Black Sea Journal of Agriculture
Open Access Journal
e-ISSN: 2618 - 6578

BSPublishers

Research Article
Volume 3 - Issue 2: 120-127 / April 2020

EFFECT OF DRIP LATERAL SPACING AND IRRIGATION AMOUNT ON TOMATO AND ONION CROPS CUM WATER PRODUCTIVITY AT KOBO GIRRANA VALLEY, ETHIOPIA

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Received: *October 20, 2019;* ***Accepted:*** *January 27, 2020;* ***Published:*** *April 01, 2020*

Abstract

Irrigation system in Kobo-Girrana valley is extensively developed into modern drip irrigation. Tomato and onion are among the major vegetables grown under drip irrigation. However, the drip lateral spacing was fixed to 1m for all irrigated crops. This leads to low crop water productivity, loss of land, less net return income and un-optimized irrigation production. An on-station experiment was conducted to determine the effects of drip line spacing and irrigation amount on yield, irrigation water use efficiency and net return income. The experimental treatments were: two lateral spacing of single (0.5 and 1m) row and double (1 and 2m) row corresponding to onion and tomato test crops and three irrigation amounts (pan coefficients /Kp/ = 0.8, 1.0 and 1.2). The experimental design was factorial arranged in RCBD. The experimental results revealed that there was an interaction effect between the lateral spacing and irrigation amounts on marketable yield and water productivity of the test crops. Application of 0.8 Kp with 2m lateral spacing and 1.2 Kp with 1m lateral spacing provided relatively higher marketable yield of tomato and onion respectively. Similarly, high water productivity was recorded with same irrigation depths and spacing. This result generally revealed that one lateral design for each two plant rows gave high net income than the one lateral design for each one plant row for drip irrigated fresh marketable yield of onion and tomato.

Keywords: Lateral spacing, Water productivity, Marketable yield, Pan coefficient

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Cite as: Wondatir S, Belay Z. 2020. Effect of drip lateral spacing and irrigation amount on tomato and onion crops cum water productivity at kobo Girrana valley, Ethiopia. BSJ Agri, 3(2): 120-127.

1. Introduction

Agriculture is the backbone of the Ethiopian economy. However the sector is predominantly rain fed and the country has experienced chronic food insecurity due to degradation of the natural resource base, and also frequent droughts (Devereux, 2000). Furthermore, the country could not meet its large food deficits through relying on rain-fed agriculture alone. To overcome the effects, the Ethiopian government has been focusing in the promotion of water-centered development approaches.

Irrigation water plays a main role for agricultural growth, which enhances the cropping intensity of high value crops and also increasing the productivity of crops. Hence irrigation water play a great contribute to sustain reduction of rural poverty too. Ethiopia is the country which endowed with abundant water resources and huge irrigable lands for irrigation agriculture (Awulachew et al., 2010; EPCC, 2015). Despite this, much of the available irrigation water is applied through the conventional surface irrigation method, where the efficiency of water is very low. The low irrigation water-use efficiency not only reduces the anticipated outcomes from investments in the water resources sector of the country, but also creates environmental problems, such as lowering of the water table due to over-exploitation of sub-surface water resources, water logging and soil salinity, thereby affecting the yields adversely.

Thus, appropriate irrigation scheduling is required for maximizing the yield and water use (Antony and Singandhupe, 2004). Recently, there is a demand to enhance vegetable production and develop ways through which maximum benefits can be obtained from the limited available water resources.

Kobo Girana valley is among the north eastern area endowed with ground and surface water sources and substantial quantities of vegetables are grown under irrigation during dry season (Abudlkadir . 2015). On the other hand the area is a semiarid with high evapotranspiration rates combined with increasing demand for water limits the production and productivity of the crop.

In order to reduce the water stress in agricultural sector and to improve the efficiency of existing irrigation systems, various initiatives have been taken in Ethiopia in recent years. Thus, in Kobo Girana Valley use of drip irrigation for vegetable crops has increased through government assisted ground water sources development program. Currently significant area, 638ha with 1975 beneficiary farmers, is under drip irrigation development (Abudlkadir, 2015). Onion and Tomato are among the major vegetable crops grown in Kobo Girana valley.

Since moisture stress is completely absent in drip irrigation, the productivity of crops is found to be significantly higher than those cultivated under flood irrigation (Narayanamoorthy, 2004; Namara, Upadhyay, & Nagar, 2005; Shah, T. & Keller, 2014).

Drip irrigation has a multiple advantages; it offers improved yields, requires less water, and decreases the cost of tillage, and reduces the amount of fertilizer and other chemicals to be applied to the crop and also reduce the amount of labor (Tan, 1995; Hanson et al., 1997; Fekadu and Teshome, 1998). Because drip irrigation makes it possible to place water precisely where it is needed and to apply it with a high degree of uniformity at very low flow rates, it decreases both surface runoff and deep percolation. These features make drip irrigation potentially much more efficient than other irrigation methods, which can translate to significant water savings (Hanson et al., 1994 and Camp, 1998). Furthermore drip irrigation is one of the best techniques to use in applying water to vegetables and orchards (Cetin and Uygan, 2008).

However, the drip lateral spacing in the study area is fixed to 1m for all irrigated crops. This leads to low crop water productivity, loss of land, less net return income and un-optimized irrigation production. According to Salah E. El-Hendawy et al, 2008; most vegetable crops in Egypt are grown at lateral spacing of 1.4 m or more with an emitter spacing of 0.3–0.5 m. Among the various components of a drip irrigation system, the cost of laterals is the major factor, which influences the total system cost.

Under drip irrigation, the ponding zone that develops around the emitter is strongly related to both the water application rate and the soil properties (Assouline, 2002). Consequently, the water application rate is one key factor determining the soil water content around the emitter (Bresler, 1978) and the water uptake pattern (Phene et al., 1991; Coelho and Or, 1999). Satpute and Pawade (1992); reported that effect of planting geometries on tomato yield was not significant. A considerable reduction in the lengths of lateral line (25–50%) and micro-tube (33–55%) was observed resulting in 35–41% savings in the cost of the drip system in the two-plant row drip irrigation layout over the individual plant row irrigation layout.

Locassio and Smajstrla (1996) carried out research on tomatoes grown on fine sandy soil with black polyethylene mulch and irrigated by drip irrigation. Water was applied at 0, 0.25, 0.50, 0.75 or 1.0 times pan evaporation. Total marketable yields were highest at 1.0 pan (87.0 t ha-1) and 0.75 pan, (79.3 t ha-1) compared with 30.7 t ha-1 for controls. Total water use was higher with the 0.75 pan schedule.

As a result design of drip irrigation systems is very important for improving the irrigation application efficiency and economic return in the production process (Pannunzio et al., 2004). Lateral spacing is always a compromise between optimal water distribution and lateral cost. Regarding drip systems, an analysis has been made to determine the optimum lateral spacing for drip-irrigated corn in Turkey (Bozkurt et al., 2006). Lateral spacing of 0.7, 1.4, and 2.1 m were compared, leading to a conclusion that the optimum lateral spacing for corn was 1.4 m (one drip lateral per two crop rows).

So, it is imperative to investigate whether spacing adjustment and using one lateral pipe between two plant rows is effective and economical in terms of initial investment cost and irrigation management efficiency. As a result this study was conducted to determine the effect of drip line spacing and irrigation amount on yield, net return, and irrigation water use efficiency.

2. Materials and Methods

The experiment was carried out at Kobo irrigation site for two consecutive years of 2011 and 2012 for onion and tomato crops. Kobo research station is situated at 12.080 N latitude and 39.280 E longitudes at an altitude of 1470 m above sea level (Figure 1).

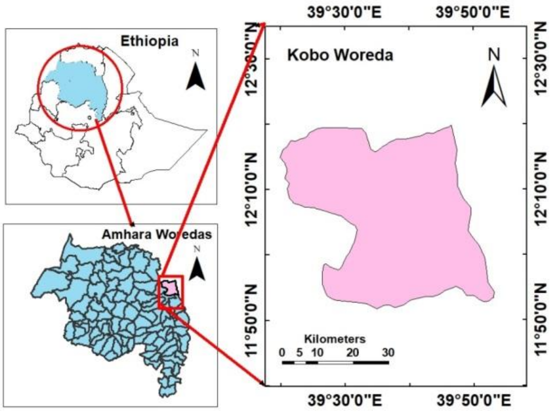

Figure 1. Location map of the study site

The 15 years mean annual rainfall is about 630mm and average daily reference evapotranspiration rate of 5.94 mm. The soil type in the experimental site is silt clay loam which has average infiltration rate of 8 mm/hr., pH value of 7.8, average FC and PWP of 11.5% and 3.2% on volume basis respectively.

The drip system was gravitational type which stand 1.5m head difference from the ground and consisted of PE laterals of 16mm in diameter and PE manifold pipeline of 32mm diameter. The discharge rates of the emitters were calculated as 0.9l/hr. and emitter spacing was chosen as 0.50m. The experimental design was factorial RCBD with 4 replications. Six treatments were composed from two factors: lateral spacing (single and double) and three irrigation depths (80%, 100% and 120%). For tomato and onion 1 and 2m lateral spacing and 0.5 and 1m lateral spacing were used respectively.

<u>For onion crop:</u> as indicated in figure 2a below; 0.5m lateral spacing, plant rows were spaced at 0.2m and the lateral was placed in between the plant rows. For 1m lateral spacing, the spacing between plant rows was 0.2m. Double rows were there on both side of the lateral. Two plant rows (1st and 2nd rows) were planted 0.1m and 0.3m far from the lateral.

<u>For Tomato crop:</u> 1m lateral spacing the plant rows were also spaced at 1m; and the lateral was placed in the plant row. For the 2m lateral spacing two plant rows were planted 0.375m on either side of the lateral. The row spacing was 0.75m. The spacing between plants was 30 and 10cm for tomato and onion respectively (Figure 2b).

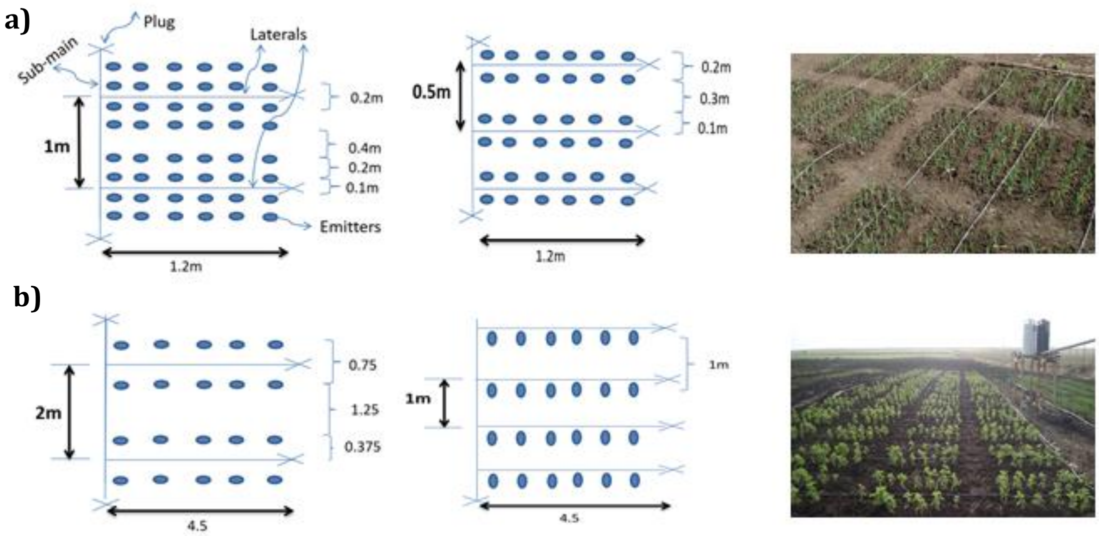

Figure 2. Schematic layout of laterals and plants in the experimental plots for onion (a) and tomato (b)

The amounts of irrigation water applied (I in m^3) in the irrigation treatments were determined by Class-A pan evaporation using the equation given below (Doorenbos and Kassam, 1979):

$$I = A \times E_p \times K_p \times P \qquad (1)$$

Where A is the plot area (m^2), Ep is the cumulative pan evaporation amount for the 4-days irrigation interval, Kp is the coefficient of pan evaporation (i.e. Kp =0.8, 1.0 and 1.2) and P is the percentage of wetted area (P). A 4 days cumulative pan evaporation amount was measured from a class A pan in the meteorological station that found in the research site.

The percentages of wetted area (P) were determined by methods from (Keller and Bliesner, 1990; Yildirim, 2003, Cetin and Uygan, 2008). The P was the average horizontal area wetted in the top 15–30 cm of the crop root zone as a percentage of each lateral line area or calculated by dividing the wet diameter by the lateral spacing.

P= Wet Diameter / Lateral Spacing (2)

Thus, the percentages of wetted area measured in the experimental site were 90% or 45% for lateral spacing of single or double, respectively. The first irrigation for all plots was based on water deficit that would be needed to bring the 0–60 cm layer of soil to field capacity. Subsequent irrigations were applied considering the 4-days irrigation interval.

Irrigation water use efficiency (IWUE) is generally defined as crop yield per water used to produce the yield (Viets, 1962; Howell, 1990).Thus, IWUE was calculated as fresh fruit weight (kg) obtained per unit volume of irrigation water applied (m^3).

IWUE= Yield obtained / Irrigation Water Applied (3)

The economic analysis was carried out through the net benefit investment method; i.e. by subtracting total annual costs from total annual benefits. All calculations were done based on a unit area of 1 ha (Cetin and Uygan, 2008). The other economic analysis parameter cost benefit ratio couldn't be computed, because there was no any continuous production and other operation costs in the project life periods. The total production cost was calculated from the results of investment, operation and production costs. Market price of each vegetable crop in the production year was used for the estimation of total income.

The statistical test was carried out through using Genstat version 18th statistical packages; Duncan's multiple range tests were used to compare and rank the treatment mean values. The differences were considered significant at $p < 0.05$.

3. Result and Discussion

There was an interaction effects between drip lateral spacing and irrigation depths on water productivity of onion and tomato. While there was no interaction effects on bulb yield of onion and tomato.

3.1. Effects of Lateral Spacing and Irrigation Depths on Onion Bulb Yield and Water Productivity

The data in Table 1 revealed that lateral spacing and different irrigation depths had a separate significant effect on marketable yield of onion ($p< 0.01$). However, there was no an interaction effects between different lateral spacing and irrigation depths on marketable yield of onion ($p < 0.05$). The lateral spacing of 1m resulted significantly higher bulb yield than 0.5m lateral spacing. The highest and the lowest marketable bulb yield of 23.54 and 18.21 ton/ha were obtained due to the effects of double (1m) lateral spacing with 120% of irrigation depth and single (0.5m) with 100% of irrigation depth respectively. Bulb yield increased as spacing became doubled. Higher level of irrigation at 120% Kp recorded significantly higher bulb yield for both lateral spacing's.

Table 1. Main effects of lateral spacing and irrigation depth on marketable bulb yield and water productivity of onion and tomato

Lateral spacing	Marketable yield (tone/ha)		Water productivity (kg/m^3)		Irrigation regime	Marketable yield (tone/ha)		Water productivity (kg/m^3)	
	Onion	Tomato	Onion	Tomato		Onion	Tomato	Onion	Tomato
Single	19.01	17.21	3.48	1.997	80%	20.01	20.48	6.93	3.87
double	22.45	21.53	8.13	4.935	100%	20.14	20.03	5.5	3.81
					120%	22.04	17.60	4.99	2.72
LSD	1.24**	2.06**	0.38**	0.244**		1.515*	ns	0.46**	0.299**
CV (%)	10.2	18.1	11	12		10.2	18.1	11	12
GM	20.73	19.37	5.80	3.466		20.73	19.37	5.80	3.466

This result was higher than when compared with the overall average World, Africa and Ethiopian National onion yield of about 15 t/ha, 13 t/ha and 10 t/ha respectively FAO (1995). Research that conducted at Melkasa research center indicated that increase in yield was found as the amount of irrigation water applied increased (IAR, 1988). On the other hand the yield was lower as compare with research results due to irrigation depth of 100% pan evaporation of 50.92t ha-1 (A. N. BAGALI et al. 2012).

As indicated in Table 1 lateral spacing and different irrigation depths separately affects water productivity ($p < 0.01$). Also the two factors had an interaction effects on water productivity of onion at $p < 0.01$ (Table 2). Maximum 9.85 and minimum 3.06kg/m3 water productivity were existed due to the effects of double row lateral spacing with 100% irrigation depth and single row with 120% irrigation depth respectively. The value of water productivity was decreased as the amount of irrigation amount increased.

The seasonal net irrigation requirements for single lateral spacing ranges from 462mm to 692mm as a pan coefficient increased. While each value decreased by half when a lateral spacing became doubled (Table 2). The total irrigation water applied to single row with 120% Kp was 50% higher than that applied to 120% with double row.

Table 2. Interaction effects of lateral spacing and irrigation amounts on marketable yield and water productivity of onion and tomato

Lateral spacing and Irrigation depth	Seasonal irrigation amount (mm)		Marketable yield (tone/ha)		Water productivity (kg/m3)	
	Onion	Tomato	Onion	Tomato	Onion	Tomato
Single row, 80%PC	461.5	449.79	18.26	17.55	4.02	1.601
Single row, 100%PC	576.9	562.24	18.21	18.21	3.36	2.293
Single row, 120% PC	692.3	674.69	20.55	15.88	3.06	2.098
Double row, 80% PC	230.8	224.9	21.76	23.41	6.91	6.130
Double row, 100% PC	288.5	281.12	22.06	21.85	9.85	5.330
Double row, 120% PC	346.1	337.35	23.54	19.33	7.63	3.343
LSD			ns	ns	0.65**	0.4230**
CV (%)			10.2	18.1	11	12
GM			20.73	19.37	5.80	3.466

*= significant ($p<0.05$), **= significant ($p<0.01$), PC= pan coefficient

3.2. Economic Analysis and Evaluation of Onion

As showed in Table 3 and 4 below; Economic analysis and evaluation were computed by using the results of this study based on investment, operation and production costs. Based on the irrigation amount of each treatment in the growing season irrigation duration, labor cost for irrigation and pump cost of 4.26birr/h were estimated. The production costs were computed by considering all production inputs (i.e. costs of seeds, plowing of land, transplanting, hoeing, weeding, pesticide, fertilizer, harvesting etc.) for onion and tomato. The production costs were similar for each treatment and calculated as 10,000.00birr/ha for onion and 7,000birr/ha for tomato in the production season. On the other hand, drip irrigation system costs can vary greatly, depending on crop (plant, and therefore, emitter spacing and hose) (Solomon, 1998).

Thus, based on lateral length, connections, tapes and drippers for the treatment in which the lateral spacing was 1m and the investment costs were 26% less than in the treatment in which the lateral spacing was 0.5 m for onion. And for tomato, 2m lateral spacing had 20.64% less investment cost than 1m lateral spacing. The investment cost of drip system was calculated with 7 years life period (Enciso et al., 2005). According to the calculation for onion 1m lateral spacing with 120% irrigation amount gave the maximum yearly net income of 81,416.03birr. On the other hand less net income of 58,957.35birr was obtained in 0.5m lateral spacing with 100% irrigation amount. This result generally revealed that one lateral design for each two plant rows gave high net income than the one lateral design for each one plant row for drip irrigated fresh marketable yield of onion.

3.3. Effects of Lateral Spacing and Irrigation Depths on Tomato Fruit Yield and Water Productivity

There was significant ($p < 0.01$) difference on marketable tomato yield due to different lateral spacing. There was no significant difference in marketable fruit yield of tomato among different irrigation amounts. A maximum of 21.53ton/ha marketable fruit yield was obtained due to the effect of double lateral spacing. There was no an interaction effects in marketable fruit yield of tomato due to lateral spacing and irrigation amounts.

The amount of marketable yields was slightly decreases as the amount of irrigation water applied increased. The maximum (23.41tone/ha) and minimum (15.88tone/ha) marketable yield of tomato were obtained due to effects of double row spacing with 80% irrigation depth and single row spacing with 120% irrigation depth. In contrast, Çevik et al. (1997) obtained that highest yield at 1.20 of kp. This might be due to the variation of soil and environmental condition of the two areas.

For tomato crops the irrigation water use efficiencies ranges from 1.6 - 6.13kg/m3 depending up on treatments. The maximum irrigation water use efficiency of 6.13kg/m3 was obtained from double lateral spacing (2m) with 80% irrigation depth. This might be related to the wider lateral spacing and low depth of application; which used low amount of total irrigation water. Similarly, Mbarek and Boujelben (2004) showed that IWUE was greatest with double rows in the tomatoes grown in the greenhouse. Also Çevik et al. (1997) found that total water use was higher with the 0.75 pan schedule. These results proved that tomato plants use irrigation water more efficiently at low levels of irrigation.

Generally the highest water use efficiencies occurred in double lateral spacing with small irrigation depth. Furthermore, IWUEs differ considerable among the treatments and generally tends to increase with a decline in irrigation (Howell, 2006). IWUE is an important factor when considering irrigation systems and water management, and probably will become more important as access to water becomes more limited (Shdeed, 2001). On the other hand, water productivity can be increased by increasing yield per unit land area. In addition, water management strategies and practices should be considered in order to produce more crops with less water.

Table 3. Economic analysis of drip lateral spacing for onion crop

T	Amount of irrigation water (mm) (1)	Irrigation water (m^3 ha^{-1}) (2)	Irrigation duration for the irrigation season (h) (3)	Labor cost for irrigation (birr h^{-1}) (4)	Total cost for irrigation labor (birr) (5)= (3*4)	Pump cost (birr) (6) (irrigation duration*unit pump cost) =(3*4.26birr*h^{-1})	Crop production cost (birr ha^{-1}) (7)	Irrigation system cost for 1ha (birr ha^{-1}) (8)	Yearly cost of the irrigation system (birr/ha) (9)=(8/7years)	Total cost for 1 year (birr ha^{-1}) (10)=(5+6+7+9)	Yield (kg ha^{-1}) (11)	Sale price (birr kg^{-1}) (12)	Gross income per ha (birr $ha^{-1}year^{-1}$) (13)=(11*12)	Net income (birr $ha^{-1}year^{-1}$) (14)=(13-10)
1	461.5	4615	90.25	3	270.75	384.47	10000	21444.05	3063.436	13718.65	18260	4	73040	59321.35
2	576.9	5769	112.82	3	338.46	480.61	10000	21444.05	3063.436	13882.51	18210	4	72840	58957.49
3	692.3	6923	135.38	3	406.14	576.719	10000	21444.05	3063.436	14046.29	20550	4	82200	68153.71
4	230.8	2308	45.13	3	135.39	192.25	10000	15768.3	2252.614	12580.26	21760	4	87040	74459.74
5	288.5	2885	56.42	3	169.26	240.35	10000	15768.3	2252.614	12662.22	22060	4	88240	75577.78
6	346.1	3461	67.68	3	203.04	288.32	10000	15768.3	2252.614	12743.97	23540	4	94160	81416.03

T=treatments

Table 4. Economic analysis of drip lateral spacing for tomato crop

T	Amount of irrigation water (mm) (1)	Irrigation water (m^3 ha^{-1}) (2)	Irrigation duration for the irrigation season (h) (3)	Labor cost for irrigation (birrh^{-1}) (4)	Total cost for irrigation labor (birr) (5)=(3*4)	Pump cost (birr) (6) (irrigation duration*unit pump cost) =(3*4.26birr*h^{-1})	Crop production cost (birr ha^{-1}) (7)	Irrigation system cost for 1ha (birr ha^{-1}) (8)	Yearly cost of the irrigation system (birr/ha) (9)=(8/7years)	Total cost for 1 year (birr ha^{-1}) (10)=(5+6+7+9)	Yield (kg ha^{-1}) (11)	Sale price (birr kg^{-1}) (12)	Gross income (birr $ha^{-1}year^{-1}$) (13)=(11*12)	Net income (birr $ha^{-1}year^{-1}$) (14)=(13-10)
1	449.79	4498	165	3	495	703	7000	15768.3	2252.61	10451	17550	2.5	43875	33424.49
2	562.24	5622	206	3	618	877	7000	15768.3	2252.61	10748	18210	2.5	45525	34777.41
3	674.69	6747	248	3	743	1054	7000	15768.3	2252.61	11049	15880	2.5	39700	28650.54
4	224.9	2249	83	3	248	351	7000	12513.8	1787.69	9387	23410	2.5	58525	49138.36
5	281.12	2811	103	3	309	439	7000	12513.8	1787.69	9535	21850	2.5	54625	45089.82
6	337.35	3374	123	3	370	526	7000	12513.8	1787.69	9684	19330	2.5	48325	38641.29

T=treatments

3.4. Economic Analysis and Evaluation of Tomato

The production costs were similar for each treatment and calculated as 7,000birr/ha for tomato in the production season. Based on lateral length, connections, tapes and drippers for the treatment in which the lateral spacing of 2m lateral spacing had 20.64% less investment cost than 1m lateral spacing. The investment cost of drip system was calculated similar with the above onion crop. The lowest 28,650.54birr and highest 49,138.36birr yearly net income were obtained due to treatments of single row spacing (1m) with 120% irrigation amount and double row spacing (2m) with 80% irrigation amount respectively. This result generally revealed that one lateral design for each two plant rows gave high net income than the one lateral design for each one plant row for drip irrigated fresh marketable yield of tomato.

However the result is contrast with Cetin and Uygan (2008), a two row for one lateral to save costs in the drip irrigation system resulted in less net productivity or net income per year. On the other hand, this result is in lined with Satpute and Pawade (1992), observed differences resulting in a 35–41% saving in the cost of the drip system in a two-plant drip irrigation layout over an individual plant irrigation layout. In this study both marketable yield and net income were higher in double lateral spacing.

In general, even though the initial investment cost of drip irrigation system is high relative to other irrigation systems; there is a great possibility to return the investment costs in the project life period. In this study the financial net returns were both positive and relatively higher; which indicated that the investment is encouraging. Due to that in the study area the system has been shifting from surface irrigation to pressurized i.e. drip and sprinkler irrigation systems.

Consequently, economic analysis based on investment and production costs, yields obtained, amounts of irrigation water applied per ha, was done to compare these two treatments. As a result 1m lateral spacing with 120% irrigation amount was given the highest as 81,416.03birr yearly net income return.

For tomato drip lateral spacing determination study the maximum marketable yield 23.41tone/ha was obtained by treatment effects of 2m lateral spacing with 80% irrigation depth to which total seasonal irrigation water amount of 225mm. Similarly 2m lateral spacing with 80% irrigation depth gave the maximum water use efficiency of 6.13kg/m3. Fresh marketable yield slightly decreases as the irrigation amount increases. To get optimum tomato production using one lateral pipe for two plant rows and 80% pan coefficient of irrigation amount is recommendable. Drip irrigation cost of double row lateral spacing was 20.64% less than a single lateral spacing for each crop rows. A maximum marketable yield obtained in treatment of 2m lateral spacing by 80% pan coefficient contribute for a high economical yearly net return income of 49,138.36birr.

An optimized production and irrigation efficiency can be attained by applying irrigation depth adjusted by the given pan coefficients and drip lateral spacing in Kobo areas. Generally in kobo Girana area double lateral spacing is more economical than a single lateral spacing design for onion and tomato vegetables.

Conflict of interest

The authors declare that there is no conflict of interest.

Acknowledgements

The authors would like gratefully acknowledged for the financial support of Sustainable Water Harvesting and Institutional Strengthening project in Amhara Region (SWHISA) and a technical support of Amhara Agricultural Research Institute and Sirinka Agricultural Research Center.

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