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Original Research Article

Sorghum Response to Supplementary Irrigation at Different Growth Stage in Rain-Fed Agriculture for Increasing Yield and Water Productivity at Raya Valley

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Abstract: In arid and semi-arid ecosystems, the efficient use of water becomes increasingly important because water is a crucial limiting factor for increased food and fibre production to supply an ever-growing number of people. A field experiment was conducted in three consecutive seasons three year in Mekhoni Agricultural Research Centre, Raya valley, to investigate with the objective of to evaluate the influence of supplemental irrigation applied at different growth stages on the yield, to prevent sorghum failure caused by less rain water and to maximize the water productivity of the sorghum. The experiment was laid out in a random complete block design (RCBD) consisting of eleven supplemental irrigation treatments (one supplemental irrigation during initial stage, one supplemental during development stage, one supplemental during mid-stage, one supplemental during Late stage, one supplemental during initial and development stage, one supplemental during initial and mid stage, one supplemental during initial and late stage, one supplemental during development and late stage, one supplemental during development and late stage and rain-fed (with no SI) as a control treatment with three replications. The result was showed a significant difference on plant height, panicle length, grain, biomass yield and water productivity sorghum. The highest grain yield was obtained from the treatment supplement one SI at development and mid stage and followed by one SI at mid stage and at late stage. Whereas, the lowest grain yield of sorghum was observed from treatment with rainfed (non-supplementary). It is concluded that in the study area the rain fed amount were very inadequate and supplementary irrigation will help to increase crop productivity, minimize crop failure due to the low rainfed. The experiment showed that supplementary irrigation offers a great potential for improving crop production in Raya valley.

Keywords: Stage, Irrigation, Rain fed, Sorghum, Supplemental irrigation, Water productivity.

1. INTRODUCTION

Irrigated agriculture is the main user of the available water resources. About 70% of the total water withdrawals and 60-80% of total consumptive water use are consumed in irrigation (Huffaker and Hamilton, 2007). The irrigated area should be increased by more than 20% and the irrigated crop yield should be increased by 40% in 2025 to secure the food for 8 billion people (Lascano and Sojka, 2007). Therefore, water resources should be used with a higher efficiency or productivity. To achieve this goal, improvement in agricultural water productivity is highly imperative. Many investigations have been conducted to gain experiences in irrigation of crops to maximize performances, efficiency and profitability and investigations in water saving irrigation still are continued (Sleper *et al*., 2007). Therefore, this project component will be developed with the aim of improving crop water productivity through different water saving mechanisms.

Supplemental irrigation may be defined as 'the addition of small amounts of water to essentially rain-fed crops during times when rainfall fails to provide sufficient moisture for normal plant growth, in order to improve and stabilize yields' (Oweis and Hachum, 2003). Ilbeyi *et al*., (2006) indicated that, when rainfall was inadequate for crop germination, supplemental irrigation given at sowing substantially increased wheat yield by more than 65% (from about 2.0 t ha−1 to the average dry farming yield of 3.2 t ha−1) in the Central Anatolian Plateau of Turkey. (Zhang and Oweis (1999) showed that yields and water use efficiency in northern Syria increased significantly by applying 75 to 212 mm of supplemental irrigation in the beginning to the end of flowering. Supplemental irrigation as a response Shortage of soil moisture in the dry rain-fed areas often occurs during the most sensitive growth stages (flowering and grain filling) of the crops. Supplemental irrigation, using a limited amount of water, if applied during the critical crop growth stages, can result in substantial improvement in yield and water productivity. In addition to yield increases, SI also stabilizes rain-fed crop production (Oweis and Hachum, 2003). Therefore, SI is an effective response to alleviate the adverse impact of soil moisture stress during dry spells on the yield of rain-fed crops.

Raya valley lies in an arid region, which characterized by low and erratic rainfall with dry spells that occur at any stage of crop development causing water stress and consequent reduction in yield. When a prolonged drought period occurs during a critical stage, crop yield may be markedly reduced or even completely lost.

Rainfall is spatially and temporally variable and has poor distribution particularly during the main cropping season (June-September), which is the most important factor affecting the productivity of the crops. Shortage of soil moisture in the dry rain fed areas often occurs during the most sensitive growth stages (flowering and grain filling) and, rain fed crop growth is poor and yield is consequently low (EIAR and TARI, 2011). Therefore, application of supplementary irrigation (SI) at times of dry spells of crops is an effective response to alleviate the adverse impact of soil moisture stress during dry spells on the yield of rained crops. Moreover, supplemental irrigation, using a limited amount of water, is applied during the critical crop growth stages, which can result in substantial improvement in yield and water productivity (Oweis and Hachum, 2012). In the Raya Valley of Ethiopia, farmers mostly rely on rainfall for crop production. The erratic nature of rainfall causes frequent crop failures and alternative technologies to increase grain sorghum production under rainfed systems are right away needed, considering the low grain yield in small-scale farming. Supplemental irrigation, fertilizer application and tillage methods are valuable available farming technologies. Supplementary irrigation is the appropriate solution for alleviating plant water stress and substantially increasing crop yield.

2. MATERIALS AND METHODS

2.1. Description of the Experimental Site

The study was conducted at the research station of Mekhoni Agricultural Research Centre (MehARC) in the Raya Valley, Northern Ethiopia, located 668 Km from the capital Addis Ababa and about 120 Km south of Mekelle, the capital city of Tigray regional state. Geographically, the experimental site is located at 12° 51'50'' North Latitude and 39° 58'08'' East Longitude with an altitude of 1578 m.a.s.l. The site receives a mean annual rainfall of 300 mm with an average minimum and maximum temperature of 18 and 32°C, respectively. The soil textural class of the experimental area is clay with pH of 7.1 to 8.1 (MehARC, 2015).

2.2. Climatic Characteristics

The average climatic data (Maximum and minimum temperature, relative humidity, wind speed, and sun shine hours) on monthly basis of the study area were collected from the near meteorological station. The potential evapotranspiration ETo was estimated using CROPWAT software version 8.

2.3. Experimental Treatments and Design

A field experiment was carried out for three consecutive years (2018-2020). This experiment was laid out in RCBD with three replications. The treatments which are presented in Table 2 consisted of ten supplemental irrigation treatments (one supplemental irrigation during initial stage, one supplemental during development stage, one supplemental during mid-stage, one supplemental during late stage, one supplemental during initial and development stage, one supplemental during initial and mid stage, one supplemental during initial and late stage, one supplemental during development and late stage, one supplemental during development and late stage and rain-fed (with no SI) as a control treatment) with a total of eleven treatment was used.

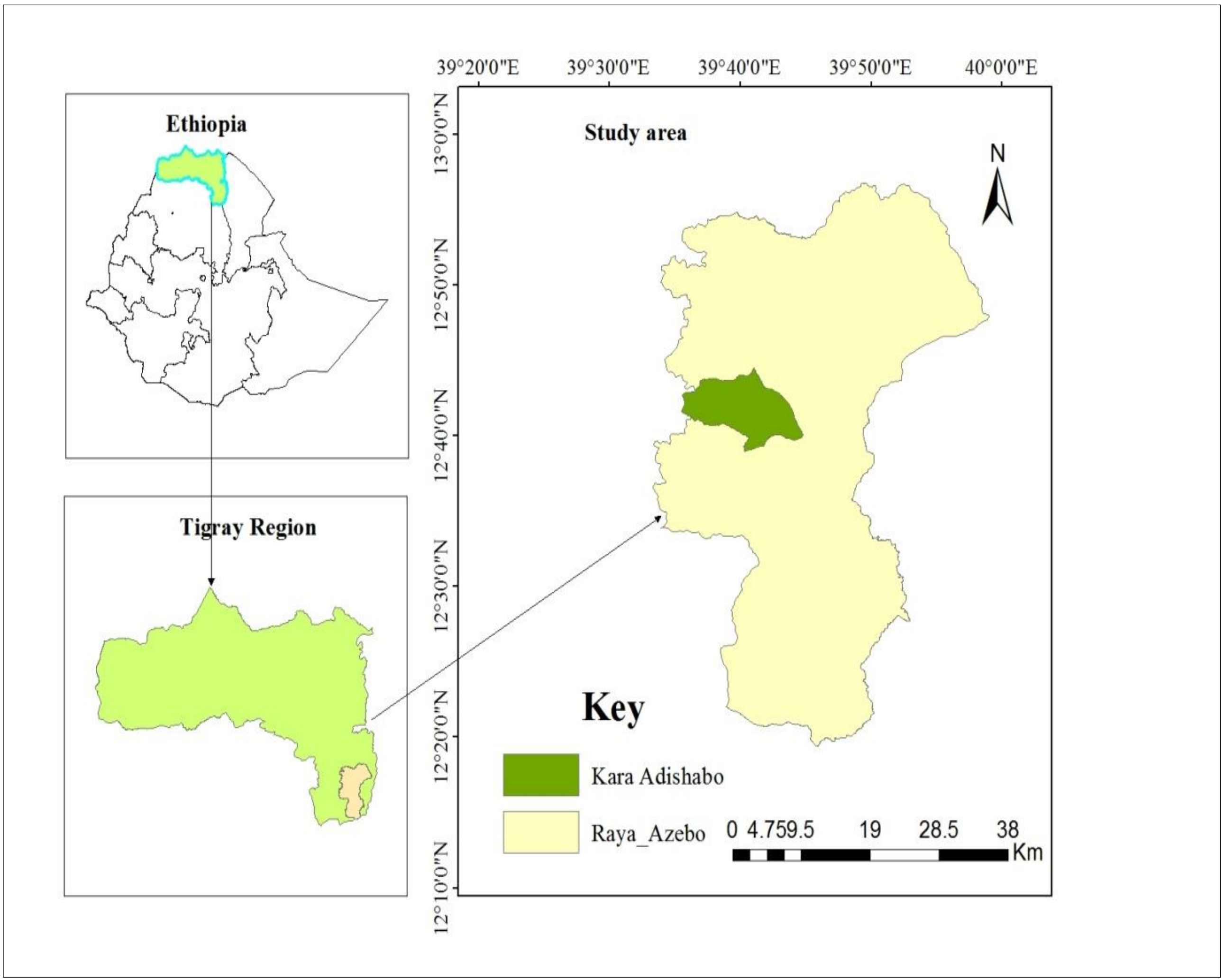

Figure 1: Map of the study area

Table 1: Long term monthly average climatic data of the experimental area

Month	T_{min} °C	T_{max} °C	RH %	Wind km/hr	Sun hours	Rad MJ/m²/day	ETo mm/day
January	11.5	27.2	73	69	7.9	18.4	3.33
February	12.8	27.1	70	86	9.4	22.0	4.02
March	13.5	29.5	68	86	8.7	22.4	4.44
April	13.8	29.7	67	95	8.7	22.9	4.65
May	15.3	32.5	58	52	9.1	23.3	4.69
June	15.8	35.0	60	43	8.6	22.2	4.70
July	15.6	31.5	90	52	6.5	19.1	4.04
August	15.0	29.7	95	43	6.5	19.3	3.89
September	14.3	30.8	74	52	6.6	19.2	3.96
October	13.1	29.8	69	86	9.2	22.0	4.36
November	12.1	28.6	67	69	9.0	20.1	3.77
December	11.3	27.1	69	69	8.8	19.0	3.4

Table 2: Treatment combination

Treatments	Combinations
T1	No supplemental irrigation (Rain fed)
T2	One SI at Initial stage
T3	One SI at Development stage
T4	One SI at Mid stage
T5	One SI at Late stage

Treatments	Combinations
T6	One SI at Initial and Development stage Development stage One SI at Initial and Development stage
T7	One SI at Initial and Mid stage
T8	One SI at Initial and Late stage
T9	One SI at Development and Late stage
T10	One at SI Development and Mid stage
T11	One SI at Mid stage and at Late stage

2.4. Water Productivity (WP)

Water productivity was calculated as a ratio of above ground dry matter at maturity or grain yield to the total etc through the growing season and it was calculated using the equation (Zwart and Bastiaanssen, 2004).

CWP =(Y/ET)

Where, CWP is crop water productivity (kg/m^3), Y crop yield (kg/ha) and ET is the seasonal crop water consumption by evapotranspiration (m^3/ha).

2.5. Data Collected

Agronomic data were recorded during the route of the experiment such as date of sowing, plant height and other relevant agronomic parameters and sorghum yield and other relevant yield parameter. The yield produced was collected and weighed from the four central rows of each to avoid boarder effects. Date of irrigation which is the amount of irrigation applied at every event, rainfall was record and the amount of supplementary irrigation was measured by parshal flumes).

The amount of supplementary irrigation at every stage were deducting from the effective rain fall amount during the treatment applied.

2.6. Statistical Analysis

The collected data were statistically analyzed using statistical analysis system (SAS) version 9.0 statistical package using procedure of general linear model (SAS, 2002) for the variance analysis. Mean comparisons were executed using least significant difference (LSD) at 5% probability level when treatments show significant difference to compare difference among treatments mean.

3. RESULTS AND DISCUSSION

3.1. Applied of Supplemental Irrigation

The amount of supplemental irrigation (SI) applied and effective rainfall is shown in (Table 3). The total effective rainfall 204.73mm was obtained during the growing stage of the sorghum. The total amount of SI water applied was 23.6, 29.8, 32.6 and 39.2 mm for initial, late, development and mid-season stage respectively. The result showed that the highest amount of water applied was 39.2 mm in the mid-season stage as compare the other stage. This highest amount of water applied to irrigate sorghum during that crop growth stage attributes to climatic factors, such as low and erratic rainfall, low humidity and high temperature (BOTHA *et al*., 2003).

Table 3: Net irrigation depth applied at each treatments (mm)

Treatment	Amount of net depth applied		
	Effective rainfall Peff (mm)	Supplementary irrigation (mm)	Total net irrigation applied (mm)
No supplemental irrigation (No SI)	204.73	0	204.73
One SI at Initial stage	204.73	23.6	126.33
One SI at Development stage	204.73	32.6	237.33
One SI at Mid stage	204.73	39.2	243.93
One SI at Late stage	204.73	29.8	234.53
One SI at Initial and Development stage	204.73	56.2	260.93
One SI at Initial and Mid stage	204.73	62.8	267.53
One SI at Initial and Late stage	204.73	53.4	258.13
One SI at Development and Late stage	204.73	62.4	267.13
One at SI Development and Mid stage	204.73	71.8	276.53
One SI at Mid stage and at Late stage	204.73	69	273.73

3.2. Effect of Parameters to Sorghum in Response of Supplementary Irrigation

3.2.1. Plant Height

Analysis of variance has shown significant ($P < 0.05$) difference in plant heights among the different treatments due to supplementary irrigation at different growth stage (Table 4). The highest plant height of (156.16 cm) was recorded from the treatment of one supplementary irrigation at development and mid stage followed by one SI at initial and mid stage. Statistically there were no significances differences among the treatment of one supplementary irrigation at development and mid stage and one SI at initial and mid stage.

The shortest plant height of (136 cm) was recorded from control treatment which is no supplemental irrigation (Rain fed) and followed by one SI at late stage. Statistically there were no significances differences among the treatment of irrigated only at maturity, initial, development and irrigate all stages except development and mid-season stages.

This is in line with the result of Singh and Singh (2002) that depth irrigation increasing plant height, size and total area of leaves, number and location of stomata, shoot growth and vigour of maize are affected by water availability.

3.2.2. Panicle Length

The longest panicle length (25.1 cm) and (24.9cm) were recorded from one SI at mid and late stage and one SI at development and mid stage respectively with statically non significances.

In the other hand, the shortest (20.1 cm) was recorded from the rainfed or no supplementary irrigation (Table 4). The different level of irrigation treatments was affected panicle length of sorghum was increased significantly with the increase in level of supplementary irrigation from the control (rain fed) to supplementary at different growth stages. In increase in panicle length at higher levels of irrigation could be due to high available of soil moisture to the crop that allowed the plants to accumulate more biomass with higher capacity to convert more photosynthesis into sink resulting in longer panicle length.

This could be attributed to better vegetative growth, more dry matter production and biological yield under more favoured soil moisture availability with supplementary irrigation as compared to less supplement irrigation treatments because of moisture stress which showed in retarded growth, hastened senescence and quick drying of leaves there by reducing photosynthetically active surface area and consequently low ear head length production.

Generally, the trend indicated consistent increment in panicle length with increment of irrigation depth from control treatment (rainfed) to supplementary irrigation at different growth stages. This is in line with the result of Yemane M and Haftamu T (2018) that increment in panicle length with increment of irrigation depth from control treatment (rainfed) to supplementary irrigation.

3.2.3. Grain Yield

The ANOVA result showed significant (P < 0.05) difference due to the effect of supplementary irrigation at different growth stage (Table 4). As can be observed from the table, grain yields of sorghum were increased as the amount of supplementary irrigation water applied increased. Significantly higher grain yield of sorghum 4.898 tones ha^{-}, was recorded from the treatment supplement one SI at development and mid stage and followed by one SI at mid stage and at late stage, one SI at development and late stage, one SI at initial and mid stage and One SI at mid stage with the value of 4.642, 4.592, 4.542 and 4.461 tones ha^{-} respectively with non-significance among the treatment.

Whereas, the lowest grain yield of sorghum was observed from treatment with rainfed (no supplementary) with the value of 2.834 tones ha^{-}. This could be might due to moisture stress leading to reduced test weight, grain weight, head weight.

Aslam *et al.*, (2013) made a similar finding and attributed this to the fact that under water stress conditions, photosynthesis, transpiration and light interception are reduced, impacting the maize traits due to a reduction of translocated assimilates. Under supplemental irrigation, all these traits were improved compared with rainfed conditions.

A study done by Yemane M and Haftamu T (2018)) also presented similar findings with this result.

3.2.4. Biomass Yield

Analysis of variance has shown a significant (P < 0. 05) difference in sorghum biomass yield among the different treatments due to supplementary irrigation at different growth stage (Table 4).

The highest biomass yield of sorghum was recorded form one SI at development and mid stage treatment (13.315 tones ha^{-}) followed by one SI at mid stage and at late stage, one SI at development and late stage with value of 12.775ton/ha and 12.655 tones ha^{-} respectively. The least biomass yield of sorghum was recorded from treatment of from the rainfed (no supplementary irrigation) (Table 3). This is in line with the result of Al Moshileh (2007) who presented similar findings with this result.

3.2.5. Water Productivity

Analysis of variance has shown significant (P < 0. 05) difference in water productivity among the different treatments due to supplementary irrigation at different growth stage (Table 4). The highest water productivity (1.71 kg m^{-3}) was recorded from the treatment of rainfed (no supplementary irrigation followed by one SI at initial stage. In the other hand, the lower water productivity was observed from the treatment of one SI at initial and development stage and one SI at initial and late stage with value of 1.55 and 1.57 kg m^{-3} respectively. The results of this research are in agreement with Gençoglan and Yazar (1999), who reported that WUE values decreased with increasing irrigation level.

Table 4: Main effects of treatment on Plant height (cm), Panicle Length (cm), Grain yield (tones ha-)), Biomass yield (tones ha-) and water productivity (kg m^{-3}) of sorghum

Treatment	PH (cm)	PL (cm)	GY (tones ha-)	BY (tones ha-)	WP (kg m^{-3})
No supplemental irrigation (No SI)	136.03^{g}	20.1^{e}	2.834^{g}	9.498^{f}	1.71^{a}
One SI at Initial stage	143.5^{ef}	21.3^{de}	3.474^{f}	10.654^{e}	1.68^{ab}
One SI at Development stage	150.7^{bc}	$22.^{cabcde}$	3.942^{de}	11.620^{de}	1.64^{abc}
One SI at Mid stage	151.24^{bc}	23.0^{abcd}	4.461^{ab}	12.008^{bcb}	1.6^{abc}
One SI at Late stage	142.9^{f}	22.4^{bcde}	3.689^{de}	11.620^{cde}	1.66^{abc}
One SI at Initial and Development stage	147.24^{cde}	22.5^{abcde}	4.421^{bc}	12.190^{bcd}	1.55^{c}
One SI at Initial and Mid stage	153.01^{ab}	22.2^{cde}	4.542^{ab}	12.413^{abc}	1.62^{abc}
One SI at Initial and Late stage	146.1^{def}	22.1^{cde}	4.410^{cd}	12.172^{bcd}	1.57^{bc}
One SI at Development and Late stage	150.03^{bcd}	24.53^{abc}	4.592^{ab}	12.655^{ab}	1.60^{abc}
One at SI Development and Mid stage	156.16^{a}	24.99^{ab}	4.898^{a}	13.315^{a}	1.66^{abc}
One SI at Mid stage and at Late stage	151.6^{b}	25.1^{a}	4.642^{ab}	12.775^{ab}	1.62^{abc}
LSD (P=0.05)	4.16	2.77	0.378	1.0017	0.113
CV	8.65	7.4	9.4	11.1	8.9

Means with the same letter (s) are not significantly different at P ≤ 0.05; LSD= least significant difference; CV = Coefficient of variation

3.3. Grain Yield with Water Productivity of Sorghum

The results obtained in this experiment showed that water production function drawn on the basis of the amount of consumed water in different depth of supplementary irrigation. The figure shows that, as the amount of supplementary irrigation depth increased the grain yield of sorghum increase. As shown in figure 2, if the rainfed was insufficient during the crop cycle the crop was not fully develop resulting in low yield and high-water productivity.

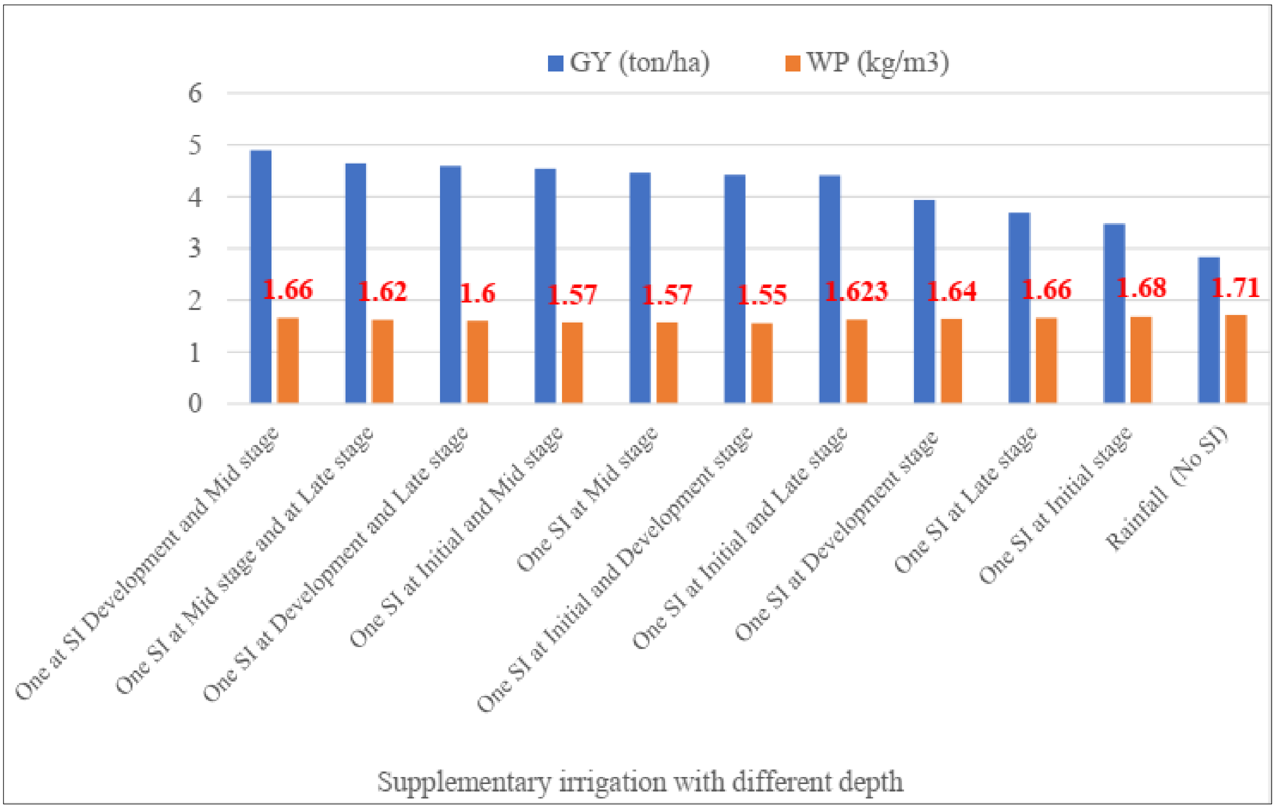

Figure 2: Effect of different depth of supplementary irrigation on sorghum grain yield and water productivity

4. CONCLUSION AND RECOMMENDATIONS

Using the SI, offers a great potential for enhanced yield productivity particularly in arid and semi as well as sub-humid region that have high rainfall variation interfere with drought spell, thus SI is a key management tool, still under-used, for sustaining yield potential and water productivity. Conclusively, adding water in development and mid, mid and late, and in mid-season stage was give higher grain yield and water productivity. It seems to be superior adapted supplementary irrigation and could be recommended to produce a high growth and grain yield and prevent crop failure caused by less rain water with high water use efficiency and more crop per drop of water could be achieved at Raya Valley. It is concluded that in the study area the rain fed amount were very inadequate and supplementary irrigation will help to increase crop productivity, minimize crop failure due to the low rainfed and decrease the deficit of food in the study area.

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