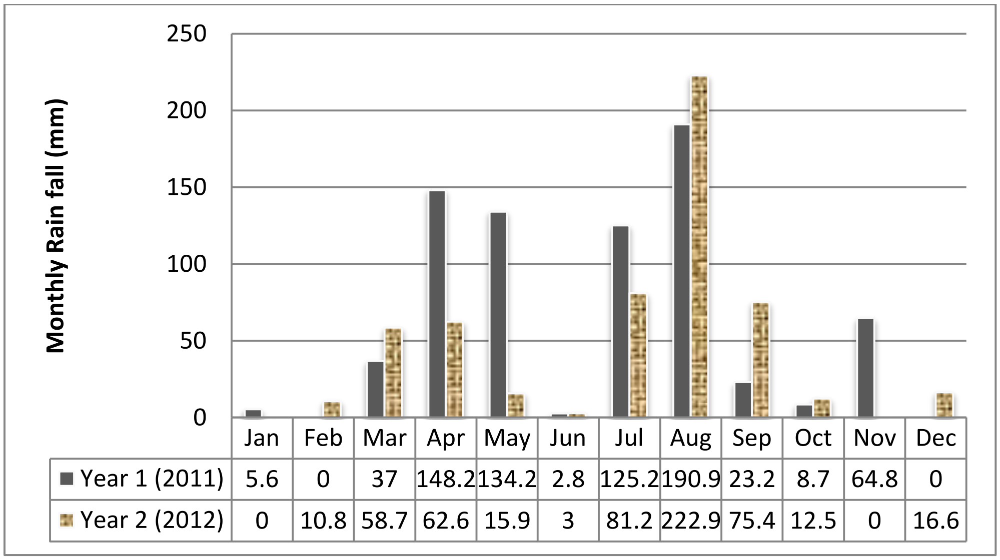

Figure 2. Monthly rainfall distribution in the experimental years (2011-2012)

Table 2. Experimental source of variations, degree of freedom and mean squares of grain yield, stalk biomass and water productivity

Source of variation	Degree of freedom	Mean square		
		Grain yield	Stalk biomass	Water productivity
Replication	2	0.7818	1.138	0.0271
Treatment	5	1.2255	3.664*	0.0958**
Year	1	59.6017**	126.875**	2.4701**
Treatment*year	5	0.4915	1.165	0.0196
Error	33	0.48	1.105	0.0196

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

Maximum grain yield of 5.39t ha^{-1} was obtained in the first experimental year due to supplementing of 100% cropwat generated depth with 8 days interval starting from DSt. Similarly in the second year, this treatment was gave the maximum grain yield. However the grain yield was diminished by half when compared with the first year result. On the other hand in both experimental years the grain yield was highly reduced when we missed supplemental irrigation at DSt. Even though, the combined two years result did not show a significant difference in grain yield, a maximum grain yield of 3.13t ha^{-1} was observed due to application of $\mathbf{S_1}$; i.e. a seasonal supplemental irrigation requirement of 330.6mm. Minimum grain yield of 2.523t ha^{-1} was recorded in the first year from the control treatment. While in the second year 1.52t ha^{-1} grain yield was obtained due to application of 100% CROPWAT depth with 8 days irrigation interval starting from DSt; which is the maximum seasonal supplemental irrigation of 426.3mm. In the first experimental year (2011), there was a significant difference among treatments in water productivity. its value decreased when SSIWR increased up to 316.2mm and then elevated maximum at 330.6mm (Figure 3). When the SSIWR reached 426.3mm the water productivity radically diminished to minimum. The maximum and minimum water productivities of 1.67kg m^{-3} and 1.02 kg m^{-3} were recorded due to the application of $\mathbf{S_6}$ and $\mathbf{S_3}$ respectively. As observed in Figure 4, similar trend situations were occurred in the second experimental year. However the amount was smaller than from the first year.

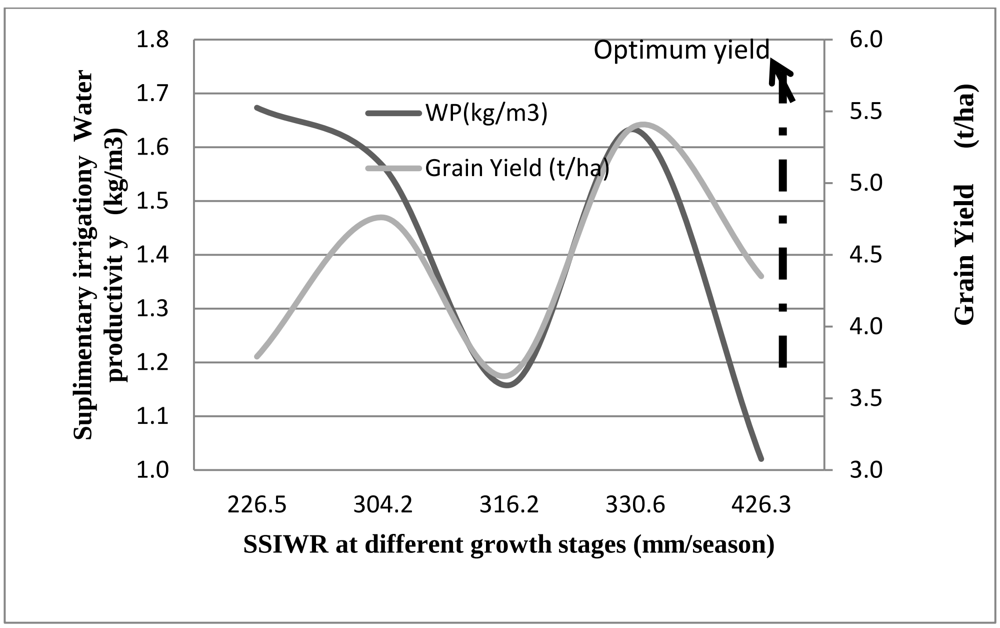

Figure 3. SSIWR at different growth stage in the first year (2011)

Table 3. Mean separation result of plant height, stalk biomass, grain yield and water productivity

S. no	Treatments (SSIWR in mm/season)	First year /2011/			Second year /2012/			combined		
		Stalk biomass (t ha^{-1})	Grain yield (t ha^{-1})	Water productivity (kg m^{-3})	Stalk biomass (t ha^{-1})	Grain yield (t ha^{-1})	Water productivity (kg m^{-3})	Stalk biomass (t ha^{-1})	Grain yield (t ha^{-1})	Water productivity (kg m^{-3})
1	C (0)	8.077^{b}	2.523^{d}	1.23^{b}	4.873^{b}	1.53^{b}	0.78^{ab}	6.49^{b}	1.88	0.81^{a}
2	S 1(330.6)	11^{a}	5.397^{a}	1.56^{ab}	6.422^{ab}	2.45^{a}	0.74^{ab}	8.35^{a}	3.13	0.54^{b}
3	S 2(426.3)	8.86^{b}	4.35^{b}	1.02^{c}	6.400^{ab}	1.52^{b}	0.45^{c}	8.34^{a}	3.03	0.48^{b}
4	S3(316.2)	9.2^{b}	3.663^{c}	1.16^{bc}	7.790^{a}	1.54^{b}	0.49^{c}	8.44^{a}	2.82	0.52^{b}
5	S4(304.2)	9.13^{b}	4.763^{b}	1.56^{ab}	5.540^{b}	1.61^{ab}	0.53^{bc}	7.24^{ab}	2.8	0.49^{b}
6	S5(226.5)	10.56^{a}	3.79^{c}	1.67^{a}	5.243^{b}	1.77^{ab}	0.72^{ab}	7.65^{ab}	2.95	0.65^{ab}
7	U(211.7)	-	-	-	6.022^{b}	1.95^{ab}	0.85^{a}	-	-	-
	Cv (%)	**7.6**	**6.2**	**11.3**	**13.3**	**24.4**	**30.6**	**13**	**25**	**24.2**
	Lsd	**1.314****	**0.458****	**0.173****	**1.467***	**0.811***	**0.2179***	**1.716***	**ns**	**0.239****
	Grand mean	**9.47**	**4.08**	**0.84**	**6.04**	**1.77**	**0.378**	**7.75**	**2.77**	**0.58**

The same letters are not significantly different (P <0.05), ** significant (p<0.01) & * significant (p<0.05) according to a Duncan's multiple range test. Note: SSIWR= seasonal supplementary irrigation water requirement, GD= generated depth, DSt= development stage, LSt=late stage, OPT= optimum time of application MSt=mid stage. Treatment : Controlled (rain fed farming) **(C),** Applying 100% CROPWAT depth starting from DSt with CROPWAT generated interval **(S_1),** Applying 100% CROPWAT depth with 8 days interval starting from DSt (S_2), Applying 100% CROPWAT depth with 8 days interval starting from MSt (S_3), Applying 100% CROPWAT depth with 8 days interval during DSt and MSt (S_4), Applying 100% CROPWAT depth with 8 days interval at only MSt (S_5), User adjustment based on soil moisture sensor measurement to re-fill to field capacity and based on plant physiological responses**(U)**

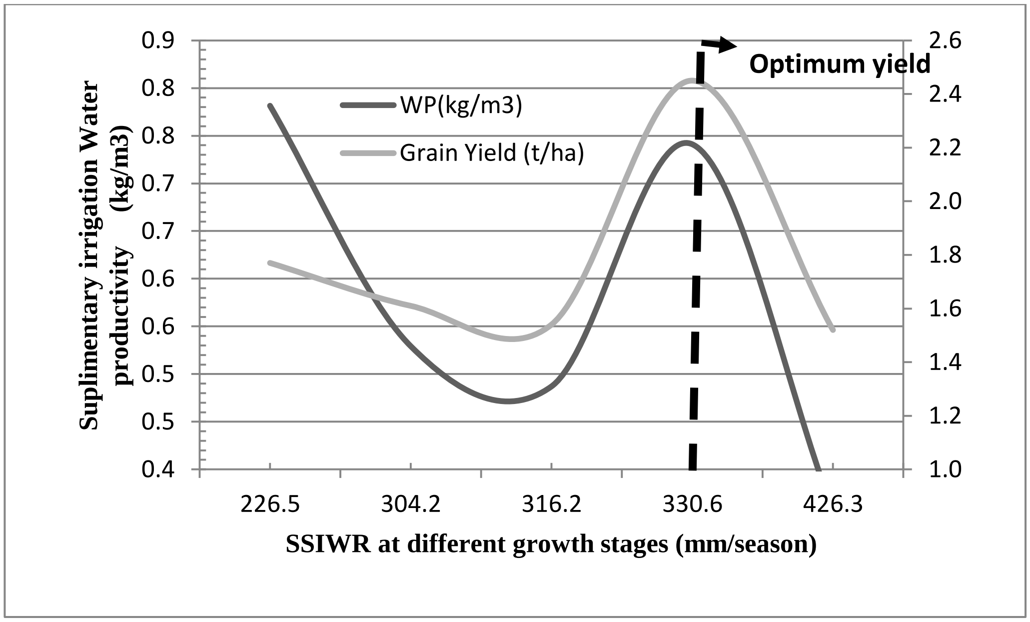

Figure 4. SSIWR at different growth stage in the second year (2012)

Discussion

The result distinguished that year to year variations occurred in treatment effects. The second year actual rainfall amount existed was less than the long term mean value. Despite of this the high amount of rainfall that occurred at initial stage affects the growth performances and became stunted growth. Furthermore, the grain yield and yield components in the second year were highly affected by the occurrence of stalk borer disease at development stage. The experimental result revealed that there was significant difference in stalk biomass, grain yield and water productivity in the first year. Sorghum grain yield, biomass yield and water productivity highly decreased in the second year, with the adverse effect of high rain in the initiation stage and disease infestation. However grain yield, stalk biomass and water productivity had significant difference. The grain yield results were widely varied from 5.4t ha^{-1} to1.5t ha^{-1}. Applying 100% of CROPWAT generated depth starting from development stage at optimal time of application gave the highest stalk biomass (11t ha^{-1}) and grain yield (5.4t ha^{-1}) and it had a maximum yield advantage 2.9t ha^{-1} compared to the control in 2011 cropping season. Research result reported by Rajarathnam and Bagvandas (cited by R.N. Athavale.,1986) supported that the yield of Sorghum at Coimbatore doubled on application of a single protective irrigation. The yield response is greater when the applied amount of water increases. Research findings pointed out that, substantial yield increases were recorded even to the application of a small amount of water (Oweis and Hachum, 2003, 2012 and Adary *et al.*, 2002). Additionally they clarified that the response of applying water would be greater when the rainfall amount is low; but more water is needed. The control treatment i.e., rain-fed condition, had low sorghum grain yield in both experimental periods. The rainfall amount and distribution variability was extremely affected the production potential of the crop. The combined result of the two cropping season shown that stalk biomass and water productivity were statistically significant, but grain yield did not.

In water productivity, applying of 100% CROPWAT generated depth during mid-stage only at 8 days interval (226.5mm seasonal irrigation water) had a maximum value of 1.67 kg m^{-3}. But it was not significantly different from applying of irrigation water at both development and mid-stages at 8 days interval (330.6mm seasonal irrigation water). In the first year applying of 100% CROPWAT generated depth beginning from DSt at optimal time of application (330.6mm seasonal water amount) had a yield advantage of 1.61 t ha^{-1} compared with applying of 100% CROPWAT depth during MSt in 8 days interval (226.5mm seasonal water). Water productivity for sorghum grain yield in first year were in the range of 1.02 to 1.7 kg m^{-3} with lower observation in the second year production season. Oweis *et al.* (1999) reported that 0.96 kg and 1.36 kg of wheat grain yields were obtained due to unit volume of applied water under rain-fed and supplementary irrigation systems respectively. Both experimental seasons of water productivity versus grain yield were coincided optimally at 330.6 mm/season supplementary irrigation during DSt and MSt only at eight days interval. Supplementary irrigation practice in Kobo-Girana valley showed the best cope-up mechanism for rainfall variability problems. It helps for farmers to sustain and doubled their rain-fed crops, specifically sorghum production. The practice is a viable strategy that helps the crop easily to escape the critical growth stages from moisture stress or terminal droughts. Finally, It concluded that for semi-arid areas like Kobo-Girana valley, which accessing to irrigation water can boost up sorghum production. Supplementing of irrigation water handed a yield advantage up to 2.90 t/ha. However, the two years combined results showed that supplementing of irrigation water starting from crop development stages to mid stage (330mm seasonal irrigation) had a yield advantage of 1 t ha^{-1}. As an alternative, if sorghum faced moisture stress problem at early stage and water is the limiting factor in the growing area or season, can get a reasonable good grain and biomass yield by supplementing only at development stage in eight days interval (226.5mm seasonal irrigation water). However, the research finding is highly remarked for better sorghum grain yield, supplementing of irrigation water starting from development to mid stage at 8 days interval would appropriate. Thus, it is needed to demonstrate and promote this technology for end users through collaboration with farmers, community leaders, NGOs, and governmental organizations.

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