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Response of Maize (*Zea Mays* L.) to Supplementary Irrigation Under Rain Fed Agriculture at Jimma Agricultural Research Center, South West Ethiopia

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Abstract: Maize is the most extensively produced crop in both Africa and Ethiopia in terms of both land area and production. However, low soil fertility, non-agronomic methods, disease, pests, weeds, and insufficient water, negatively affect its yield. Although there are a lot of maize farming in the Jimma Zone, the yield is very low. The variability of rainfall is one of the causes of the low production, and it has to be supplemented through irrigation. This study was initiated with the objective of determining the effect of supplementary irrigation on the production and productivity of maize (*Zea mays* L.) under rain-fed agriculture. The field experiment was carried out for three consecutive years, from 2020 to 2022, on the maize (*Zea mays* L.) crop at the Jimma agricultural research center. The plots were laid out in a randomized complete block design (RCBD) consisting of eight treatments in three replications. The results of the analysis of variance showed that, the different levels of supplementary irrigation had a highly significant ($P < 0.05$) effect on ear height, but there was no significant difference on plant height. Grain yield and 100 seed weight were significantly ($p<0.05$) influenced by the application of different levels of supplementary irrigation. The pooled mean analysis indicated that the highest grain yield of 10623.1 kg ha^{-1} and 100 seed weight of 56.19 gm/plot were recorded from the application of full irrigation (100% ETc). However, the plot with rain fed has given the lowest grain yield (5216.5 kg ha^{-1}) and the lowest 100-seed weight (41.97 gm /plot). In this study, there was a 49.1% yield increment between the fully supplied and the rain-fed maize. The result of partial budget analysis of maize showed that, the highest marginal rate of return and maximum net benefit of 16118 % and 255465 ETB were recorded from one SI at flowering stage and full Supplementary irrigation, respectively. The lowest net benefit (125984 ETB) was obtained at a rain fed treatment. Even though the marginal rate of return was lower, for a sustainable production of maize a full supply irrigation can be recommended.

Keywords: Full Supply, Maize, Rain Fed, Supplementary Irrigation, Water Productivity

1. Introduction

Irrigation agriculture accounts for about 72% of global and 90% of developing country water withdrawals [16]. In many regions, it may be necessary to limit the amount of water available for irrigation in order to meet expanding water demands for home and industrial use as well as environmental concerns. Ethiopia is using irrigation development more than ever to support rain-fed agriculture, increase agricultural productivity, diversify the production of food and inputs for the agro-industry, and ensure that agriculture plays a significant part in advancing the country's economic growth.

There is more competition for water among various industries in many parts of the world including Ethiopia. Because more of the water flowing regularly is likely to be used as a result, the risk of water shortages during periods of low flow is increasing. Irrigation uses around 70% of the world's developed water supplies. According to many studies, the majority, if not all, of the future water requirements across all sectors can be met by increasing irrigation efficiency and diverting the water saved from irrigation to the domestic, industrial, and environmental sectors [20]. In Ethiopia, most of the land was used by rain-fed agriculture; hence, variations in climate change and rainfall variability during the growing season have an impact on agricultural productivity and yield [11]. In line with this, crop farming depends on the nature of the climate, and changes in the climate have a significant impact on farmers' livelihoods. The communities that are impoverished and have a low capacity for adaptation to climate change are those who are most vulnerable. Therefore, climate change still affects human life and means of subsistence in rural communities. Water has become a more precious resource because of Ethiopia's extensive expansion of irrigated agriculture, growing competition for water because of the growth of other water-using industries, and rising environmental awareness.

In Africa, rainfall, temperature, and climate patterns have changed during the previous few decades. The last three decades since 1850 have all been successively warmer than the decade before [14]. River run-off in arid and semi-arid regions has decreased because of increasing rates of evaporation from land and surface water resources brought on by rising temperatures. Water shortages can also occur in locations with substantial fresh water supplies and/or significant rainfall, in addition to arid and semi-arid regions [1].

Maize is the most widely grown crop in Africa and Ethiopia in terms of land area and productivity. According to the [23], it is one of the most significant food sources for human consumption worldwide and in sub-Saharan Africa. According to [15], it is the main source of food, feed, fodder, and industrial raw materials and offers tremendous opportunity for crop diversification, value addition, and job creation. It is also essential to ensuring food security in Ethiopia [3, 10]. Most farmers in rural homes and private investors in Ethiopia cultivate it extensively. Next to teff, it accounts for 16.79% of the nation's overall 80.71% grain cereal production [5]. The national maize grain yield in Ethiopia, however, was 3.94 t ha^{-1} [5] and 3.99 t ha^{-1} [6], which is extremely low compared to the global average of 5.75 t ha^{-1} [8].

Low soil fertility, the use of non-agronomic techniques, diseases, pest weeds, and inadequate water are the main causes of Ethiopia's low maize production. According to [22, 17], using adaptive farming practices (fertilizer application, improved varieties, irrigation, sowing time, sowing density, and row and plant spacing) can increase maize grain yield. In Jimma Zone, the production of maize is very high; unfortunately, the yield obtained is low. The spatial and temporal variability of rainfall is one of the causes of the low production, and it has to be supplemented through irrigation. In this regard, there was a limited study conducted on supplementary irrigation that dealt with the optimal use of limited water resources during the crop's most water stress-sensitive growing period to avoid larger yield losses. Accordingly, this study was initiated with the objective of determining the effect of supplementary irrigation on the production and productivity of maize (*Zea mays* L.) under rain-fed agriculture.

2. Materials and Methods

2.1. Description of the Study Site

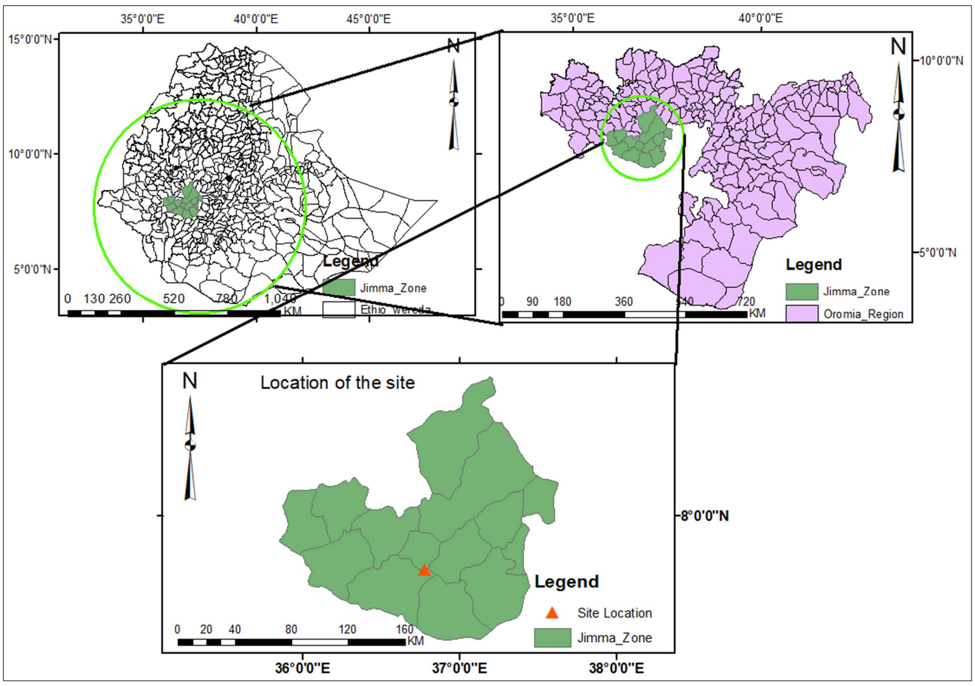

Figure 1. *Location of the study site.*

The experiment was conducted at the Jimma Agricultural Research Center (JARC), which is located in Jimma Zone, Oromia Regional State, in southwest Ethiopia. Geographically, the site is located at 7.67 latitude, 36.78 longitude, and 1753 m a.s.l. elevation, 377 kilometers from the capital Addis Ababa and 12 kilometers from Jimma town. It has an average annual rainfall of 1541 mm, an average monthly maximum and minimum temperature of 24°C and 11.7°C, respectively. The site is often characterized by a mono-modal rainfall distribution pattern with alternate dry and rainy seasons, with the majority of the rain falling between June and September. The remaining months of the year, however, were dry. Therefore, crop production is challenging during these dry spells and has to be supplemented through irrigation.

2.2. Experimental Design and Treatment Set up

The field experiment was carried out at the end of the off-season for three consecutive years, from 2019/2020 to 2021/2022, on the BH 661 variety of maize (*Zea mays* L.). The field was ploughed and harrowed before laying out the plots. The plots were laid out in a randomized complete block design (RCBD) consisting of eight treatments in three replications (Table 1). All management practices were the same with the exception of the amount of applied water, which was applied as per the treatment. The recommended fertilizer rate was applied to each plot. With the aid of the CROPWAT 8.0 computer program, the crop water requirement of maize was calculated for the various treatments.

Table 1. *Treatment arrangement of the experiment.*

No	Treatments
1.	Rain-fed (no Irrigation)
2.	¼ Irrigation (25% ETc)
3.	½ Irrigation (50% ETc)
4.	¾ Irrigation (75% ETc)
5.	Full Irrigation (100% ETc)
6.	One Irrigation at Flowering Stage
7.	One Irrigation at Fruit Setting Stage
8.	Two Irrigation at Flowering and Fruit Setting Stage

2.3. Data Collection and Analysis

The input data collected for the CROPWAT 8.0 computer program were daily climatic data, soil physical properties, and crop data. The following soil physical properties, such as soil texture, field capacity, permanent wilting point, available water, and infiltration capacity, were collected as an input data for the CROPWAT 8.0 software. The crop data, such as information on growth stages along with their periods, effective rooting depth, and days from sowing to maturity for the maize crop was used. Finally, the crop water requirement and irrigation requirement were determined. A three-inch (3') parshal flume was used to apply the determined irrigation water requirement of the crop as per the treatment; the water that was diverted from the river was used as a source of water. During the treatment application, soil data before and after irrigation was taken, its moisture was determined, and daily rainfall data from the Jimma Agricultural Research Center (JARC) meteorology station was used to determine the effective rainfall before irrigation application.

Data on grain yield and yield component (growth parameter) at harvest were collected from the experimental plot. The yield data was recorded, its moisture content was measured in the field, and its moisture content was adjusted to the cereal crop's moisture content. Measurements of plant height (PH), fresh biomass (FBM), 100 seed weight, ear height, and cob length were recorded. Other parameters taken include the soil moisture content, cob diameter, and weight taken, which includes the fresh biomass weight of the plants. The water productivity was estimated as the ratio between grain yields and the total irrigation water applied during the growing season (equation 1). The collected data were subjected to analysis of variance using the statistical analysis system (SAS) software version 9.0 with the General Linear Model (GLM) procedure [19]. Mean separation was employed using the least significant difference (LSD) at a 5% probability level to compare the differences among the treatments. The water productivity was calculated using the grain yield and the amount of water applied at each treatment using equation 1.

$$\text{Water productivity } \left(\frac{Kg}{m^3}\right) = \frac{Grain\ yield\ (Kg)}{crop\ water\ use\ \ (m^3)} \quad (1)$$

2.4. Economic Analysis

The partial budget analysis was carried out using the methodology described in CIMMYT [4] by using grain yield data for analysis. The price of 1 kg of Maize grain at local market near the experimental site, the total price of 1 Kg fertilizer and the average labor cost incurred for incorporating hectar of farmland from sowing to harvesting was taken as 30, 24 and 2872 Ethiopian Birr (ETB), respectively. Accordingly, the total variable cost (TVC) was calculated as the sum of all costs that are variable to a treatment against the rain fed treatment. The gross benefit (GB) was calculated as average adjusted grain yield (kgha^{-1}) × grain price. Adjusted Yield (AY) refers to 90% of the total grain yield that was adjusted by a certain percentage to show the difference between the experimental yield and the yield farmers could expect from the same treatment. Net benefit was calculated by subtracting TVC from the GB. The marginal rate of return (MRR) was calculated as the ratio of differences between net benefits to the difference between TVC with the control treatment using equation 2.

$$\text{Marginal rate of return (\%)} = \frac{\text{Changge in net benifit}}{\text{Change in total variable cost}} \text{x } 100 \quad (2)$$

3. Results and Discussion

3.1. Soil Physico-Chemical Properties of the Study Site

The laboratory results of soil showed that the experimental site was dominated by sandy clay loam soil, with its average water holding capacity of 111 mm/m, field capacity ranged from 34.8 to 36.92% and permanent wilting point ranged from 24.5 to 25.51%. The result of soil chemical analysis showed that, the average p^H value of the soil ranges from (5.40-5.65) which is Medium to Strong acidic (Table 2). The soil test result also displayed that the available phosphorus of the experimental site ranged (6.01-2.11ppm) which is in low ranges according to [2] (Table 2).

The total organic carbon content of the testing soil ranged from (1.27-1.58%) which is rated as low to moderate and gives average structural condition and stability to the soil. The value of organic matter content was found to be (2.19-2.72%) indicating that organic matter could be rated as low to moderate that the field had an average structural condition with average structural stability. Moisture content at field capacity and permanent wilting point for the experimental site soil were ranged 34.8% -36.92% and 24.5-25.2, respectively.

Table 2. *Soil physico-chemical properties of the experimental site.*

Tested Parameter	Soil Depth (cm)			Rating
	0-30	30-60	60-90	
Chemical Properties				
pH (1:2.5)	5.40	5.67	5.65	Medium to Strong acidic
TN (%)	0.21	0.25	0.12	Low to medium
Organic carbon (%)	1.27	1.54	1.58	Low to medium
Organic matter (%)	2.19	2.66	2.72	Low to medium
EC (mS/cm)	38.60	31.60	25.30	Low
CEC (meq/100 gm)	14.08	13.90	12.96	Low
Phosphorus (ppm, Bray)	6.01	3.49	2.11	Low
Physical properties				
Sand (%)	55	57	61	-
Clay (%)	29	31	27	-
Silt (%)	16	12	12	-
Soil textural Class	SCL	SCL	SCL	-
Soil bulk density (g/cm^3)	1.20	1.30	1.32	Normal
FC (%)	35.51	36.92	34.80	-
PWP (%)	24.50	25.20	24.60	-
TAW (%)	11.01	11.72	10.20	-

SCL (sandy clay loam), CEC (cation exchange capacity), EC (electrical conductivity), TN (total nitrogen), FC (field capacity), PWP (permanent wilting point) and TAW (total available water)

3.2. Long Year Climatic Condition of the Site

From the analysis of the long-year average meteorological data for a period of 33 years, there was a high amount of rainfall during the four months of June, July, August, and September (Figure 2). In these months, there is no requirement for irrigation for the cultivation of maize. In the remaining months of the year, since the effective rainfall is not sufficient for the full development of the crop, it requires irrigation water fully or as a supplementary, depending on the growth stage of the crop (initial, development, mid-season, and late) and its planting data.

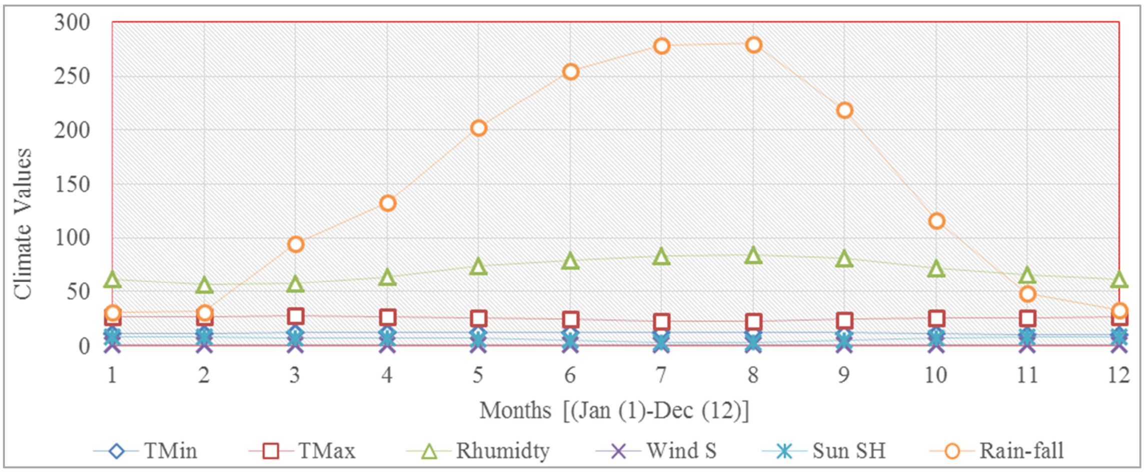

Figure 2. *Long year climatic condition of the site.*

3.3. Crop Water Requirement of the Crop

The calculated water requirement and net irrigation requirements of maize in the study area were 5320m^3/ha and 2300.6 m^3/ha, respectively (Table 3). From the three year meteorological data, for the full development of the crop the contribution of rainfall was nearly 40% of the water requirement and the remaining 60% has to be supplied through irrigation. Sometimes the rainfall may fall after two or three days after irrigation, was lost through deep percolation, and was not used for the crop effectively; and sometimes it will be dry even during the most sensitive growth stage of the crop. Hence, there was inconsistent rainfall in the area; the reliance on it may affect the productivity of the crop because the seasonal rainfall during the crop period was very low. Hence, it demands the application of irrigation for its development since the precipitation could not satisfy the crop water requirement of maize.

Table 3. *Growth period, water requirement and net irrigation requirement of Maize at Jimma.*

Growth stage	Length of growth period (Days)	ETc (mmday^{-1})	Crop water requirement (mm)	Effective rainfall (mm)	Net irrigation requirement (mm)	Irrigation Supplied (%)
Initial	30	1.11	24.2	4.3	19.9	82.23
Development	40	2.32	95.7	57.6	38.1	39.81
Mid-season	50	4.96	243.2	121.6	121.6	50.00
Late season	40	3.45	168.9	67.1	101.8	60.27
Total	160	-	532	250.6	281.4	

3.4. Effects of Supplementary Irrigation on the Yield and Yield Components of Maize

As shown in Table 4 below, except for plant height, girth and cob diameter supplementary irrigation has an effect on the yield and yield component of the plant in the agro ecology of the study site, as disused below.

3.5. Ear Height and Plant Height

The results of the analysis of variance showed that the different levels of supplementary irrigation had a highly significant ($P < 0.05$) effect on ear height, but there was no significant difference on plant height. However, the plant height observed at full irrigation was the highest, and the lowest was recorded at the non-irrigated treatment. Some scholars argue that one of the major effects of water stress is decreasing plant height, which also causes a reduction in dry matter accumulation and subsequently plant production [12-13].

In this study, there was no statistically significant difference between the treatments on plant height; this may be due to the uniform application of fertilizer, other agronomic practices, and the variety of the crop. In addition to this, there was a rainfall interruption and due to a little difference on the moisture level, the plant height was not affected from the three year collected growth parameter data. Similarly, [7] observed no significant difference between plants heights of maize on a research conducted to determine the Effect of Deficit Irrigation on Yield and Water Use Efficiency of Maize at Selekleka District, Ethiopia.

3.6. Plant Girth

The girth of the plant is advantageous for anchoring the whole plant and the root system to the soil. A plant that has a large girth has the ability to carry external physical factors and wind effects and is not susceptible to lodging. The results of the analysis reveals that, the different levels of supplementary irrigation have no significant effect on the girth of the maize at ($p>0.05$). However, the highest girth was observed at a full supply of irrigation, and the lowest was recorded at no supply of irrigation or rain-fed (Table 4). This might be due to the positive effects of full supply irrigation on soil physical condition, thus improving moisture retention and delivery capacity of the soil.

3.7. Cob Length and Cob Diameter

The statistical analysis of the study reveals that the rate of supplementary irrigation has an effect on the cob length; however, there was no significant difference in the cob diameter (Table 4). The highest cob length was observed at a treatment with a fully supplied supply of irrigation water, which is 23.33 cm, and the lowest was at a treatment with no supply of irrigation or rain fed water, which is 18.83 cm (Table 4). Even though there is no significant effect on the cob diameter, the highest was observed at a full supply of irrigation, as shown in Table 4 below.

3.8. Fresh Biomass

The average analyzed data reveals that, stastically the fresh biomass was affected by the rate of supplementary irrigation. The maximum fresh biomass (75,667 kg ha^{-1}) of maize was obtained from the full irrigation of the crop. This is possibly due to better growth, development, and dry matter accumulation with a proper supply of water to the plant. However, the lowest values of fresh biomass were recorded from the non-irrigated/rain fed (60,417 kg ha^{-1}). There is an approximately 20% difference between the fully supplied maize and the non-irrigated or rain-fed maize fresh biomass.

3.9. Grain Yield and 100 Seed Weight

Grain yield and 100 seed weight were significantly ($p<0.05$) influenced by the application of different levels of supplementary irrigation (Table 4). The pooled mean analysis indicated that the highest grain yield of 10,623.1 kg ha^{-1} and 100 seed weight of 56.19 gm/plot were recorded from the application of full irrigation (100% ETc) (Table 4). However, the plot with no irrigation or rain fed has given the lowest grain yield (5216.5 kg ha^{-1}) and the lowest 100-seed weight (41.97 gm/plot) (Table 4). In this study, there was a 49.1% yield increment between the fully supplied maize and the rain-fed maize. Some scholars argue that continuous, heavy rains and subsequent water-stressed conditions are abnormal conditions for maize growth, which affects its yield adversely [18, 21]. Therefore, the pre-determined application of irrigation is advantageous for sustainable production of the crop in addition to the unconditional loss of yield and yield improvement. This result concludes the same argument as [9, 24].

3.10. Water Productivity

In this study, the water productivity is significantly different, and the productivity was highly ($P<0.01$) affected by the supplementary irrigation. The result reveals that 15.7 kg/m^3 was obtained from the application of irrigation water once at the flowering stage. The lowest product was obtained from the full supply of irrigation, which is 1.57 kg/m^3 (Table 4).

3.11. Partial Budget Analysis

The partial budget analysis weighs the advantages (reduced costs and added returns) and the level of profitability in using supplementary irrigation. The result of partial budget analysis of maize showed that, the highest marginal rate of return and maximum net benefit of 16118 % and 255,465 ETB were recorded from one SI at flowering stage and full Supplementary irrigation, respectively. The next highest MRR and maximum net benefit were 12363% and 202,215 ETB, respectively obtained at one SI at Fruit Settling Stage. In other way, the lowest net benefit (125,984 ETB) was obtained at a rain fed treatment (Table 5). Therefore, considering the net benefit and marginal rate of return, irrigating maize once at a fruit setting stage is preferable; however, it may face a water stress and a yield reduction because of a prolonged rainfall. Hence, even though the marginal rate of return is lower for a sustainable production of maize a full supply irrigation can be recommended.

Table 4. *Effect of the treatment on Yield and Yield Components.*

No	Treatment	Ear height (cm)	Plant height (cm)	Girth (mm)	Cob length (cm)	Cob diameter (cm)	Fresh biomass (kg/ha)	100 seed weight (gm/plot)	Grain yield (kg/ha)	Water Productivity (kg/m^3)
1	Rain fed/no Irrigation	153.87^b	282.07	23.79	18.83^c	46.58	60417^c	41.97^c	5216.5^c	-
2	Full Irrigation/100%ETc	179.73^a	308.07	30.71	23.22^a	56.21	75667^a	56.19^a	10623.1^a	1.57^{bd}
3	¾ Irrigation/75%ETc	168.27^{ab}	307.33	29.49	22.4^{ab}	53.69	66750^{abc}	48.53^{bc}	9575.1^{ab}	1.92^{de}
4	½ Irrigation/50%ETc	157.93^b	288.2	27.43	20.83^{abc}	54.01	66000^{bc}	51.75^{ab}	8789.5^{ab}	2.74^{cd}
5	¼ Irrigation/25%ETc	167.33^{ab}	297.03	29.98	20.15^{bc}	54.07	67167^{abc}	50.3^{ab}	8090.2^b	5.06^{bc}
6	One Irrigation at flowering stage	157.53^b	289.13	27.04	19.95^{bc}	53.16	63417^{bc}	42.27^c	9185.8^{ab}	15.7^a
7	One Irrigation at fruit setting stage	166.75^{ab}	286.2	28.17	21.31^{abc}	54.21	71917^{ab}	50.95^{ab}	8266^b	14.20^a
8	Two Irrigation at flowering and fruit setting	165.53^{ab}	296.53	28.38	20.65^{abc}	53.25	67583^{abc}	50.44^{ab}	8653.9^b	7.42^b
	LSD	15.52	NS	NS	2.99	NS	9348.7	6.96	1923.8	2.48
	CV	3.27	4.5	7.44	4.96	3.46	4.82	4.93	7.81	14.21

Numbers with the same letter are not statically significant @5% level of significance.

Table 5. *Partial budget analysis of the crop.*

No	Treatment	Grain Yield (Kg/ha)	Adjusted Grain Yield (Kg/ha)	Cost of Land Preparation	Cost Of Fertilizer	Cost Of Irrigation	Total Variable Cost (TVC)	Total Revenue from Maize (ETB)	Net Benefit	Absolute MRR	MRR (%)
1	No SI	5216.5	4694.85	2872	2600	-	5472	131456	125984	-	-
2	Full SI	10623.1	9560.79	2872	2600	6765	12237	267702	255465	19	1914
3	¾ SI	9575.1	8617.59	2872	2600	5088	10560	241293	230732	21	2059
4	½ SI	8789.5	7910.55	2872	2600	3393	8865	221495	212631	26	2554
5	1/4 SI	8090.2	7281.18	2872	2600	1696	7168	203873	196705	42	4169
6	1SI at Flowering Stage	9185.8	8267.22	2872	2600	617	6089	231482	225393	161	16118
7	1 SI at Fruit Settling Stage	8266	7439.4	2872	2600	617	6089	208303	202215	124	12363
8	2 SI at Flowering & at Fruit Settling Stage	8653.9	7788.51	2872	2600	1234	6706	218078	211372	69	6921

N.B: All the costs are in Ethiopian Birr

4. Conclusion and Recommendation

From the study conducted, supplementary irrigation is essential in the agro-ecology of the study for yield improvement and the sustainable production of crops. The statistical analysis of the study reveals that the highest maize production was obtained from the full supply of irrigation. Unfortunately, considering the water productivity issue, the production of maize was high when irrigating the crop once during the flowering stage, but the yield was low. However, it is not recommended to irrigate the crop once it is at the flowering stage because it will face water scarcity and the yield and other yield components can be adversely affected. It was also observed that there is approximately a 50% yield increment as compared to rain-fed agriculture. Therefore, the adaptability of supplementary irrigation is essential for productivity improvement.

During the cropping season of 2018/2019, the crop was totally affected by fall armyworm (*Spodoptera frugiperda*), and no result was obtained in that year. Hence, it is better to use pesticides for the effective production of the crop, especially at the initial stage. Even though the previous gap on supplementary irrigation in rain-fed agriculture was addressed in this study, for yield improvement and land productivity, it is recommended to study the plant population density on yield and yield components.

Declaration

The manuscript entitled "Response of Maize (*Zea Mays* L.) To Supplementary Irrigation under Rain Fed Agriculture at Jimma Agricultural Research Center, South West Ethiopia," was a research conducted at Jimma Agricultural Research Center by the responsible researchers namely Etefa Tilahun, Minda Tadesse, Addisu Asefa, Huluhager Ayanawu and Robel Admassu. We hereby declare that this research is our original work and all information in this document has been worked responsibly and with ethical conducts. We also declare that, as required by these rules and conducts, all sources of materials that are not original to this work have been cited and duly acknowledged.

Competing Interests

The Authors declare that there are no competing interest.

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Availability of Data and Materials

All data are available on the paper itself.

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References

[1] Admasu, R., Asefa, A., & Tadesse, M. (2019). Effect of Growth Stage Moisture Stress on Common Bean (Phaseolus Vulgaris L.) Yield and Water Productivity at Jimma, Ethiopia. *International Journal of Environmental Sciences & Natural Resources*, *16* (1), 25–32.

[2] Bray, R. H. and Kurtz, L. T., (1945). Determination of total, organic, and available forms of phosphorus in soils. *Soil science*, *59* (1), pp. 39-46.

[3] Buchaillot, M. L., Gracia-Romero, A., Vergara-Diaz, O., Zaman-Allah, M. A., Tarekegne, A., Cairns, J. E., Prasanna, B. M., Araus, J. L., & Kefauver, S. C. (2019). Evaluating maize genotype performance under low nitrogen conditions using RGB UAV phenotyping techniques. *Sensors*, *19* (8), 1815.

[4] CIMMYT (International maize & wheat improvement Center), Economics Training Manual, Mexico City, Mexico, 1998.

[5] CSA. (2018). Agricultural Sample Survey 2017/18 (2010 E.C). Report on Area and Production of Major Crops Volume I. Statistical Bulletin 586. Addis Ababa, Ethiopia.

[6] CSA. (2019). Area and production of major crops. Agricultural Sample Survey 2018/19 (2011 E.C.). V1. Statistical Bulletin. 589. Addis Ababa, Ethiopia.

[7] Gebreigziabher, E. T., 2020. Effect of deficit irrigation on yield and water use efficiency of maize at Selekleka District, Ethiopia. *Journal of Nepal Agricultural Research Council*, *6*, pp. 127-135.

[8] FAOSTAT. (2017). Food and Agriculture Organization Statistics Data Base, Agricultural production indices. FAO, Rome, Italy.

[9] Festo Richard Silungwe, Jans Bobert, Henry Mahoo and Japhet J. Kashaigili, (2022). Maize Yield and Water Productivity under Strategic Supplemental Deficit Irrigation during short rainy seasons, Global scientific journal (GSJ): Volume 10, Issue 4, April 2022, Online: ISSN 2320-9186.

[10] Feyisa, F. A., Abraham, T., & Ashagre, H. (2019). Influence of plant population and NPSB blended fertilizer rates on yield parameters and yield of maize (Zea mays L.) in Bako, Ethiopia. *International Journal of Agriculture, Environment and Biotechnology*, *12* (4), 345–349.

[11] Gebeyehu, L., Emana, B., & Mitiku, F. (2020). Impact of agricultural credit on maize productivity among smallholder farmers in Hababo Guduru district, Oromia, Ethiopia. *Ethiopian Journal of Applied Science and Technology*, *11* (1), 23–35.

[12] Grant, R. F., Jackson, B. S., Kiniry, J. R., & Arkin, G. F. (1989). Water deficit timing effects on yield components in maize. *Agronomy Journal*, *81* (1), 61–65.

[13] Guelloubi, R., Hamdy, A., & Sardo, V. (2005). Maize production under two water saving techniques. *El Gamal F.(Ed.), Lamaddalen a N. (Ed.), Bogliotti C. (Ed.), Guelloubi R.(Ed.). Non-Conventional Water Use: WASAMED Project. Bari: CIHEAM/EU DG Research*, 77–91.

[14] IPCC, W. G. (2014). Fifth Assessment Report-Climate Change 2014: Mitigation of Climate Change. *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*.

[15] Kumar, A., Jat, S. L., Kumar, R., & Yadav, O. P. (2013). *Maize production systems for improving resource-use efficiency and livelihood security*. Directorate of Maize Research.

[16] Oweis, T., & Hachum, A. (2009). Supplemental irrigation for improved rainfed agriculture in WANA region. In *Rainfed agriculture: Unlocking the potential* (pp. 182–196). CABI Wallingford UK.

[17] Pasuquin, J. M., Pampolino, M. F., Witt, C., Dobermann, A., Oberthür, T., Fisher, M. J., & Inubushi, K. (2014). Closing yield gaps in maize production in Southeast Asia through site-specific nutrient management. *Field Crops Research*, *156*, 219–230.

[18] Rathor, P. S. (2005). Techniques and management of field crop production. India: Agro-bios. 524-536.

[19] SAS, S. A. S. (2002). User′s Guide, Version 9.0 SAS Institute Inc. *Cary. NY*.

[20] Seckler, D., Barker, R., & Amarasinghe, U. (1999). Water scarcity in the twenty-first century. *International Journal of Water Resources Development*, *15* (1–2), 29–42.

[21] Sharma, S. K. (2005). Techniques and Management of Field Crop Production. *Editor PS Rathore. Agrobios (India)*.

[22] Sileshi, G., Akinnifesi, F. K., Debusho, L. K., Beedy, T., Ajayi, O. C., & Mongomba, S. (2010). Variation in maize yield gaps with plant nutrient inputs, soil type and climate across sub-Saharan Africa. *Field Crops Research*, *116* (1–2), 1–13.

[23] Statistics, F. A. O. (2018). World Food and Agriculture Statistical Pocketbook. *FAO: Rome, Italy*.

[24] Zeleke, Z. A. (2020.). *Effect of Different Levels of Supplementary Irrigation on Yield and Yield Component of Maize (zea mays L) at Teppi, South West Ethiopia.*