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Effect of Deficit Irrigation on Yield and Water Use Efficiency of Maize at Indris Irrigation Scheme in Western Oromia, Ethiopia

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Abstract: Water shortages are a critical issue in the agricultural sector. An experiment was conducted in the field to evaluate the effects of deficit irrigation on maize yields and water productivity. There was a significant (P<0.01) effect of deficit irrigation levels on yield and yield component parameters. A maximum grain yield of 5346.9 kg/ha and a lowest grain yield of 3061.5 kg/ha were obtained with 100% ETC and 50% ETC, respectively. It was found that 50% ETC produced the maximum irrigation water use efficiency (1.08 kg/m^3) and 100% ETC produced the minimum irrigation water use efficiency (0.94 kg/m^3). According to the economic analysis, applying 75% ETC under conventional furrow irrigation systems is economically feasible for small-scale farmers. As a result, applying 75% ETC to conventional furrows allowed for a water savings of 1288.8 m^3/ha, which was then used to irrigate an additional 0.33 ha that could be used for downstream irrigation users in irrigation scheme.

Keywords: Irrigation Level, Water Use Efficiency, Maize, Indris Irrigation Scheme, Conventional Furrow

1. Introduction

Irrigated agriculture is known for ensuring food security and being one of the most important concerns. In a rapidly growing country like Ethiopia, this is seen as a method of boosting food production and self-sufficiency. The country's poor use of water, especially in agriculture, drives up demand for water across all water-using industries. [1]. Nevertheless, as cities and populations expand, the demand for water in agriculture, industry, and farmers rises, making the issue of water shortage worse if not addressed [2]. There have been studies that indicate some small-scale irrigation schemes developed have not covered the designed command area nor are they producing optimum yields, mainly due to structural problems and inefficient irrigation water management [3]. It is especially true of the Indris small-scale irrigation scheme, where farmers downstream are increasingly susceptible to water supply shocks. Farmers have been motivated by this water shortage to find ways to produce crops with less irrigation water and switch from fully-irrigated to deficit irrigated cropping systems that maximize water use efficiency. The aim of this study was to evaluate the effects of deficit irrigation on maize yield and water use efficiency, and also determined the optimal deficit irrigation level for maximizing yield and water productivity.

2. Materials and Methods

The research was conducted at Eastern wollega zone, Sibu Sire woreda char kebele, located about 270 km west of the capital city of Ethiopia, Addis Ababa and also found an altitude of 1826 meters above sea level and lies in 9°02'38.9" N and 36°52'31.3" E Latitude and longitude respectively. Average maximum and minimum temperature of the area was about 23.2 and 13.9°C respectively.
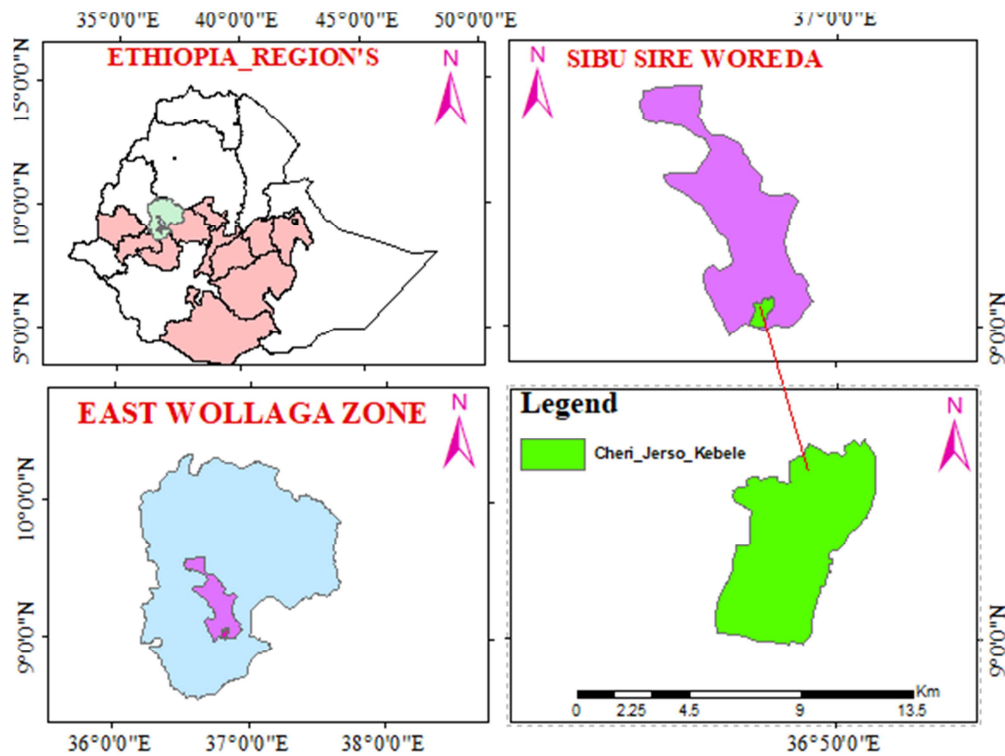
Figure 1. *Location map of study area.*

2.1. Experimental Design and Treatment

The experimentation was designed with four deficit irrigation level of furrow irrigation (conventional) methods. Randomized complete Block design (RCBD) was used with three replications for four level of treatments. 50% ET_C was selected because of maximum allowable deficit recommended for grain maize [4]. The experiment plot has a net size of 6m X 8m with spacing of 75cm X 25cm between row rows and plants respectively. Experimental treatments were; T_1 = 100% ET_C water application, T_2=85% ET_C water application, T_3 = 75% ET_C water application, T_4 = 50% ET_C water application. After setting of treatments soil moisture contents at field capacity and permanent wilting point were analyzed by applying pressure at 0.33 bar (for FC) and 15 bar (for PWP). Based on these the total available water (TAW) was determined as expressed [5].

2.2. Crop Water Requirement and Irrigation Scheduling of Maize

Crop water requirement and irrigation of maize were prepared based on metrological data, soil characteristics, and crop data, Maize crop coefficient (Kc) from given by Allen et al. [4] and Crop water requirement was determined by multiplying the ETo with crop coefficient (Kc). The net irrigation requirement was calculated using crop water requirement and effective rainfall as described by Allen et al. [4]. To determine the effective rainfall, dependable rain (FAO/AGLW Formula) was used [6] and gross irrigation requirement was calculated by considering 60% of application efficiency. 3-inch Parshall flume was used to measure amount

of water applied to the experimental field. The time required to deliver the desired depth of water into each plot was calculated using the equation [7].

$$t = \frac{dg \times A}{6 \times Q}$$

Where; dg = gross depth of water applied (cm), t = application time (min)
A = Area of experimental plot (m^2) and Q = flow rate (discharge) (l/s)

The irrigation depth was converted to volume of water by multiplying it with area of the plot

$$V = A \times dg$$

V = Volume of water in (m^3), A = Area of plot (m^3) and dg = Gross irrigation water applied (m)

2.3. Data Collection Methodology

To collect data representative maize plant samples were cut at ground level after plant height recorded and gathered for each plot from the middle ridge (row) of each treatment. Additionally, data on plant height, cob length, and cob diameter, as well as yield and yield component parameters, were gathered.

2.4. Crop Water Production Function and Yield Response Factor

Crop yield and seasonal water requirements (ETC) were fitted into multiple regression equations to create a crop water production function, and the regression equation with the highest coefficient of determination was chosen.

$$Y = a + b\,(ETc) + C\,(ETc)^2 + d\,(ETc)^3$$

Where; Y = grain yield (kg/ha), ET_C = seasonal actual evapotranspiration (mm), a = Y-axis intercept and b, c and d = Regression coefficients indicating the magnitude of yield variation (kg/ha) per unit increase in ETc.

According to the method described by Doorenbos et al. [8] the yield response factor (Ky), which is defined as the drop in yield with respect to the deficit in water consumptive use (ET), was computed.

2.5. Economic Water Productivity

Net income and marginal rate of return were calculated taking into account the average cost of local people paying for daily labor (75.00 Birr/day), farm gate price corn during harvest period (10.50 Birr/kg), and the price of irrigation water (1.00 Birr 0.5 m^3 of water). CIMMYT [9] states that the adjusted yield was calculated by deducting 10% from the average yield.

2.6. Statistical Analysis

RCBD analysis of variance for the assessed variables was performed using the SAS system. To compare mean separation, LSD at 5% and 1% level of probability was utilized.

3. Result and Discussions

3.1. Soil of Experimental Site

The results of the soil study indicated that the average percentages of sand, silt, and clay were 23.67, 34.0, and 42.33%, respectively, and that the texture was clay loam (Table 1). As shown in Table 1, the average soil moisture content at Field Capacity and Permanent Wilting Point (PWP) was 39.2% and 27.77%, respectively, and the total amount of water accessible was 142.89mm/m with a bulk density of 1.25g/cm^3 (Table 1).

***Table 1.** Soil of Experimental site.*

| Depth (cm) | BD (g/cm³) | FC (%) | PWP (%) | TAW (mm/m) | Distribution of particles by size (%) | | | Textural class |
					sand	Clay	silt	
0-20	1.3	38	27	143.33	23	41	36	Clay loam
20-40	1.24	39	28	136.32	23	43	34	Clay loam
40-60	1.21	41	28.3	148.89	25	43	32	Clay loam
Average	1.25	39.2	27.77	142.89	23.67	42.33	34.0	Clay loam

3.2. Crop Water Requirement and Irrigation Schedule of Maize

The reference evapotranspiration measurements were multiplied by the maize crop coefficient to determine the irrigation schedule and the crop water need for maize, which came out to be 518.72mm (5187.2m^3/ha). According to FAO [10], the seasonal crop water demand for maize for maximum yields is between 500 to 800 mm, depending on climate. The effective rainfall from ETc was used to calculate the net crop water requirement, while the gross crop water requirement was calculated using a field application efficiency of 60%. The results were 416.53 mm and 694.21 mm, respectively.

3.3. Effect of Deficit Irrigation Levels on Yield and Yield Component of Maize

3.3.1. Plant Height

Anova result indicated the effect of irrigation levels on plan height was highly significant (P< 0.01) as shown (Table 2). The maximum plant height (287.07cm) and minimum plant height (24.04cm) obtained from control treatment and T_4, respectively. This is because shorter plant heights were produced when less irrigation water was applied, whereas larger plant heights were connected with more irrigation water application. This outcome is consistent with the research [11] found.

3.3.2. Cob Length and Cob Diameter

The results of the analysis of variance revealed that the variation in cob length and diameter as a result of various deficit irrigation treatment amounts was very significant (P<0.01) (Table 2). The longest cob length (25.25cm) and minimum cob length (16.97cm) was obtained from control treatment and T_4, respectively. The highest cob diameter was obtained from control treatment which is 51.7cm while the smallest cob diameter 38.9cm was observed from T4.

3.3.3. Grain Yield

Anova result indicated the effect of irrigation levels on maize yield was highly significant (P < 0.01) as shown (Table 2). The maximum maize yield (5346 kg/ha) and minimum maize yield (3061 kg/ha) obtained from T1 and T4, respectively. Similar to the present observation [15] also reported that water application with no deficit or control (100% ETc) at any stage of plant growth gave highest marketable and unmarketable yield of onion.

3.4. Effect of Deficit Irrigation Level on Water Use Efficiency of Maize

Crop water use efficiency (CWUE) was significantly (P<0.01), impacted by deficit irrigation levels, according to an analysis of variance indicated (Table 3). The highest crop water use efficiency (1.43kg/ha/mm) and lowest (1.29 kg/ha/mm) was obtained at T4 and under full water application level (T1). This outcome is consistent with that of the findings [12]. According to an analysis of variance, deficit irrigation levels had a significantly significant (P<0.01), impact on irrigation water use efficiency. The maximum water consumption efficiency for irrigation

(1.08kg/m3) was achieved under T4, which statistically differed significantly (P<0.01), from all other treatments (Table 2). This outcome is consistent with the findings [13], who found that irrigation water use efficiency increased at decreased soil moisture availability levels. The water uses efficiency results demonstrated that 75% ETC deficit irrigation levels could be used in areas with restricted irrigation water by increasing water use efficiencies with a sizable and tolerable yield reduction. As a result, it was determined that 75% ETC should be applied throughout the entire crop of this particular maize variety (shoney) under conventional furrow irrigation.

Table 2. Effect of Deficit Irrigation Level on yield and water use efficiency of maize.

| Treatment	Irrigation water applied(m³/ha)	PH (cm)	CL (cm)	CD (cm)	Yield (kg/ha)	CWUE(Kg/ha/mm)	IWUE Kg/m³	Water saved (m³/ha)
T1	5187.2	287.07A	25.25H	51.73L	5346.9G	1.29C	0.94 K	
T2	4, 409.12	275.47B	23.22I	48.53M	4786.9F	1.35E	0.99J	778.08
T3	3898.4	264.40C	21.15J	45.73N	4399.3T	1.39E	1.03L	1288.8
T4	2593.8	240.47D	16.97K	38.93P	3061.3S	1.42B	1.08M	2593.4
LSD(0.05)	1.35	1.87	0.77	1.59	1.97	1.56	1.9	
CV	2.3	3.75	2.79	3.4	5.8	2.69	2.79	

3.5. Crop Water Production Function and Yield Response Factor

The best relationship between seasonal crop evapotranspiration and grain yield was found (R2 = 0.98; Figure 1). The coefficients a, b, and c had values of -0.0091, 1.5768, and -4.0695, respectively

$$Y = -0.0091(P+ I)^2 + 1.5768 (P+ I) - 4.0695$$

Where, y= grain yield (qt/ha), P= effective Rain fall (cm), and I= net irrigation water (cm)
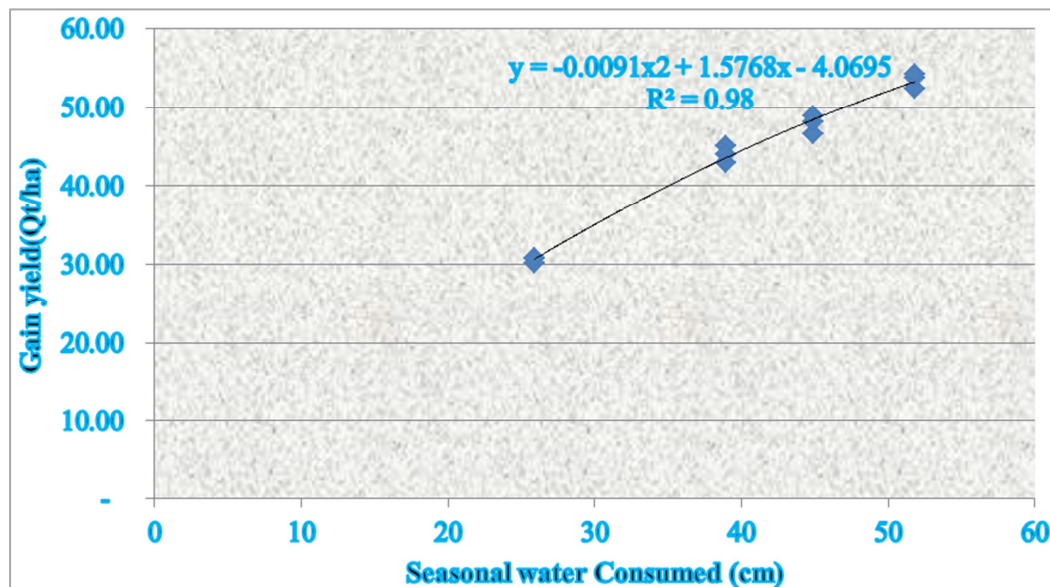
Figure 2. Water production function of maize based on seasonal water consumed.

The yield response factor that was achieved for each treatment was less than one and was 0.68, 0.62, 0.57, 0.61, and 0.65, respectively (Table 3). These findings are consistent with Doorenbos et al. [8], who found that deficiency levels that persisted throughout the entire growing season could withstand yield drop (Ky < 1) throughout the local cropping season.

Table 3. Effect of deficit irrigation level on yield response factor of maize.

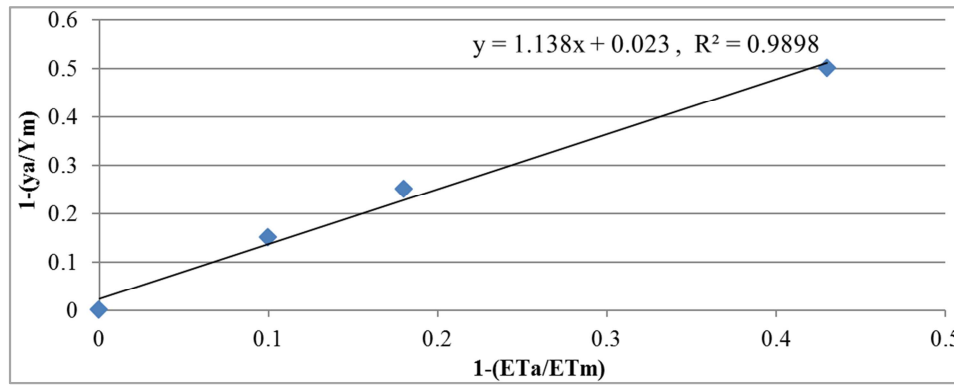| Treatment	Grain yield (Kg/ha)	Eta (mm)	$\frac{ET_a}{ET_m}$	$\frac{y_a}{y_m}$	$1 - \frac{ET_a}{ET_m}$	$1 - \frac{y_a}{y_m}$	ky
T1	5,346.90	518.70	1.00	1.00	0.00	0.00	-
T2	4,786.90	440.90	0.85	0.90	0.15	0.10	0.70
T3	4,399.30	389.80	0.75	0.82	0.25	0.18	0.71
T4	3,061.30	259.40	0.50	0.57	0.50	0.43	0.86

Figure 3. *Relation between relative yield reduction and Relative evapotranspiration deficit for maize.*

In comparison to the (T1) irrigation water application, stressed treatments with irrigation application under T2, T3, and T4 revealed yield reductions of 10%, 18%, and 43%, respectively. This suggests a linear relationship (Figure 2) between the relative yield decline and the relative water use decline. This relationship closely resembles that found in the research [14].

3.6. Partial Budget Analysis

The outcome showed that T1 had the biggest net benefit, 30,840.42 ETB/ha, for a higher cost, with an MRR of 297.83%. T2 had the next-highest net benefit, 26,878.63 ETB/ha, with an MRR of 150.68%. The biggest net profit, 24,676.97 ETB/ha, was gained from T3, which had a marginal

rate of return of 289.47% and cost of production of around 16896.42 ETB/ha. This means that growers should expect to receive an additional Birr 2.8947 for every Birr 1.00 spent in T3. According to CIMMYT [9], the minimum MRR that is acceptable is between 50% and 100%. Thus, according to the results of the current study (Table 4), the marginal rate of return is greater than 100%. This demonstrated that, in line with all treatments being economically significant.

But by using T3, small-scale farmers with minimal production costs and the largest net gain were attained. However, the usage of T1 for incredibly profitable with higher cost which is advised as second alternative when water is not a limiting problem in area for crop production.

Table 4. *Partial Budget Analysis of Maize production under Deficit Irrigation level.*

Treatmt	Amount of water applied (m³/ha)	Average of grain yield (ton/ha)	Adjusted grain yield (ton/ha)	Total return (ETB/ha)	Variable cost (ETB/ha)	Net income (ETB/ha)	MRR (%)
T1	5,187.20	5.3469	4.81221	50,528.21	19687.79	30,840.42	297.83
T2	4, 409.12	4.7869	4.30821	45,236.21	18357.58	26,878.63	150.68
T3	3898.40	4.3993	3.95937	41,573.39	16896.42	24,676.97	289.47
T4	2593.80	3.0613	2.75517	28,929.29	13649.89	15,279.40	-

4. Conclusions and Recommendation

Through field experimentation, a study was conducted to determine the impact of the level of deficit irrigation on yield and water productivity of maize. According to the findings, all levels of deficit irrigation had a highly significant (P 0.01) impact on maize's yield, yield component, and water use efficiency. T1 and T4 gave the highest and lowest amounts of maize grain, respectively. Similarly, T4 produced the highest IWUE and CWUE, whereas T1 produced the lowest. However, compared to T1, T4, T3, and T2 showed significantly lower yields, which may not be acceptable to farmers. This leads to the conclusion that applying a 75% ETC deficit irrigation level under a conventional furrow irrigation system resulted in water savings of 1288.9mm (1288.8m³/ha) compared to a full irrigation level, which could be used for downstream water user in irrigation scheme.

Acknowledgements

References

[1] Ayana, M., Teklay, G., Abate, M., Eshetu, F. and Mada, M., 2015. Irrigation water pricing in Awash River Basin of Ethiopia: Evaluation of its impact on scheme-level irrigation performances and willingness to pay. African Journal of Agricultural Research, 10 (6), pp. 554-565.

[2] Tolera, T., Legesse, B., Aman, M. and Etensa, T., 2017. Economic valuation of improved irrigation water use: the case of Woliso district, South West Shoa Zone, Oromia national regional state, Ethiopia. Journal of Economics and Sustainable Development, 8 (13), p. 2017.

[3] Seleshi Bekele Awulachew and Mekonnen Ayana, 2011. Performance of irrigation: An assessment at different scales in Ethiopia. *Expl. Agri.* 47 (Sl): 57–69.

[4] Allen, R. G., L. S. Pereira, D. Raes and M. Smith, 1998. Crop Evapotranspiration Guidelines for Calculating Crop Water Requirements. FAO Irrigation and Drainage Paper 56. FAO, Rome, Italy.

[5] Jaiswal, P. C. 2003. Soil, plant and water analysis. Kalyani puplishers. New Delhi, India.

[6] FAO (Food and Agricultural Organization). 2009. CropWat for windows version 8.0. FAO, Rome, Italy. FAO.

[7] Kandiah, A. 1981. A guide for measurement of irrigation water using Parshall flumes and siphons. Technical Bulletin no. 1 Irrigation Agronomy Section Melka Werer Research Station Institute of Agricultural Research, FAO irrigation Specialist. Addis Ababa.

[8] Doorenbos, J. and A. H. Kassam. 1979. Yield response to water. FAO irrigation and drainage No. 33. FAO, Rome, Italy, 194p.

[9] CIMMYT (International Maize and Wheat Improvement Center). 1988. From agronomic data to farmer recommendations: An economics-training manual. Completely Revised Edition. CIMMYT, D. F, Mexico.

[10] FAO (Food and Agriculture Organization). 1977. Crop water requirements. FAO Irrigation and drainage paper 24, Rome.

[11] Dirirsa, G., Woldemichael A. and Hordofa T. 2017. Effect of Deficit Irrigation at Different Growth Stages on Onion (Allium Cepa L.) Production and Water Productivity at Melkassa, Central Rift Valley of Ethiopia. Acad. Res. J. Agri. Sci. Res. 5 (5): 358-365.

[12] FAO (Food and Agricultural Organization). 2002. Deficit irrigation practices. Water report No. 22. Food and Agricultural Organization of the United Nations Rome, Italy.

[13] Sarkar, S., S. B. Goswami, S. Mallick and M. K. Nanda, 2008. Different indices to characterize water use pattern of micro sprinkler irrigated onion (Allium cepa L.). Agricultural Water Management, 95: 625-632.

[14] Bhagyawant, R. G. Gorantiwar, S. D. Dahiwalkar, S. D. Bhalekar, M. N. and Khedkar, D. D. 2015. Yield Response Factor for Onion (Allium Cepa L) Crop under Deficit Irrigation in Semiarid Tropics of Maharashtra. Curr. Agri. Res. Jour., Vol. 3 (2), 128-136 (2015).

[15] Temesgen T, Ayana M, Bedadi B., 2018. Evaluating the Effects of Deficit Irrigation on Yield and Water Productivity of Furrow Irrigated Onion (Allium cepa L.) in Ambo, Western Ethiopia. Irrigat Drainage Sys Eng 7: 203. doi: 10.4172/2168-9768.1000203.