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Effect of Furrow Method and Mulch on Bulb Yield and Water Productivity of Irrigated Onion under Central Highland Vertisol of Ethiopia

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ይህ የምርምር ሥራ በመስኖ በሚመረት ሽንኩርት ላይ በጣም ውጤታማ የውኃ ቆጣቢ ቴክኖሎጂዎችን ለመምረጥ እና የውኃ ምርታማነትን ለማሻሻል በደብረ ዘይት የግብርና ምርምር ማዕከል የተካሄደ ነው። ሙከራው የተካሄደው በሶስት የቦይ መስኖ ውኃ አሰጣጥ ዘዴዎች እና በሶስት አፈር የመሸፈን ዘዴዎች በተከፋፈለ መደብ ውስጥ ነው። ከጥናቱ ውጤት እንደተገኘው የተለያዩ የቦይ መስኖ ዘዴዎች በሽንኩርት ምርትና ውኃ አጠቃቀም ላይ ከፍተኛ ተፅዕኖ አሳድሯል። በተጨማሪም፣ የሽንኩርት ዕድገት፣ የምርት እና ምርታማነትን ከማሻሻል አንፃር የተለያዩ የትነት መከላከያ ልባስ ዘዴዎች መካከል የታየው ተፅዕኖ ከፍተኛ እንዳልሆነ ውጤቱ አሳይቷል። ይሁንና በጣም ከፍተኛ የሆነ የሽንኩርት ምርት (39.5 ቶን በሄክታር) በተለመደው መደበኛ የመስኖ ዘዴ የተመዘገበ ሲሆን ተለዋጭ የቦይ መስኖ ውኃ አሰጣጥ (34.3 ቶን በሄክታር) ምርት በማስገኘት በሁለተኛነት ተመዝግቧል። ሆኖም ከፍተኛ የውኃ አጠቃቀም ውጤታማነት (9.7 ኪ.ግ/ኩዩቢክ ሜትር) የተገኘው በተለዋጭው የመስኖ ዘዴ ምክንያት ሲሆን ይህም ከተለመደው የመስኖ ውኃ አሰጣጥ የውኃ ፍጆታ (5.7 ኪ.ግ/ኩዩቢክ ሜትር) ጋር ሲነፃፀር በጣም ከፍተኛ ነው። ስለሆነም የሽንኩርት ምርት እና የውኃ ምርታማነት ከተለምዶ የመስኖ ውኃ አሰጣጥ ዘዴ ከ18 እስከ 22 በመቶ ጭማሪ አሳይቷል። ተለዋጭ የቦይ መስኖ ውኃ አሰጣጥ ዘዴ ደግሞ ከተለመደው እስከ 42 በመቶ የውሃ አጠቃቀምን ምርታማነትን አሳይቷል። ስለዚህ የመስኖ ውሃ እጥረት ባለባቸው አከባቢዎች ተለዋጭ የቦይ መስኖ ውኃ አሰጣጥ ዘዴ የአፈርን በፕላስቲክ የመሸፈን ዘዴን በማቀናጀት በተለያየ ምክንያት የሚባክነውን የመስኖ ውኃ በከፍተኛ ሁኔታ መቀነስ እንደሚቻል የተገኘው ውጤት ያሳያል።

Abstract

The aim of this study was to select the most effective water-saving techniques and improve the water use efficiency of irrigated onions under limited agricultural water availability. The experiment was conducted in split plot design with three types of furrow irrigation methods and mulch types in three replications. The result revealed that different types of furrow method and mulch type are significantly affected ($p<0.01$) marketable yield of onion. It has been observed that the significantly highest marketable yield (39.5 t/ha) of onion was recorded due to CFI and followed by AFI method (34.3 t/ha). However, the highest WUE (9.7 kg/m3) was obtained due to AFI method when compared with the CFI method of 5.7 kg/m3. Hence, there was 18 to 22% increment of marketable yield and WUE of the onion by applying mulching over the non-mulching condition and also 42% improvement of WUE by using AFI over the conventional furrow method. Therefore, for maximizing the marketable yield of onion under limiting irrigation water resource, irrigation of onion could be done with AFI method with plastic mulch application to minimize evaporation loss and maximize water productivity of onion for similar agro-ecology and soil type.

Keywords: Water use efficiency, furrow method, mulch type and water productivity

Introduction

Globally and more particularly for many developing countries including India, Ethiopia, changing water availability and quality pose complex problems and management options are not easy. The changing situation comes partly from increasing demands such as population, industry and domestic requirements partly from consequences of climatic change. Major concerns on future planetary freshwater resources are the effects of climate change on changing sea temperature and levels, drought and flood events, as well as changes in water quality, and general ecosystem vulnerabilities (USGCRP, 2011). Changes in the extreme climatic events are more likely to occur at the regional level than shown in national or global statistics. The unpredictability of climatic events is of key concern to farmers in all countries, particularly in Africa.

As indicated by Rogers et al. (2014), effective management of available water resources (Awulachew *et al.,* 2010) for crop production requires the producer to understand relationships between soil, water, and plants. Knowledge about available soil water and soil texture can influence the decision-making process, such as determining what crops to plant and when to irrigate. The basic soil, water, and plant relationships are important to agricultural producers, but especially to irrigation users that desire to use best management practices such as mulches and efficient furrow management. Hence, it a prudent to make efficient use of water and bring more area under irrigation through available water resources. This can be achieved by introducing advanced methods of irrigation and improved water management practices.

Regulated furrow (deficit) irrigation is one way of maximizing water use efficiency for higher yields per unit of irrigation water used in agriculture (Geerts and Raes, 2009; Negaz *et al.,* 2012). In a deficit irrigation application, the crop is exposed to a certain level of water stress either during a particular growth period or throughout the whole growing season, without significant reductions in yields (FAO, 2000). The expectation is that the yield reduction by inducing controlled water stress will be insignificant compared with the benefits gained through diverting the saved water to irrigate an additional cropped area (Gijon *et al.,* 2007). In South-northern Ethiopia conditions, results on deficit irrigation level have positively influenced the marketable yield of Onion bulb, with bulb yield decreasing as the water deficit level increased (Bekele and Ketema, 2007; Mulu and Alamirew, 2012) However, previous findings showed that the amount of water applied and method of application varied across the reports by crop and study site.

Mulch in tropics improves nutrient and water retention in the soil encourages favorable soil microbial activity and worms, and suppresses weed growth. When properly executed, mulching can significantly improve the well-being of plants and reduce maintenance as compared to bare soil culture (Ramakrishna *et al.*, 2006). The use of mulch reduces the natural water losses through evaporation on the soil surface, thus leading to net return of crops though maximizing yield & water productivity with limited available water (Singh *et al.*, 2016; Kumar *et al.*, 2007). Hence, reducing non-productive loss of irrigation water is best achieved through the integrated use of regulated deficit irrigation along with mulching material for maximum water use efficiency (WUE) in arid and semi-arid lands (Igbadun *et al.,* 2012). So, to improve crop production to feed the ever-increasing population under limiting water resource condition, strategies that conserve moisture in the soil and efficient irrigation techniques should be identified and practiced (Zaman *et al.*, 2001). Therefore, this study aimed to select most effective water-saving techniques for Onion and evaluate the effect of different furrow irrigation and mulching type on the marketable yield of Onion bulbs.

Materials and Methods

Description of study area

The study was conducted at Debre Zeit Agricultural Research Center in Bishoftu town which is located in the central highlands of Ethiopia from 2015-2017. Its geographical extent ranges 08°30’00” to 09°00’00” North and 38°48’30” to 39°10’30” East. It has low relief difference with altitude ranging from 1610 to 1908 meters above the sea level. The soil at the experimental site was heavy clay in textures with field capacity and permanent wilting point of 35% and 19%, respectively. The area receives an annual mean rainfall of around 810.3 mm with the medium annual variability and bimodal pattern. Seasonal variations and atmospheric pressure systems contribute to the creation of three distinct seasons in Ethiopia: Kiremt (June to September), Bega (October to February) and Belg (March to May).

The Kiremt is the main rainy and Belg is the short lasting one while the dry season is attributed to Bega (Selshi and Zanke, 2004). Belg in the study area receives quite small rainfall to support crop production whereas Kiremt is known by long rainy season. About 76 % of the total rainfall of the area falls in Kiremt or wet season, about 15% in Belg and the rest is Bega or dry season which needs full irrigation in the area. The mean maximum temperature varies from 23.7 to 27.7^{0}C while mean minimum temperature varies from 7.4 to 12.1^{0}C (Table-1). However; maximum and minimum reference Evapo-transpiration (ETo) was recorded as 4.9 and 3.3 mm/day in May and July respectively (Table 2).

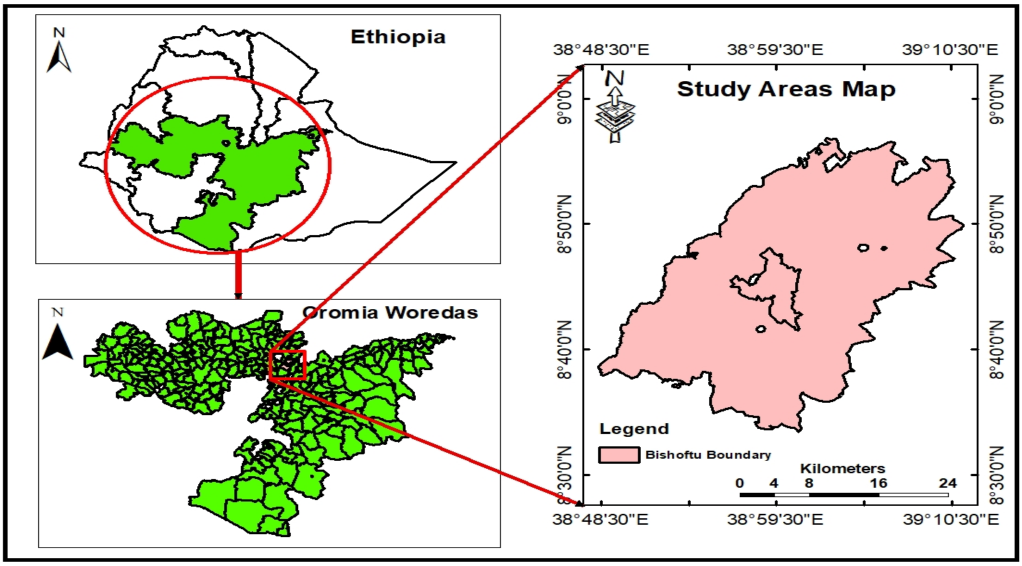

Figure 1. Map of the study area

Table 1. The climate data of 42 years (1975 – 2017) for the study area.

Month	T max (ºC)	T min (ºC)	Relative humidity (%)	Wind speed (m/s)	Sunshine hour (hrs)	Solar radiation (MJ/M²/day)
January	25.2	8.9	63.0	1.3	9.8	22.0
February	26.3	10.2	46.4	1.4	8.5	21.4
March	27.0	11.3	46.4	1.5	8.1	21.8
April	27.1	11.9	47.7	1.5	7.1	20.4
May	27.7	11.6	46.5	1.6	8.6	22.2
June	26.4	11.4	54.9	1.0	6.3	18.4
July	23.7	12.1	66.4	0.9	4.9	16.4
August	23.9	12.1	67.8	0.9	5.5	17.7
September	24.1	11.5	63.3	0.8	6.7	19.6
October	25.0	9.5	49.9	1.4	8.6	21.7
November	24.6	8.0	47.0	1.3	9.3	21.4
December	24.8	7.4	46.9	1.4	9.4	20.9
Average	**25.5**	**10.5**	**53.9**	**1.2**	**7.7**	**20.3**

Reference evapotranspiration (ET0)

The reference evapotranspiration ETo was calculated by FAO Penman-Monteith method, using decision support software CROPWAT8 developed by FAO, based on Allen *et al*., (2007). FAO56 adopted the Penman-Montieth method as global standard to estimate ET_o from meteorological data. The Penman Monteith equation integrated in the CROPWAT program is expressed by the following equation.

Equation-1: $$ET_0 = \frac{0.408\,\Delta(Rn-G)+\gamma\frac{900}{T+273}U2(es-ea)}{\Delta+\gamma(1+0.34u2)}$$

Where: ET_0 is reference evapotranspiration (mm day^{-1}), T, G and Rn are daily mean temperature ^oC at 2 m height, soil heat flux density (MJ m^{-2} day^{-1}) and net radiation value at crop surface (MJ m^{-2} day^{-1}) respectively. Also, u2, e_s e_a, (es–ea), D and c represent wind speed at 2 m height (m s^{-1}), saturated vapour pressure at the given temperature (kPa), actual vapour pressure (kPa), saturation vapour pressure deficit (kPa), slope of the saturation vapour pressure curve (Pa/^oC) and psychometric constant (kPa/^oC), respectively (Allen *et al.,* 1998).

According to Djaman et al. (2013, 2015) being a significant part of the hydrological cycle, the ETo will have its important impacts on ecosystem models, water uses by agriculture, humidity/aridity conditions and runoff due to precipitation estimation. The ETo was calculated using FAO Penman-Monteith method which is one of the most precise equations and CROPWAT8 model is based on this equation:

Table 2. Mean Monthly rain fall, effective rainfall and ETo values of study area.

Month	Rainfall (mm)	Effective Rainfall (mm)	ETo (mm/day)	Season
January	9.4	0.0	4.0	Bega
February	24.8	4.9	4.4	
March	31.5	8.9	4.7	Belg
April	44.2	16.5	4.6	
May	41.3	14.8	4.9	
June	88.9	47.1	3.9	Kiremt
July	235.1	164.1	3.3	
August	208.2	142.6	3.5	
September	83.6	42.9	3.7	
October	25.9	5.5	4.3	Bega
November	7.4	0.0	4.1	
December	1.0	0.0	4.0	
Average	**810.3**	**447.3**	**4.1**	

Crop data and characteristics

Crop data for Onion (Allium cepa) crop characteristics used as input parameters was mainly length of the growth cycle, crop factors, rooting depth, critical depletion factor, yield response factor for each growth stages specified in table-3 below. The basal crop coefficients, Kc, for non-stressed, well-managed crops in sub humid climates (RHmin ≈ 45%, u2 ≈ 2 m/s) for use with the FAO Penman-Monteith ETo (Allen *et al.,* 1998).

Table 3. Kc values, critical depletion and yield response factors for Onion.

Kc and Yield Factors	Growing stages (days)			
	Initial season	Development	Mid-season	Late- season
Growing Periods (120 days)	20	30	45	25
Kc values	0.45	0.75	0.99	0.86
Critical Depletion Fraction	0.15	0.24	0.29	0.32
Yield Response Fraction (Ky=1.1 ave.)	0.9	1.0	1.3	1.2
Maximum Crop height (m)	0.4			
Maximum Root Depth (m)	0.6			

Soil data and specific characteristics

The soil data attribute has their particular data properties to be entered for the software to work accurately. It has the following blanks such as the soil name data, total available soil moisture (FC-WP), maximum rain infiltration rate, maximum rooting depth, and the initial available soil moisture. The soil types had chosen according to FAO soil triangle and soil laboratory characteristics (USDA-NRCS, 2004). According to following soil properties and soil triangle, all layers have loamy sand texture. Therefore, the soil under study could meet the medium soil characteristic FAO soil database and international standards.

To calculated the total available soil moisture for Cropwat8 model, total available soil water (TAW) was computed from the soil permanent wilting point (PWP) and at field capacity (FC)) using the following parameter:

Equation-2: $$\boldsymbol{TAW = \frac{(FC-PWP)}{100} * BD * Dz}$$

Where: TAW is total available soil water (mm/m), FC and PWP in % on weight basis, BD is the bulk density of the soil in gm cm^{-3}, and Dz is the maximum effective root zone depth in mm.

Optimal irrigation regime was applied at 100 % ASMD and hence 100% ETc, RAW to bring the soil root zone depth back to FC. The ASMD, RAW is the amount of water that crops can extract from the root zone without experiencing any water stress. The RAW is computed from the following expression:

Equation-3 $$\boldsymbol{RAW = p * TASW}$$

Where, RAW is the readily available water in mm; p the critical soil moisture depletion in % and TAW is the total available water in mm/ m.

Table 4. Soil properties and characterization

Soil Depth (cm)	Soil Texture (%)				pH, H_2O 1:2.5	EC, 1:2.5 (mS/cm)	BD (g/cm^3)	FC (% vol.)	PWP (% vol.)	TAW (mm/m)
	Sand (%)	Silt (%)	Clay (%)	Class						
0-20	10	30	60	C	6.27	0.15	1.33	39.35	23.76	207.35
20-40	10	32	58	C	6.27	0.15	1.57	35.94	24.58	178.35
40-60	16	34	50	C	6.26	0.12	1.44	39.90	24.94	215.42
Average	**12**	**32**	**56**	**C**	**6.27**	**0.14**	**1.45**	**38.40**	**24.43**	**200.37**

Source: Soil laboratory result analysis of Debre Zeit Agricultural Research Center.

Experimental design and procedure

The experiment was done in a split plot design with three irrigation water application methods (fixed, alternate and conventional furrow method) in main plot and two mulch types (straw and plastic) and control as no mulch. Each main plot factors (furrow irrigation methods) was assigned randomly within each replication and every sub plot factor (mulching) was randomly assigned inside each main plot. Plot size was 3.0 m x 3.0 m which consists of 5 ridges with the spacing 40cm and plant with 5cm spacing interval. Wheat straw mulch with a rate of 6 t/ha was used as mulching types in the sub plots.

The amount of irrigation water applied was calculated using CROP WAT software by using necessary input data (crop, soil and long term climatic data). Irrigation water was applied up to field capacity by monitoring soil moisture content using gravimetric method in the conventional furrow plot. The calculated irrigation depth based on the water holding capacity of the soil profile at every irrigation event. The amount of water was calculated based on the treatments used. For instance for AFI and FFI half of the recommended amount of irrigation water was applied at each events. Three-inch Parshall flume was installed in the experimental area for measuring the amount of water applied to each sub plots.

Data collection and analysis

The selected variety of Onion (Var. Nafis) was planted in November for the consecutive three years in Debre Zeit Agricultural Research Center of main station. During the implementation period, all agronomic & yield parameters and data of irrigation water was collected following the data sheet including date of 50% emergency, days of 95% maturity, stand count at harvesting, fresh biomass yield, marketable yield, bulb diameter and weight was measured after the sample was sun dried for three days. Water use efficiency was calculated using the following formula.

$$\textbf{Equation- 4: } \boldsymbol{Water\ use\ efficiency} = \frac{\boldsymbol{Marketable\ Bulb\ yield}\left(\frac{kg}{ha}\right)}{\boldsymbol{Net\ irrigation\ water\ applied}\left(\frac{m^3}{ha}\right)}$$

Where; Water use efficiency (kg/m^3), Marketable bulb yield (kg/ha) and Net irrigation water applied (m^3/ha).

The collected data were analyzed using statistical analysis system (SAS) software procedure of general linear model for the variance analysis. Mean comparisons were carried out to estimate the differences between treatments using Fisher's least significant difference (LSD) at 5% probability level.

Results and Discussions

Marketable Yield of Onion Bulb

The combined analysis of marketable yield data showed that different types of furrow irrigation and application of mulch in agricultural water management was significantly ($p<0.01$) influenced.

Effect of Furrow Type on Onion Yield

Result analysis showed that different types of furrow method had a significant difference ($p<0.01$) on onion yield as indicated in table-5 below. The maximum Onion yield (39.5 t/ha) were observed at conventional furrow irrigation water application method (Table-5). The maximum marketable Onion yield obtained at conventional furrow irrigation was statistically superior to both alternate and fixed furrow irrigation. However, minimum marketable yield (28.9 t/ha) were obtained at fixed furrow irrigation method. Therefore, the highest marketable yield of onion obtained at conventional furrow irrigation method lead to an improvement of 27 % while alternative furrow was 16% than the fixed furrow irrigation method.

Table 5. Combined analysis of marketable Onion bulb yield (t/ha)

Furrow type	Mulch type				
	No	Straw	Plastic	Mean	LSD (0.05)
CFI	34.65	41.81	42.04	39.50^{a}	
AFI	29.51	37.47	35.81	34.26^{ba}	**5.45**
FFI	24.38	32.00	30.24	28.87^{b}	
Mean	29.51^{b}	37.09^{a}	36.01^{a}		
LSD (0.05)		**1.98**			
CV (%)		**4.51**			

N.B. Treatments with similar letter in the column & also in rows are not significantly different; CV: coefficient of variation; LSD: least significant difference; CFI: conventional furrow irrigation; AFI: alternate furrow irrigation; FFI: fixed furrow irrigation.

Effect of Mulching on Onion Yield

Field experiment of combined analysis result also revealed that different types of mulch on onion yield had highly significant ($p<0.01$) influence as indicated in Table-5. Therefore, maximum marketable yield of onion bulb (37.1 t/ha) were observed at straw mulching condition but the maximum bulb yield obtained at straw mulching condition was statistically similar with that of plastic mulch. Moreover, the minimum (29.5 t/ha) marketable yield obtained at no mulching condition was statistically significant different with both straw and plastic mulching. So, the highest marketable yield of onion bulb obtained at straw followed by plastic mulching showed an improvement of 20% and 18% respectively over the conventional non-mulching condition.

Even though irrigation water depth is reduced due to different irrigation water management methods like alternate and fixed furrow, the applied depth could be conserved due to reduction of evaporation from soil surface by mulching. The conserved moisture content of soil in the root zone could enhance crop transpiration and nutrient uptake and transportation in the plant body. Similarly, Xu *et al. (*2015) reported that plastic mulching improves the accumulation of dry matter, leading to a significantly greater final biomass and an improvement of grain yield of maize by 15-26% both in the dry years. Moreover, Yaseen *et al.* (2014) revealed that maximum increase in biomass (29.56%) and grain yield (35.5%) were recorded on mulch and higher irrigation depth treatments. Panigrahi *et al.* (2011) also revealed that application of black plastic mulching improves yield of okra plant by 21.4 to 36.9% at different allowable soil moisture depletion level and alternate furrow irrigation method.

Water Use Efficiency (WUE)

Water use efficiency was significantly ($p<0.01$) influenced due to different types of irrigation water management methods (Table-6).

Effect of Furrow type on water use efficiency

Results indicated that the water use efficiency of marketable Onion bulb was significantly influenced by application of irrigation water though furrow type. The highest was recorded under alternate furrow irrigation as compared with conventional and fixed furrow method. Maximum water use efficiency (9.86 kg/m^3) observed at alternate furrow which was statistically superior to both conventional and fixed furrow whereas minimum water use efficiency (5.7 kg/m^3) was recorded at conventional furrow irrigation (Table-6). Therefore, the highest water use efficiency of onion obtained at alternative furrow irrigation showed an improvement of 42% and fixed furrow type 31% over the conventional non-mulching condition.

Table 6: Combined analysis of WUE (kg/m3) of Onion.

Furrow type	Mulch type				
	No	Straw	Plastic	Mean	LSD (0.05)
CFI	5.01	6.04	6.06	5.70[c]	
AFI	8.45	10.91	10.20	9.86[a]	5.45
FFI	7.07	9.15	8.71	8.31[b]	
Mean	6.84[b]	8.70[a]	8.32[a]		
LSD (0.05)		**1.98**			
CV (%)		**4.51**			

N.B. Treatments with similar letter in the column & also in rows are not significantly different; CV: coefficient of variation; LSD: least significant difference; CFI: conventional furrow irrigation; AFI: alternate furrow irrigation; FFI: fixed furrow irrigation.

Effect of mulch type on water use efficiency

Application of different types of mulch in field experiment had significantly ($p<0.01$) influenced marketable yield of Onion bulb and water use efficiency. The combined analysis revealed that, water use efficiency was maximized at straw mulch followed by plastic mulching than no mulch condition. The maximum water use efficiency (8.7 & 8.32 kg/m^3) obtained at straw & plastic mulching was statistically no difference with each other but both are superior to no mulch conditions. Hence, the minimum water use efficiency (6.84 kg/m^3) was observed at no mulch condition. Hence, there was 21.4 % and 21.6% increment of water use efficiency of onion by applying straw and plastic mulching respectively over the conventional non-mulching condition.

Generally, different mulching types lead to maximize water use efficiency. Xu *et al.* (2015*)* reported that water use efficiency of maize under plastic mulching (3.27 kg/m^3) was increased by 16% compared to the control treatment without mulching, although the overall evapotranspiration was similar between the two treatments. With reduced soil evaporation, the conserved moisture due to plastic mulching might be allotted to transpiration which improve nutrient uptake and transportation to plant body. Based on different studies in different location, Montazar and Kosari (2007) reported that water use efficiency of different crops including onion could be enhance though mulching to conserve moisture in the soil for proper utilization by the plant. The conserved moisture content of soil in the root zone due to mulching could enhance crop transpiration and nutrient uptake and transportation in the plant body with limited available water.

Opportunity cost of alternative management

The opportunity cost indicates the advantages a producer can get or benefit from the amount of water saved water in other uses that may include production of alternative crops or use in municipal, industrial, or recreational activities. The opportunity cost of water must be considered when seeking an efficient allocation of scarce water resources. In water-limiting conditions, if the water saved by reducing the depth of irrigation is used to bring additional land under irrigation (with the same profit per unit of land), the total farm profit is increased still more. The net income from the additional land represents the opportunity cost of water.

Conclusion and Recommendations

Based on the findings of this experiment, application of mulch played a greater role in minimizing evaporation, due to that available water to plants root varied appreciably. Generally, there was 18 to 22% increment of marketable yield and water use efficiency of onion by applying mulching over the conventional non-mulching condition and also 42% improvement of water use efficiency by using alternative furrow irrigation over the conventional furrow type. Moreover, the highest onion bulb yield obtained at conventional furrow irrigation method lead to an improvement of 27 % while alternative furrow was 16% than the fixed furrow irrigation method.

Therefore, for increasing marketable bulb yield of onion under no water stress scenario, irrigation of onion with conventional furrow irrigation methods could be used. However, under limiting irrigation water resource condition, irrigation of onion could be done with alternate furrow irrigation method with straw mulch application to minimize evaporation loss and maximize water use efficiency of onion for similar agro-ecology and soil type.

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