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Full Length Research Paper

Effect of mulching and amount of water on the yield of tomato under drip irrigation

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The main challenge confronting both rain fed and irrigated agriculture is to improve WUE and sustainable water use for agriculture. An experiment was conducted to evaluate the effect of mulch and amount of water on the yield of tomato under drip irrigation system and to assess the potential of deficit irrigation to improve the economic efficiency of tomato production at Adet Agricultural Research Center, horticultural crops trial site (Woramit) (North Western Ethiopia) from 2006 to 2007. A factorial combination of three levels of water (namely 315, 440 and 565 mm) combined with three mulch treatments [namely without mulch (WM), black plastic mulch (PM) and straw or crop residue mulch (STM)] amid three replications and two days irrigation interval was used. Amount of water significantly affected the number of fruits per plant, average weight of fruits marketable and total fruit yield/ha. Significant difference was also shown between mulch treatments on number of fruits, unmarketable, marketable and total fruit yield/ha. Based on the partial budget analysis, the highest net benefit was obtained via 440 mm water with straw mulch amid a net benefit (52,959.40 birr/ha and a marginal rate of return (MRR) 690%. Therefore, application of 440 mm/ha water in two days interval with straw mulch is found to be economically and agronomically feasible and is recommended for Woramit and its surrounding and other similar agro-ecologies under drip irrigation system.

Key words: Tomato, drip, mulching, water levels, marketable fruit yield, total fruit yield, marginal rate.

INTRODUCTION

The advent of increasing water scarcity in this century will observe less increase in irrigated land availability for food production than in the past. Novel irrigation technologies need to be tested under local environments and parti-cularly in agricultural production systems of developing countries. While irrigation can benefit yields and enhance water use efficiency (WUE) in water limited environ-ments, the potential for full irrigation is decreasing, with increased competition from the domestic and industrial sectors. Thus, the main challenge confronting both rain fed and irrigated agriculture is to improve WUE and sustainable water use for agriculture.

Ethiopia is facing a tremendous challenge in meeting the food needs of rapidly growing population. There are small, medium and large scale irrigation systems in Ethiopia (FAO, 1995). To this end, both irrigated and dry land cropping areas will have to be developed or improved in the future. However, these tasks will not be easy, the cost of developing large scale and medium scale level irrigation is by now sky rocketing. Therefore, efficient utilization of water resources and development of small scale irrigation schemes at family level is crucial for countries like Ethiopia, which has a huge water resource: yet their population is chronically food insecure Micro irrigation system was found to result in 30 to 70% water savings in various orchard crops and vegetables along with 10 to 60% increases in yield as compared to conventional methods of irrigation. It is 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 (Zaman et al., 2001). Drip irrigation in combination with mulch is one of the best irrigation methods, which can improve the water management practice significantly. Surface mulches have been used to improve soil water retention, reduce soil temperature and reduce wind velocity at the soil surface and arid lands (Kay, 1978; Jalota and Prihar, 1998). Surface mulches can also improve water penetration by impeding runoff and protecting the soil from raindrop-splash and reducing soil crusting (Munshower, 1994).

Tomato is the leading vegetable crop in the world. It is

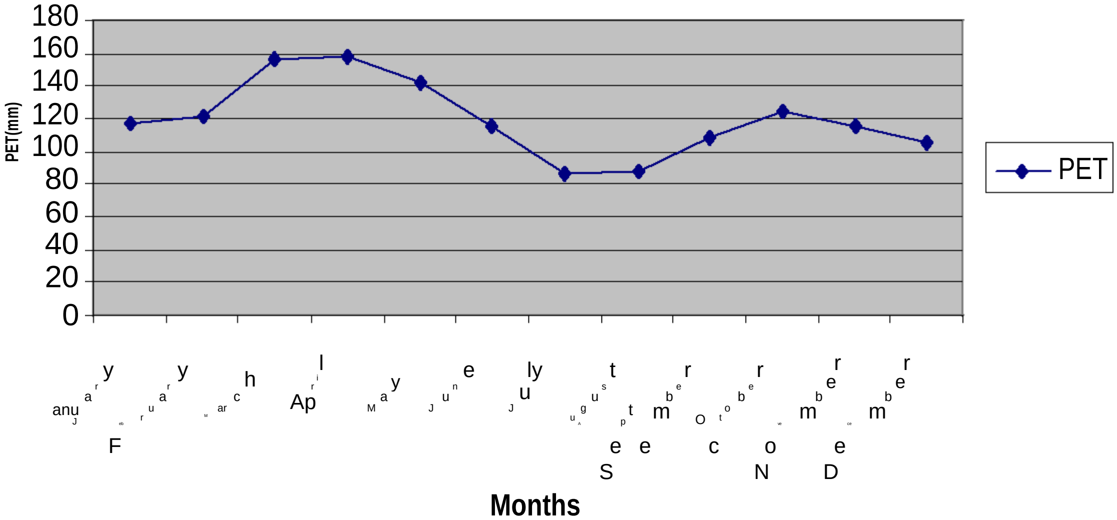

Figure 1. Monthly potential evapotranspiration at Woramit. Source: FAO Climatic Database (2005).

also one of the dominant vegetable crops in Ethiopia that is best suited for drip irrigation in combination with mulch. However, no work has been done to study the effect of drip irrigation in combination with mulch in the area. The present study was planned to evaluate the effect of mulch and amount of water on the yield of tomato under drip irrigation system and to assess the economic feasibility in relation to mulch used in tomato production.

MATERIALS AND METHODS

Experimental site

An experiment was conducted to evaluate the effect of mulch and amount of water on the yield of tomato under drip irrigation system and to assess the potential of deficit irrigation to improve the economic efficiency of tomato production at Woramit from 2006 to 2007. Woramit is located in the Northwestern part of Ethiopia, Bahirdar, at Adet Agricultural Research Center, horticultural crops trial site at an altitude of 1800 m above sea level. It is regarded as a warm temperate climatic zone where there is distinct dry months in winter. The soil is deep with red-brown color (netosol). The mean daily maximum temperature is 23.5°C in August and 29.5°C in April. The mean daily minimum temperature is 6.2°C in January and 13.3°C in May. The area receives a total annual rainfall of 800 to 1250 mm. The average potential evapo-transpiration (4.08 mm/day) and evapo-transpiration of the crop (ETc) value is (6.73 mm/day) (Figure 1).

Experimental materials and design

Factorial combination of water levels (namely 315, 440 and 565 mm) and three mulch treatments [namely without mulch, black plastic mulch (BPM) and straw mulch (SM)] were tested with two days irrigation interval under drip irrigation with three replications. A total of 9 treatment combinations were evaluated. The variety of Melka-salsa (processing type tomato variety) was used as the testing material. Seedlings were raised before a month and undamaged, reasonably uniform and clean seedlings were selected and transplanted to properly prepare plots on November 13, 2006 and December 8, 2007. Each plot consisted of two rows that are 3 m long with row spacing of 1 m. It was planted at a spacing of 30 cm between plants accommodating 20 plants per plot.

Irrigation system

Chapin bucket kits drip irrigation system was used. A 20 L bucket, which serve as a container (water source) was mounted 1 m above the ground on a stand constructed from wood (Figure 2). The drip tape was stretched on each row and installation of the system was made as per the instructions of Chapin bucket kits drip irrigation system. Measured volumes of water were filled in the bucket manually. The system was trickling water at every 30 cm space for each plant with a discharge rate of 0.03 liters/second for the dripper.

RESULTS AND DISCUSSION

Tomato plants are sensitive to water stress and they show high correlation between evapo-transpiration and crop yield. The statistical analysis in Table 1 indicates that average weight of fruits, marketable and total fruit yield were significantly (P=0.01) affected by the amount of water applied. However, the effect on plant height, average weight of fruits per plant, and unmarketable fruit yield was not significant. Even though the effect is statistically non- significant, the maximum plant height and average weight of fruits were recorded at 565 mm water level.

The statistical analysis in Table 2 shows that average weight of fruits, marketable and total fruit yield are significantly affected by the amount of irrigation water. The overall year combined effect of the amount of water as indicated in Table 3, on average weight of fruits was significant (P= 0.05) and highly significant (P=0.01) on marketable and total fruit yield. The highest marketable and total fruit yield (50.94 and 57.51 tone/ha) was

Figure 2. Chapin bucket kits drip irrigation system mounted 1 m above the ground on a stand constructed from wood.

obtained via 565 mm (WL), while the lowest marketable and total fruit yield (39.97 and 46.16 tone/ha) was recorded via 315 mm (WL) (Table 3).

The result indicates that, even with a minimal amount of water, we can get a reasonable fruit yield. According to Amhara Region Bureau of Agriculture (BOA) 2002 unpublished report, the blanket average water requirement of tomato in the low and mid altitude areas of Amhara region is up to 830 mm. This result showed that drip irrigation system reduced the water requirement of the crop by 47 to 62% as compared to furrow irrigation. As Fekadu and Teshome (1997) cited Pruitt, drip irrigation increased the yield of tomato and water use efficiency (WUE) by 19 and 20%, respectively as compared to furrow irrigation. Similarly, Stein et al. (1996) and Raina et al. (1998) reported that drip irrigation system significantly reduced the water requirement of field pea and cantaloupe as compared to furrow irrigation, because it properly managed the drip systems supply of adequate moisture to the root zone and do not wet the area between beds. This technique applies the water when and where needed, while maintaining a dry area that can absorb excess moisture during heavy rain.

Water saving using drip irrigation on crops can be as much as 80% when compared to other irrigation techniques (Bogle and Hartz, 1986). Raina et al. (1998) reported that drip irrigation besides giving a saving of 32% water resulted in 49.5% higher yield as compared to surface irrigation. The analysis of variance shows that mulch has significant influence on yield and yield components of tomato. In view of that, plant height, number of fruits per plant, unmarketable yield, marketable and total fruit yield were significantly affected by mulch in the first year of study (Table 4), while in the second year, the influence of mulch was significant on plant height, marketable and total fruit yield (Table 2). The highest marketable and total fruit yield (48.02 and 55.32 tons/ha) in the first and (65.44 and 70.85 tons/ha) second year, respectively were obtained through black plastic mulch. The second maximum marketable and total fruit yield (38.92 and 47.72) in the first and (50.02 and 59.0 tons/ha) second year were recorded via straw mulch, respectively.

The overall year combined effect of mulch on number of fruits, unmarketable, marketable and total fruit yield was significant. Consequently, among the mulch applications, the maximum marketable and total fruit yield (56.43 and 63.0 tons/ha) were obtained via black plastic mulch (BPM) followed by straw mulch. This result is disparate with the investigation of Levent et al. (2001), who reported that the highest fruit yield was obtained from wheat straw mulch followed by transparent and black polyethylene mulch, respectively.

The highest and lowest unmarketable yield (7.65 and

Table 1. Effect of amount of water, mulch and interaction of mulch and amount of water on the mean fruit yield and yield components of tomato in 2006.

Water level treatments	Plant height (PH) (cm)				Average weight of fruits (g)				Marketable fruit yield (MFY) (Ton/ha)				Total fruit yield (TFY) (Ton /ha)			
	Mulch treatments				Mulch treatments				Mulch treatments				Mulch treatments			Means
	WM	BM	SM	Means	WM	BM	SM	Means	WM	BM	SM	Means	WM	BM	SM	
315	44.13	49.80	46.47	46.80	27.38	29.84	27.93	28.38	22.52	47.45	32.22	34.07^{b}	27.95	55.32	39.72	40.99^{b}
440	47.27	52.93	47.87	49.36	30.14	28.94	29.50	29.53	40.88	49.06	41.82	43.92^{a}	47.24	56.04	52.56	51.95^{a}
565	51.73	50.13	47.07	49.64	31.55	29.36	27.71	29.54	46.83	47.54	42.73	45.70^{a}	56.04	54.60	51.06	53.89^{a}
Means	47.7b	50.96a	47.13b	-	29.69	29.38	28.38		36.74b	48.02a	38.92b		43.74b	55.32a	47.72ab	
C.V%			5.75				8.23			26.43					16.65	
LSD 5% LxM	NS	NS	NS		NS	NS	NS		NS	NS	NS		NS	NS	NS	
LSD 5% WL				NS								**				**
LSD 5% M		*				NS		NS		**				**		

M = Mulch, WL = water level, WM = without mulch, BM = black plastic mulch, SM = straw mulch, w = water level, M = mulch, NS = Non significant, * = significant at P = 0.05, ** = significant at P = 0.01

Table 2. Effect of amount of water, mulch and interaction of mulch and amount of water on the mean fruit yield and yield components of tomato in 2007.

Water level treatments	Plant height (PH) (cm)				Average weight of fruits (g)				Marketable fruit yield (MFY) (Ton/ha)				Total fruit yield (TFY) (Ton /ha)			
	Mulch treatments				Mulch treatments				Mulch treatments				Mulch treatments			
	WM	BM	SM	Means	WM	BM	SM	Means	WM	BM	SM	Means	WM	BM	SM	Means
315	**48.47**	57.07	54.00	53.18	**18.43**	23.92	24.02	22.12b	**28.71**	61.85	47.98	45.88b	32.70	67.08	54.21	51.33b
440	50.40	58.73	55.20	54.78	26.27	25.29	24.35	25.30ab	56.56	64.37	49.54	56.17a	62.65	70.01	56.11	62.92a
565	54.00	58.27	53.20	55.16	26.05	26.87	25.24	26.05a	45.87	70.11	52.53	56.82a	50.52	75.47	57.39	61.13a
Means	50.96b	58.02a	54.13b		23.59	25.36	24.54		43.41b	65.44a	50.02b		48.62b	70.85a	59.90b	
C.V%			8.90				13.26				24.01				15.40	
LSD5%WLxM	NS	NS	-		NS	NS	NS	-	NS	NS	NS	-	NS	NS	NS	-
LSD 5%W	-	-	NS		-	-	-	*	-	-	-	*	-	-	-	*
LSD5%M		*		-						**		-		**		

M = Mulch, WL = water level, WM = without mulch, BM = black plastic mulch, SM = straw mulch, w = water level, M = mulch, NS = Non significant, * = significant at P = 0.05, ** = significant at P = 0.01.

5.99 tone/ha) were recorded through straw mulch and without mulch treatments, respectively. In this case, the vegetative growth of the crop was vigor in straw and black plastic mulch and this high vegetative growth may favor the occurrence of insect pest and fruit decay that may lead to high unmarketable yield. However, from the total unmarketable fruit yield, 49.18% was due to fruit decay, 37.04% was due to insect damage and the rest 13.77% was due to crack. The effect of mulch in respect of weed control was non significant. Even though there is no significant difference between mulch treatments on number of weeds/m^2, mulching reduced the incidence of weed from 38 to 50% as compared to the control

Table 3. Overall year combined ANOVA of water level and mulching effect on fruit yield and yield components of tomato at Woramit in 2006 and 2007.

Water level treatments (mm)	Plant height (cm)				Average weight of a fruit (g)				Marketable fruit yield (MFY) (Ton/ha)				Total fruit yield (TFY) (Ton /ha)			
	Mulching				Days											
	WM	**BM**	**SM**	**Means**	**WM**	**BM**	**SM**	**Means**	**WM**	**BM**	**SM**	**Means**	**WM**	**BM**	**SM**	**Means**
315	**46.30**	53.43	50.23	49.99	22.91	26.88	25.97	25.25b	**29.24**	47.23	38.84	38.44b	34.39	53.78	45.51	44.56b
440	48.83	55.83	52.53	52.07	28.20	27.11	26.92	27.41a	49.68	56.72	52.19	52.86a	56.96	63.02	59.03	59.67a
565	52.87	54.20	50.13	52.40	28.80	28.11	26.48	27.79a	51.31	61.93	51.79	55.01a	565.63	68.14	57.87	60.86a
Means	49.33	54.50	50.63	-	26.64	27.37	26.46	-	43.41c	55.29a	47.61b	-	49.30c	61.65a	54.14b	-
C.V%		7.54				10.90					27.94				11.77	
P.L WxM	NS	NS	NS	-	NS	NS	NS	-	*	*	*	-	*	*	*	-
PL W	-	-	-	NS	-	-	-	*	-	-	-	**	-	-	-	**
PL M		NS		-		NS		-		NS		-		**		-

M = Mulch, WL = water level, WM = without mulch, BM = black plastic mulch, SM = straw mulch, w = water level, M = mulch, NS = Non significant, * = significant at P = 0.05, ** = significant at P = 0.01.

(without mulch treatment). Mulching is not only important to reduce weed incidence, but also, it improves the soil micro-environment (Dickerson, 1996), which indicated that organic mulches help to cool the soil, conserve soil moisture, reduced annual weed production and return nutrients to the soil through decomposition.

Maximum control of the soil environment including water conservation can be obtained with the use of drip irrigation under either organic or plastic mulch (Lamont, 1991). Generally, the result points out that mulch have significantly increase the growth and fruit yield of tomato. Similarly, Geber et al. (1988) and Salman et al. applications increase the soil temperature so that vegetative development and fruit yield of tomato increased. The interaction effect of the amount of water and mulch in both years was not significant in any parameter. However, the highest marketable and total fruit yield (61.93 and 68.13 tons/ha) were obtained via the interaction effect of 565 mm (WL) with black plastic mulch. The second maximum marketable and total fruit yield (56.72 and 63.02 tone/ha) respectively were recorded through the interaction of 440 mm (WL) with black plastic mulch. In straw mulch, the maximum marketable yield (47.63 ton/ha) was obtained via 440 (WL). Drip irrigation combined with mulch has a momentous influence on the water use efficiency of tomato. Water use efficiency (WUE) is agronomically, simply the efficiency in which water is used to produce an economic yield. Water use efficiency of each treatment was determined after the marketable yield was obtained. The total water utilized was calculated taking the actual application volume (315, 440 and 565 mm) of irrigation levels, while the water use efficiency was calculated by dividing marketable yield by the volume of applied water. The highest water level (565 mm) combined with black plastic mulch gave the maximum fruit yield. However, the highest water use efficiency value was recorded at the lowest water level (315 mm) with black plastic mulch, whereas the lowest WUE (9.08 kg/m^3) was obtained at 565 mm without mulch treatment, which indicated that the plastic mulch distinctly improve the water use efficiency of tomato (Table 5).

The result is in line with the findings of Seyfi et al. (2007), which showed that drip irrigation with black plastic mulch markedly decreased the amount of water applied, increased water use efficiency (WUE) and increased crop yield (cantaloupe) due to increase in number of fruits per plant, fruit weight and fruit thickness. Similarly, Stein et al. (1996) reported that the use of mulch combined with drip reduced supplemental water needs 29 to 36% as compared to non mulched plots. Tomato, grown under plastic mulch, significantly increased earliness, fruit quality and control weeds by about 30 to 90% and increased total fruit yield and marketable fruit yield by about 20 and 24%, respectively (http://www.actahort.org). This might be due to the frequent application of water resulting in more even distribution of soil moisture in crop root zone, sufficient moisture conservation, and proper temperature control owing to presence of mulch, better utilization of nutrients and negligible infestation of weeds.

Based on the biological yield data, 565 mm of water combined with black plastic mulch gave the (1992) pointed out that mulch and tunneling maxi-mum marketable fruit yield(61.93 ton/ha) (Table 6). However, in order to recommend this result for farmers, it is necessary to estimate the minimum

Table 4. Effect of mulch and/or amount of water on water use efficiency of tomato.

Water levels (mm)	Marketable yield (ton/ha)			Volume of water/ha ($m^{3/LGP}$)	Water use efficiency (kg /m^3)		
	Mulch type				Mulch type		
	WM	BM	SM		WM	BM	SM
315	**29.24**	47.23	38.84	3150	9.28	**15.00**	12.33
440	49.68	56.72	52.19	4400	11.29	**12.89**	11.86
565	51.31	61.93	51.79	5650	9.08	**10.96**	9.17

WM = without mulch, BM = black plastic mulch, SM = straw mulch.

Table 5. Partial budget, dominance and marginal rate of return (MRR) analysis at Woramit with 10% sensitivity (considering the cost of tap water as cost of irrigation water).

Water m^3/Mulch levels	Unadjusted marketable Yield/ha (tone)	Adjusted marketable Yield/ha (tone)	Gross benefit	Total variable cost (birr)	Net benefit (birr)	Marginal rate of return (MRR%)
3150/WM	29.236	26.312	35,521.20	12,530.90	22,991.20	-
4400/WM	47.232	42.509	57,387.15	17710.00	39,677.15	322.20
3150/SM	49.683	44.715	60,365.25	18,030.90	42,334.35	828.05
5650/WM	38.844	34.956	47,190.60	22,522.50	24,668.10	D
4400/SM	56.715	51.044	68,909.40	23,210.00	45699.40	3059.10
5650/SM	52.192	46.973	63,413.55	28,022.50	35,391.05	D
3150/BM	51.313	46.182	62,345.70	235,204.52	-	-
4400/BM	61.931	55.738	75,246.30	240,383.62	-	-
5650/BM	51.788	46.609	62,922.15	245,196.12	-	-

WM - without mulch, SM - Straw mulch, BPM - black plastic much. D: Stands for dominated treatment; the marketable fruit yield was adjusted by 10% adjustment coefficient. During the experimentation period, the field price of tomato, straw, black plastic and water was 1.50 birr/kg, 9birr/m^3, 18.22 birr/kg and 1.5 bir/m^3, respectively.

Table 6. Assumption of the partial budget, dominance and MRR analysis that there is no water cost with 10% for other variable costs increment.

Water m^3/Mulch levels	Unadjusted marketable Yield/ha(tons)	Adjusted marketable Yield/ha(tons)	Gross benefit	Total variable cost	Net benefit	Marginal rate of return (MRR%)
3150/WM	29.236	26.312	35,521.20	7333.40	28,187.80	-
4400/WM	47.232	42.509	57,387.15	10,450.00	46,937.15	601.60
3150/SM	49.683	44.715	60,365.25	12,833.40	47,531.85	25.00
5650/WM	38.844	34.956	47,190.60	13,200.00	33,990.60	D
4400/SM	56.715	51.044	68,909.40	15,950.00	52,959.40	690.00
5650/SM	52.192	46.973	63,413.55	18,700.00	44,713.55	D
3150/BM	51.313	46.182	62,345.70	230,007.02	-	-
4400/BM	61.931	55.738	75,246.30	233,123.62	-	-
5650/BM	51.788	46.609	62,922.15	235,873.62	-	-

rate of return acceptable to farmers in the recommendation domain. According to CIMMYT (1988), the minimum acceptable marginal rate of return (MRR) should be between 50 and 100%. So far, there is no estimated cost for irrigation water in our country. Therefore, we did the partial budget analysis in two ways: considering the cost of tap water as cost of irrigation water and assuming the cost of irrigation water as zero. Based on the partial budget analysis, considering the cost of tap water as a cost of irrigation water with 10% variable cost increment and 10% produce price reduction, the highest net benefit was obtained via 440 mm with straw mulch amid a net benefit (45,699.40 birr/ha) and a marginal rate of return (MRR) 3059.10%. The result indicates that even when the cost of drinking water (tap water) is used as the cost of irrigation water, it is still gainful to produce tomato under drip irrigation.

Considering the cost of irrigation water as zero with 10% prices increment of other variable costs, the highest net benefit was obtained via 440 mm with straw mulch amid a net benefit (52,959.40 birr/ha) and a marginal rate of return (MRR) 690.00%. The marketable fruit yield advantage of 440 mm/with SM over 315 mm/without mulch was 94%.

Based on the biological data, the highest water level (565 mm) combined with black plastic mulch gave the maximum fruit yield and the highest water use efficiency value was recorded at the lowest water level (315 mm) with black plastic mulch. Even though, we have obtained a higher fruit yield and better water use efficiency value from plastic mulch treatments, they were not economi-cally feasible. Therefore, application of 440 mm/ha water with straw mulch amid a net benefit (52,959.40 birr/ha) and marginal rate of return (MRR) (690.00%) is found to be economically and agronomically feasible and is recommended around Bahirdar and other similar agro-ecologies under drip irrigation.

SUMMARY AND CONCLUSION

Novel irrigation technologies need to be tested under local environments and particular agricultural production systems. Thus, the main challenge confronting both rain fed and irrigated agriculture is to improve WUE and sustainable water use for agriculture. Drip irrigation increased fruit yield of tomato and improved WUE due to consumption of less water. However, integrated use of drip irrigation and straw mulch was more appropriate and profitable.

The interaction effect of the two factors had shown non-significant difference on all parameters. The highest marketable and total fruit yield (61.93 and 68.14ton/ha) were obtained via the interaction effect of 565 mm (WL) with black plastic mulch. Based on the partial budget analysis, the highest net benefit was obtained via 440 mm with straw mulch amid a net benefit of 52,959.40 birr/ha and a marginal rate of return (MRR) of 690%. The marketable fruit yield advantage of 440 mm water with straw mulch over 315 mm without mulch was also very high (94%).

In conclusion, the present study points out that 440 mm/ha of water with straw mulch are economically more profitable than the other mulch treatments around Bahir-dar and similar areas. Therefore, it is the subject of future investigations, to consider water levels below 315 mm and between 315 and 440 mm combined with straw mulch under drip irrigation, especially in drought prone areas where water is very scarce to produce crops.

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