International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 4 Issue 11, November-2015

Effect of Deficit Irrigation on Maize under Conventional, Fixed and Alternate Furrow Irrigation Systems at Melkassa, Ethiopia

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Abstract: **Deficit irrigation and application system in furrow irrigation are important concerns to improve water productivity in areas of water scarcity. This study aims to identify suitable furrow irrigation system and level of deficit irrigation which allows achieving optimal crop yield, quality and water use efficiency of Maize. Twelve treatment combinations of four levels of irrigation water application based on crop evapotranspiration of the crop and three types of furrow irrigation system such as Alternate furrow, Fixed furrow and Conventional furrow were used in completely randomised block design with three replications. Results indicated that different level of deficit irrigation had a significant effect on maize fresh biomass and highly significant effect on grain yield. The highest water use efficiency of 2.06kgm^{-3} was obtained from alternate irrigation system at 70 percent of crop water application. The highest grain yield of 8.4 tons per ha was obtained from conventional furrow irrigation at 100 percent of crop water application and had no significant difference with 85 percent of crop water application. Alternate furrow irrigation at 70 percent of crop water application showed 20 percent yield reduction and saved 65 percent irrigation water while at 100 percent crop water application it resulted in 50 percent water saving for 5.5 percent yield reduction.**

Key words: Deficit irrigation, furrow irrigation, crop evapotranspiration, water use efficiency, Maize.

I. INTRODUCTION

Agriculture is the dominant economic sector; most of Ethiopia’s cultivated land is under rain-fed agriculture. It is becoming risky practice due to highly erratic and uneven distribution of rain in most areas of the country. Failure of a given seasonal rain leads to severe drought conditions and widespread food insecurity. In the semi-arid areas of Ethiopia, water is the most limiting factor for crop production. In these areas where the amount and distribution of rainfall is not sufficient to sustain crop growth and development, an alternative approach to make use of the rivers and underground water for irrigation is necessary.

Ethiopia receives an apparently adequate rainfall for crop production if one considers country-wide average annual rainfall. However, the production of sustainable and reliable food supply is becoming almost impossible due to temporal and spatial imbalance in the distribution of rainfall and the consequential non-availability of water at the required period. Often, crop failure occurs because of insufficient water at some critical growth stages. To curb such conditions, and improve water productivity, there is a growing interest in deficit irrigation, an irrigation practice whereby water supply is reduced below maximum level and mild stress is allowed with minimal effect on yield [16]. Satisfying crop water requirements, although it maximizes production from the land unit, does not necessarily maximize the return per unit volume of water [11]. Therefore, in an effort to improving water productivity, there is an increasing interest in judicious application of irrigation water, irrigation practice which controls the spatial and temporal supply of water so as to promote growth and yield, and to enhance the economic efficiency of crop production. However, this approach requires precise knowledge of crop response to water as drought tolerance varies considerably by growth stage, species and cultivars.

Irrigation development is increasingly implemented in Ethiopia more than ever to supplement the rain-fed agriculture and increase agricultural productivity. It aims to increase agricultural productivity and diversify the production of food and raw materials for agro-industry as well as to ensure that the agriculture to play a pivot for driving the economic development of the country [7]. However, the overall performance of the crop production is still hindered due to unsustainable water supply. So as to surmount the problem in water deficit for crop production supplemental water has to be supplied in the form of irrigation. But, water for irrigation may not be ample or not be available nearby the irrigation field. This needs additional investment for water convergence and is a difficult task to carry in poor farmer level. Therefore, one has to learn how to wisely manage the limited water, as water management is an important element of irrigated crop production.

Increasing water productivity is crucial in arid and semi-arid regions. Development of new methods for reducing water loss in agriculture sector can mitigate the water shortage. Deficit irrigation including alternate furrow irrigation could be applied in agricultural land with limited available irrigation water. Among the surface irrigation methods, furrow irrigation technique is known to have better efficiency and can be used in situations where water shortage is critical. According to [4], 97.8% of irrigation in

Ethiopia is made by surface methods of irrigation especially by furrow system in farmer’s fields and majority of the commercial farms. Deficit irrigation of maize distributed over the whole growing season might not always result in increasing crop water productivity. This is due to variation in sensitivity of different growth stages to less water application. Therefore, it is important to know the crop response to water deficit at different levels of crop evapotranspiration (ETc) and irrigation systems and under cropping and irrigation conditions of a given area. Considering the scarcity of irrigation water in the region and the sensitivity of maize crop to less amount of moisture, this research was aimed at determining the yield response factor of maize under deficit irrigation practice using the three furrow irrigation systems during which the crop (maize) can produce optimum yield with less amount of water.

II. MATERIALS AND METHODS

2.1 Site Description

This study was conducted at Melkassa Agricultural Research Center (MARC). The center is found near Awash Melkassa (8˚ 24’N latitude, 39˚21’E longitude) that is 17 km southeast of Nazareth town and 107 km South East direction away from Addis Ababa. The area is situated at an altitude of 1550m.a.s.l. The long term meteorological data of Melkassa indicated that average annual rainfall is 768 mm. The average monthly maximum and minimum temperatures are 28.5˚C and12.6˚C, respectively. The soil of the experimental farm has a dominantly loam and clay loam texture.

2.2 Experimental Design

The experiment was a two factor factorial experiment laid out in Randomized Completely Randomized Block Design (CRBD) with three replications. Randomized complete block design was selected to prevent the effect of soil fertility difference on the treatments and blocking was made across the fertility gradient. The experiment included three furrow irrigation systems and four irrigation levels. The three furrow irrigation systems are Alternate furrow irrigation (AFI), Fixed furrow (FFI) and Conventional furrow irrigation (CFI) and the four irrigation levels are 100% ETc, 85%ETc, 70% ETc and 50% ETc of the requirement. The experiment had twelve treatment combinations and 36 plots. The amount of irrigation water to satisfy the crop water requirement was computed with soil moisture balance model. Each experimental plot had 5m length and 4.30 m width with 2 m free space between plots and 3.2m wide double band between replications.

2.3 Climatic Characteristics

Thirty years average climatic data (maximum and minimum temperature, humidity, wind speed, and sunshine hours) on monthly basis were collected from Melkassa, meteorological observatory station. Potential Evapotranspiration ETo was estimated using CROWAT software version 8.

TABLE 1: LONG-TERM MONTHLY AVERAGE CLIMATIC DATA OF THE EXPERIMENTAL AREA

Month	T_{max} (˚C)	T_{min} (˚C)	RH (%)	Wind velocity (m/s)	Sunshine hrs (%)	ETo (mm/day)
January	27.66	11.91	50.96	3.10	8.90	5.92
February	28.89	13.37	49.73	3.17	8.88	6.61
March	30.13	15.18	50.54	3.02	8.33	6.79
April	30.15	15.42	51.56	2.75	8.28	6.56
May	30.84	15.50	50.73	2.66	8.87	6.59
June	29.94	16.32	53.68	3.23	8.43	6.48
July	26.93	15.63	65.99	3.21	7.07	5.20
August	26.22	15.31	68.99	2.48	7.08	4.73
September	27.46	14.38	65.14	1.73	7.45	4.79
October	28.66	11.73	49.84	2.31	8.54	6.02
November	28.30	10.83	45.31	2.94	9.74	6.23
December	27.55	10.73	49.23	3.14	9.43	5.79

2.4 Crop Water Requirement of Maize

Using daily meteorological data the daily reference evapotranspiration was determined with the help of CROPWAT software 8. The crop water requirement of the test crop was calculated by multiplying the reference ETo with crop coefficient (Kc). In fact this estimated daily crop water requirement has been used as a control mechanism to know how much water could be possibly consumed by the test crop; however the amount of water applied was based on monitoring the allowable depletion level, growth stage and the correspondent effective root depth.

2.5 Water use efficiency

Crop water use efficiency is the yield harvested in kilogram per total water used. Crop Water Use Efficiency (WUE) is the ratio of crop yield to the amount of water depleted by the crop in the process of evapotansiparation (kg/mm), Y stands for Yield of maize (kg/ha) and I is Total net irrigation water applied (mm/ha) [8].

$$\mathrm{WUE} = \frac{\mathrm{Y}}{\mathrm{I}}$$

2.6 Harvest index (HI)

Harvest index (HI) is the amount of maize grain yield production per biomass production

$$\mathrm{HI} = \frac{\mathrm{Y}}{\mathrm{BM}}$$

Where: Y - Yield of maize (kg/ha)
BM – Above ground biomass of maize (kg/ha)

2.7 Yield Response factor

Yield response factor which links relative yield decrease to relative evapotranspiration deficit, was determined using the next equation: ky stands for yield response factor, Ya for actual yield (kg/ha), Ym for maximum yield (kg/ha), ETa for actual evapotranspiration (mm) and ETm for maximum evapotranspiration (mm) [14].

$$\left(1-\frac{Y_a}{Y_m}\right)=K_y\times\left(1-\frac{ET_a}{ET_m}\right)$$

From the four parameters, it is possible to calculate Ky where the available water supply does not meet the full moisture requirements of the crop.

2.8 Data analysis

Data collected were statistically analyzed using SAS software version 9.0 when treatments are significant mean separation using least significant difference (LSD) at 5% probability level was employed to compare the differences among the treatments mean.

III RESULTS AND DISCUSSION

To evaluate the yield response to deficit irrigation in combination with the AFI, FFI and CFI irrigation systems, a number of direct and indirect measurements had been made. These included computations of crop water requirement using climate data, determination of water use efficiency and yield performance assessment. .

3.1 Crop water and Irrigation Demand

Maize variety Melkassa - II was planted on 24th February, 2014. Total precipitation during the months of February to July was insignificant. As a result, throughout the growing period, the climatic water deficit was important and irrigation was necessary for crop production in the area. From effective rainfall and crop water demand data, net irrigation was arrived using CROPWAT software version 8. Totally 12 irrigation events were adopted during the crop period.

TABLE 2: CROP WATER REQUIREMENT OF THE CONTROL TREATMENT (100%ETC AND CFI)

Date	Net Irrigation (mm)	Effective Rainfall(mm)	Gross Irrigation (mm)
13-Mar/2014	29.86	0.00	45.93
18-Mar	24.86	5.00	38.24
24-Mar	72.90	5.50	112.15
1-Apr	72.90	5.50	112.15
7-Apr	84.95	10.25	130.69
16-Apr	95.20	0.00	146.46
25-Apr	79.84	15.36	122.83
3-May	95.20	0.00	146.46
15-May	106.40	0.00	163.70
26-May	101.28	5.12	155.82
5-Jun	101.20	0.00	155.69
20-Jun	101.20	0.00	155.69
Total	864.58	46.73	1330.12

The control treatment plot was monitored and used as a reference to apply irrigation water in other treatments. Soil moisture variation shows that after irrigation the soil moisture rarely exceeded the field capacity of 37.5% and at the same time it never reached the permanent wilting point (Fig 1).

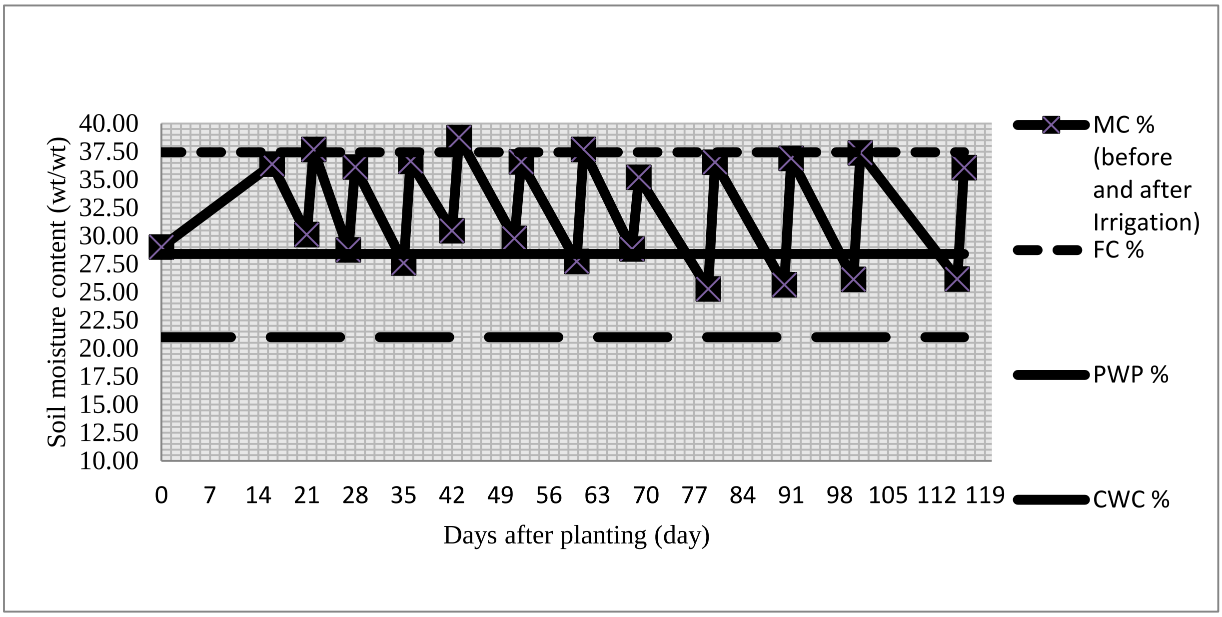

Fig 1: Soil moisture dynamics of control treatment

TABLE 3: NET IRRIGATION DEPTH OF DEFICIT PLOTS

Date	AFI/FFI 50%ETc	AFI/FFI 70%ETc	AFI/FFI 85% ETc	CFI 50%ETc, AFI/FFI 100%ETc	CFI 70%ETc	CFI 85%ETc
13-Mar	7.46	10.45	12.69	14.93	20.90	25.38
18-Mar	0.00	5.45	7.69	9.93	15.90	20.38
24-Mar	16.56	21.94	27.82	33.70	49.38	61.14
1-Apr	14.10	21.94	27.82	33.70	49.38	61.14
7-Apr	13.55	23.07	30.21	37.35	56.39	70.67
16-Apr	23.80	33.32	40.46	47.60	66.64	80.92
25-Apr	8.44	17.96	25.10	32.24	51.28	65.56
3-May	23.80	33.32	40.46	47.60	66.64	80.92
15-May	26.60	37.24	45.22	53.20	74.48	90.44
26-May	21.48	32.12	40.10	48.08	69.36	85.32
5-Jun	21.50	32.40	39.35	48.30	69.34	85.23
20-Jun	21.50	32.40	39.35	48.30	69.34	85.23
Total	177.30	269.21	336.92	406.63	589.69	727.09

Note: All the values are in mm

3.2 Soil characterization of the experimental site

Soil physical characteristics were determined at Melkassa Agricultural Research Center laboratory and the results are presented below (Table 4).

TABLE 4: SOIL CHARACTERISTICS OF THE EXPERIMENTAL SITE

Soil property		Soil depth (cm)		
	0-30	*30-60*	*60-90*	*average*
Particle size distribution				
Sand (%)	35.88	34.68	34.31	34.96
Silt (%)	28.91	28.16	28.15	28.40
Clay (%)	35.21	37.16	36.15	36.17
textural class	Clay loam	clay loam	clay loam	Clay loam
Bulk density (g/cm^3)	1.11	1.17	1.17	1.15
Field Capacity (Volume basis %)	41.56	36.05	35.21	37.60
Permanent Wilting Point (Volume basis %)	23.31	21.17	20.68	21.72
Total Available Water (mm/m)	54.75	89.25	130.77	170

3.3 Yield

Deficit irrigation in combination with irrigation systems has significantly influenced the grain yield of maize production ($P < 0.01$) from the result obtained highest yield was scored 8.41 tons/ha from control treatment and it has no significant difference from CFI at 85% ETc., AFI at 100%ETc. and AFI at 85%ETc. The minimum grain yield 3.1ton/ha was obtained from FFI and 50% ETc. The result indicated the irrigation water applied to the highest yielding treatment next to the control was 50% less than that of applied to the control and the yield reduction was 5.58%. Then there was no significant difference between CFI and AFI in terms of the biomass and dry matters. While the yield decreased significantly in FFI compared to AFI. In fact, AFI had smaller yield reduction relative to FFI. The highest biomass and dry matters were obtained in CFI (55.0 and 20.2 ton ha^{-1}, respectively), but AFI had the highest WUE (2.82 kg/ m^3). The WUE values for CFI and FFI were 1.61 and 1.31 kg/ m^3 respectively. FFI not only decreased the biomass and dry matters (27.3 and 8.3 ton ha^{-1}, respectively) but also had the lowest WUE relative to two other irrigation treatments.

TABLE 5: ANALYSIS OF VARIANCE OF YIELD AND YIELD PARAMETERS

Source of variation	df	Average Mean Square					
		PH	*FBMPHA*	*DBMPHA*	*GYPHA*	*HI*	*WUE*
REP	2	391.75*	9682514ns	4135398ns	1983920.03ns	17.29ns	0.07ns
TRT	11	827.6***	201172716*	149814846**	7562099.63***	57.04ns	0.704***
Error	22	76.08***	76340835*	42779686*	844516.3***	49.23ns	0.04***
CV(%)		5.08	25.54	23.44	15.2	31.08	15.48
R-square		0.85	0.63	0.63	0.82	0.379	0.889

PH : Plant Height FBMPHA : Fresh Biomass per Hectare DBPHA : Dry Biomass per Hectare GYPHA : Grain Yield per Hectare HI : Harvest Index WUE : Water Use Efficiency * ** *** significant at($P<0.05$), ($P<0.01$) and ($P<0.001$) ns – non significant

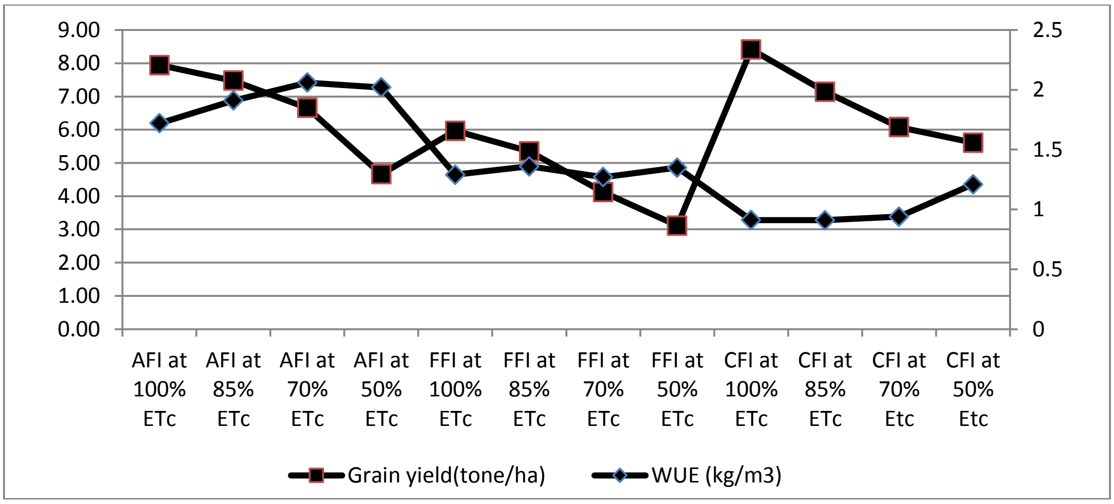

Fig 2 : Effect of deficit irrigation on grain yield of Maize

3.4 Water use efficiency

WUE was significantly influenced ($P < 0.001$) by the deficit irrigation applied in Maize production. The highest WUE 2.06 kg/m^3 was obtained by AFI at 70% ETc and 0.911kg/m^3 was the minimum WUE obtained by FFI at 50% ETc. AFI and FFI have indicated better performances in terms of WUE. The amount of water saved ranges from 15% to 75% of the control treatment. The results also indicated that deficit irrigation enhances water use efficiency. The reason of having high WUE and lower reduction of yield for AFI could be related to better distribution of the roots in both sides of the ridges it increases water and fertilizer up take by plants and the physiological response of the crop specifically in the root and leaf parts. [9] showed that AFI increased WUE for maize (1.37 kg/m^3) relative to CFI and the study of [6] indicated that AFI had better performance for increasing WUE (2.67 – 5.75kg/m^3) relative to alternate furrow irrigation resulted in significant reduction in Maize grain yield. Alternate furrow irrigation also increased water use efficiency in wheat-cotton rotation in Punjab, India [15]. Moreover, application of the alternate furrow irrigation increased water productivity rather than conventional furrow irrigation in sugarcane fields in southern part of Iran [12]. [6] evaluated the alternate furrow irrigation (AFI), fixed furrow irrigation (FFI) and conventional furrow irrigation (CFI) with different irrigation amounts for maize production. They reported that yield reduction in AFI was not significant unlike FFI.

TABLE 6: EFFECT OF DEFICIT AND FURROW IRRIGATION SYSTEMS ON YIELD AND YIELD COMPONENTS

Treatments (Irrigation. as % Etc)	FBMPHA* (kg/ha)	DMPHA** (kg/ha)	GYPHA** (kg/ha)	HI	WUE** (kg/m^3)
AFI at 100%	41908^{abc}	32769^{abc}	7942.8^{ab}	24.94^{ab}	1.72^{a}
AFI at 85%	38869^{abc}	31690^{bcd}	7477.3^{abc}	25.63_{ab}	1.91^{a}
AFI at 70%	31714^{bcd}	25058^{cde}	6657.0^{abcd}	27.67a	2.06^{a}
AFI at 50%	25055^{d}	19479^{e}	4661.0^{fgh}	24.04^{ab}	2.02^{a}
FFI at 100%	32800^{bcd}	26255^{cde}	5968.3^{cdef}	22.88^{ab}	1.29^{bc}
FFI at 85%	30070^{cd}	25062^{cde}	5349.4^{efg}	21.47^{ab}	1.36^{bc}
FFI at 70%	29201^{cd}	24896^{cde}	4122.1^{gh}	16.99^{ab}	1.27^{bc}
FFI at 50%	24875^{d}	20815^{de}	3112.4^{h}	14.49^{b}	1.35^{bc}
CFI at 100%	50029^{a}	42965^{a}	8412.9^{a}	19.56^{ab}	0.912^{c}
CFI at 85%	46306^{ab}	38026^{ab}	7141.2^{abcd}	19.48^{ab}	0.91^{c}
CFI at 70%	30338^{cd}	24461^{cde}	6075.7^{cdef}	25.34^{ab}	0.94^{c}
CFI at 50%	29340^{cd}	23320^{cde}	$5611.6d^{efg}$	27.43^{a}	1.21^{bc}
LSD at 0.05	14795	11075	1556.1	11.44	0.526
C.V %	25.54	23.44	15.2	30.03	15.48

Groups : a,b,c,d,e,f,g,h Means followed by the same letters in column are not statistically different at 5% level for Least Significant Difference Test. * Significant at $p<0.05$ and **significant at $p<0.01$

3.5 Crop response factor

The result indicated crop response ranged $0.35 < Ky < 2.58$. There is insignificant yield reduction in AFI while in FFI deficit irrigation system the yield penalty was quiet significant. The yield reductions were not similar for the same amount of water saved in different ways of irrigation systems. The reason behind this finding need to be investigated, and research findings on crop physiological response to moisture deficit are showing there is a systematic metabolic impulse to the moisture stress imposed. There has been a vital questions raised by [6] stated how can the AFI method save water without a trade-off in grain yield? And they discussed in detail about the physiological response of the maize crop to the water stress in the effective root zone. By a root drying signal of the stomatal opening when roots are in drying soil, even in a situation where only part of the root system is dry, substantial Abscisic acid is produced in the roots and transported through the xylem to the shoots where stomatal opening is regulated [2]. AFI takes advantage of this physiological response and exposes part of the root system alternatively to the drying soil. As [5], described alternate method of watering can lead to continuous stomatal inhibition and reduced leaf transpiration. Photosynthesis and dry matter accumulation are less affected by such partial stomatal closure because photosynthesis and stomatal opening have a saturation relationship. Maximum stomatal opening does not necessarily lead to maximum photosynthesis.

Transpiration and stomatal opening, however, have a linear relationship. [6] believe that AFI can avert severe leaf water deficit, which develops in the shoots when irrigation is drastically reduced. Evidence for this conclusion is that the AFI treatments show no significant reduction in terms of shoot height and grain yield when irrigation was reduced. It is well known that leaf growth and shoot elongation are inhibited when shoot water deficit develops and turgidity is reduced as a result [1]. [6] has also investigated on Why to use alternate furrow irrigation instead of continuously exposing part of the root system to drying, i.e. the FFI system? This is because prolonged exposure of roots to dried soil may cause some anatomical changes in the roots [10]. The effect of such changes is that the roots develop much reduced water permeability on their surface and no longer respond to the dried soil. Alternate wetting may improve this situation through a continuous stimulation of new secondary roots on these primary roots

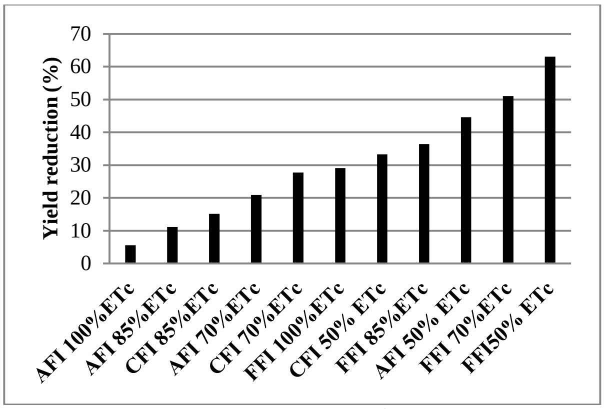

Fig 3: Yield reduction due to deficit irrigation

As shown in fig. 6 the percent of yield reduced is increased as the amount of water saved increased, besides the water application system has a significant impact on yield reduction. Fixed furrow irrigation system and deficit irrigation level treatment combinations have a minimum of 29.06% yield reduction as compared with the control treatment. Whereas alternate furrow irrigation showed 20% yield reduction to save 65 % irrigation water, and 5.5% yield reduction with 50% irrigation water, thus becoming best treatment. [13] reported that AFI exhibited 50% reduction in irrigation water without significant variation of grain yield. This is achieved due to precise measurement and application of irrigation water minimizing percolation losses in alternate furrow irrigation. Furthermore the scheduling of irrigation was done by soil moisture observation and most of the irrigation events were performed to replenish soil moisture within field capacity of the soil. This reveals that well scheduled and controlled irrigation can also help coping with water scarcity along with appropriate irrigation water application method.

IV Conclusion

The results of the study revealed that, deficit irrigation has improved the water use efficiency without significantly reducing the grain yield. The main objective of this study was to find the higher water use efficiency with the possibility of lower reduction in grain yield of Maize production in irrigated agriculture. Based on the objective, among the twelve treatments used in this experiment, deficit irrigation AFI at 100% ETc was the best treatment to be selected. However, the conventional furrow irrigation with 100% ETc (control) demonstrated the highest biomass, grain yield and yield parameters measured except in water use efficiency. Despite this fact alternate furrow irrigation method with all the four deficit irrigation levels showed higher WUE and only 5.58% of yield reduction was observed in 50% less application of water as compared to the control treatment.

In general plots received AFI treatments were be able to deliver comparable yield and yield parameter such as number of row per cob, number of seed per row, dry matter per hectare, above ground biomass per hectare, plant height, grain yield per hectare and water use efficiency. When compared with irrigating every- furrow high water savings without significant reductions of yield were obtained by alternate furrow irrigation. Similarly average WUE were 1.93 kg/m^3 in AFI and 1.32 kg/m^3 in FFI this means both AFI and FFI have higher WUE than the average value of the CFI which is 0.99kg/m^3. The results demonstrate that deficit irrigation in Maize is possible and shows the clear advantage of alternate furrow irrigation over conventional furrow irrigation system. Though fixed furrow irrigation system had higher water use efficiency the loss in yield for the correspondent level of deficit was much higher than that of the alternative furrow irrigation.

Applying deficit irrigation, water use efficiencies was improved and 50% to 75% of water was saved without significantly reducing the yield and therefore water saved could be used to cultivate additional land in areas where there is water scarcity and it could increased the cultivated land especially in regions having scarcity of natural resources. Alternate furrow irrigation method was able to save water by 65% of the irrigation water with a minimum 5.58% decrease in yield as compared to the control treatment. The water saved can therefore be used to increase the irrigation areas in places where water scarcity is severe. Among the treatments induced alternate furrow irrigation with 70% ETc depth of application was recommended technique since it saves highest for insignificant yield trade - off

Acknowledgment

The authors thank Dr. Tilahun Hordofa for his technical support. We are also highly indebted to the Melkassa Agricultural Research Center, Soil and Water Research Process. Mr. Gobena Dirirsa irrigation team representative, and Mr. Mitiku, field assistant, are acknowledged for technical assistance. Thanks to Ethiopian Institute of Agricultural Research (EIAR), Sustainable intensification of maize legume cropping sytem in eastern and southern Africa project (SIMLESA) for providing the financial support for the research.

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