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Research Article

Effect of Deficit Irrigation and Mulch Application on Onion (*Allium cepa L.*) Bulb Yield and Water Productivity Under Drip Irrigation at Ambo, West Shoa, Ethiopia

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Abstract

Drip irrigation, combined with mulch and deficit water application, can significantly improve the water efficiency of irrigated agriculture. Study at Ambo Agricultural Research Center during the 2021/22 and 2022/23 irrigation seasons aimed to determine the most suitable deficit levels and mulch for drip-irrigated onion. The experiment used a randomized complete block design with two factors: irrigation levels (at 55%, 70%, 85%, and 100% of the Evapotranspiration of the crop) and mulch types (un-mulched, plastic, and straw mulch), resulting in a total of twelve treatment combinations replicated three times. The results showed that irrigation levels and mulch significantly affect bulb yield, water productivity, and yield-attributing parameters. Applying 100% ETc level and straw mulch resulted in the highest yields of 39450 kg/ha and 41038 kg/ha, respectively. On the other hand, the lowest yields were obtained with 55% ETc levels and un-mulched treatments, with respective values of 30913 kg/ha and 33969 kg/ha. Water productivity was also higher for irrigation levels at 55% and 70% ETc compared to 85% and 100% ETc, with values of 10.1 kg/m^3 and 9.7 kg/m^3, respectively. Additionally, straw mulch application resulted in significantly higher water productivity. Economic analysis indicated that straw mulch had a higher net return with 369% MRR (Marginal Rate of Return) and a benefit-cost ratio of 32.8, while applying a 70% ETc level resulted in a 125% MRR. Based on the results, 70% ETc level with straw mulch for onion production is recommended for the study area, considering bulb yield, water productivity, and economic viability.

Keywords

Economic Return, Irrigation Level, Onion, Straw Mulch, and Water Productivity

1. Introduction

All sectors demand freshwater, which is under stress due to a rise in population and warming related to climate change [1, 2]. Globally, irrigated agriculture consumes around 70% of extracted freshwater, with numerous factors influencing its development, particularly the pressure on water resources due to inadequate management [3, 4]. Thus, promoting modern irrigation systems, sustainable utilization, and management practices of water resources is key to improving the productivity of water and land units [5, 6].

The drip irrigation system is an efficient strategy for irrigated agriculture, enhancing productivity by precisely applying water to the root zone and reducing losses through

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evaporation, depreciation, and runoff [7-9]. As outlined by Biswas *et al.*, drip irrigation is superior to other irrigation systems, especially for fruit and vegetable crop production [10]. Research results of Berbel *et al.* conclude that drip irrigation systems can boost irrigation efficiency from 65% in traditional irrigation to 87% [11]. It reduces the contact of water with crop leaves, stems, and fruit, which prevents favorable conditions for disease development [12]. Enhancing water productivity is crucial for alleviating potential water crises, as implementing drip irrigation alongside deficit irrigation techniques increases crop yield per drop of water [13].

Deficit irrigation (DI) practice is a strategy for maximizing water use efficiency with higher yields per unit of water applied. In this practice, the crops are exposed to water stress at certain parts of the growing season or throughout the growing season, expecting yield reduction to be insignificant [14, 15]. Several researchers reported that the DI strategy for different crops can save water with little yield reduction. Research findings Enchalew *et al.* conclude that applying DI up to 20% deficit levels saves 45 to 108 mm of water from the gross onion irrigation water requirement [16]. Also, the results of Biswas *et al.* noted that applying a 20% irrigation level had no significant yield reductions compared to full irrigation with increased water productivity [10]. The findings of Abdulkalik *et al.* stated that onion production irrigates onions at 75% of the irrigation water requirement, resulting in high water productivity with a minimal yield penalty. The yield response factor of 0.71 suggested that the crop was tolerant to water stress [17].

Mulch is any organic or plastic material applied to the soil's surface to preserve moisture and enhance soil structure, lowering soil temperature, inhibiting the growth of weeds, and promoting crop root development [18-20]. Research findings of Biswas *et al.* revealed that mulch applied at any deficit level improves tomatoes' yield and yield-contributing characteristics under drip irrigation. The study also concludes that mulch applied with drip irrigation significantly increases tomatoes' net benefits and water productivity [10]. Metwally and Geries concluded that applying mulch reduced water loss through evaporation and reduced irrigation water by 20% with acceptable yield reduction [21]. Also, El-Metwally *et al.* and Teame *et al.* outlined that mulch materials enhanced crop yield under deficit irrigation conditions [18, 22].

Onion (*Allium cepa L.*) is a worldwide vegetable crop for its daily uses and economic benefits [21, 23]. It is a globally significant vegetable crop, particularly in Ethiopia, where it is a staple in daily diets and a key financial contributor. Its ease of cultivation and high yield per unit of land make it a crucial part of the country's agricultural landscape [24]. According to Ethiopia's CSA (Central Statistical Agency) report, the total area under onion production was about 38,952.58 ha, of which 3,460,480.88 tons were produced in 2020/2021.

In Ethiopia, irrigated agriculture and its management are implemented in water-scarce areas of the country. The country has experienced considerable rainfall variability due to climate change, and this variable rainfall necessitates using irrigated agriculture practices. However, limited research has been conducted in highland areas of the country on the management of irrigated agriculture. Given this, the present study was carried out to evaluate the effect of organic and plastic mulch along with deficit irrigation on bulb yield, water productivity, and economic importance of onion production under drip irrigated conditions in Ambo.

2. Materials and Method

2.1. Description of the Study Area

The experiment was conducted during the dry season of 2021/22 and 2022/23 at the Ambo Agricultural Research Center Farm site, Ambo Woreda, West Shewa Zone. Geographically, the site is located at 37.51 °E and 08. 58 °N with an altitude of 2144 m a.s.l. (Figure 1). The annual average precipitation of the site is around 1029 mm with a mean minimum and maximum temperature of 10.3 °C and 26.4, respectively, as described in (Figure 2). Following the USDA soil texture classification based on the relative soil particle contents in sand, silt, and clay percentages, the soil class of the experimental site was determined to be clay in texture throughout the depth, as indicated in (Table 3).

2.2. Experimental Design and Treatment Combination

The experiment was conducted for two consecutive years under drip-irrigated conditions. The experiment was arranged as a randomized complete block design with two factors: three irrigation application levels and two mulch types. The first factor was irrigation application levels with three levels (55% ETc, 70%ETc, and 85% ETc), and the full irrigation application level was considered a control. The second factor is the application of mulch materials with three mulch types (straw, plastic, and no mulch). There were 12 treatment combinations, and each treatment was replicated threewise. The detail of the experimental treatment combination is given in (Table 1). Wheat straw mulch with an application rate of 6 tons/ha and white plastic with 30 μ thickness were used as mulch material.

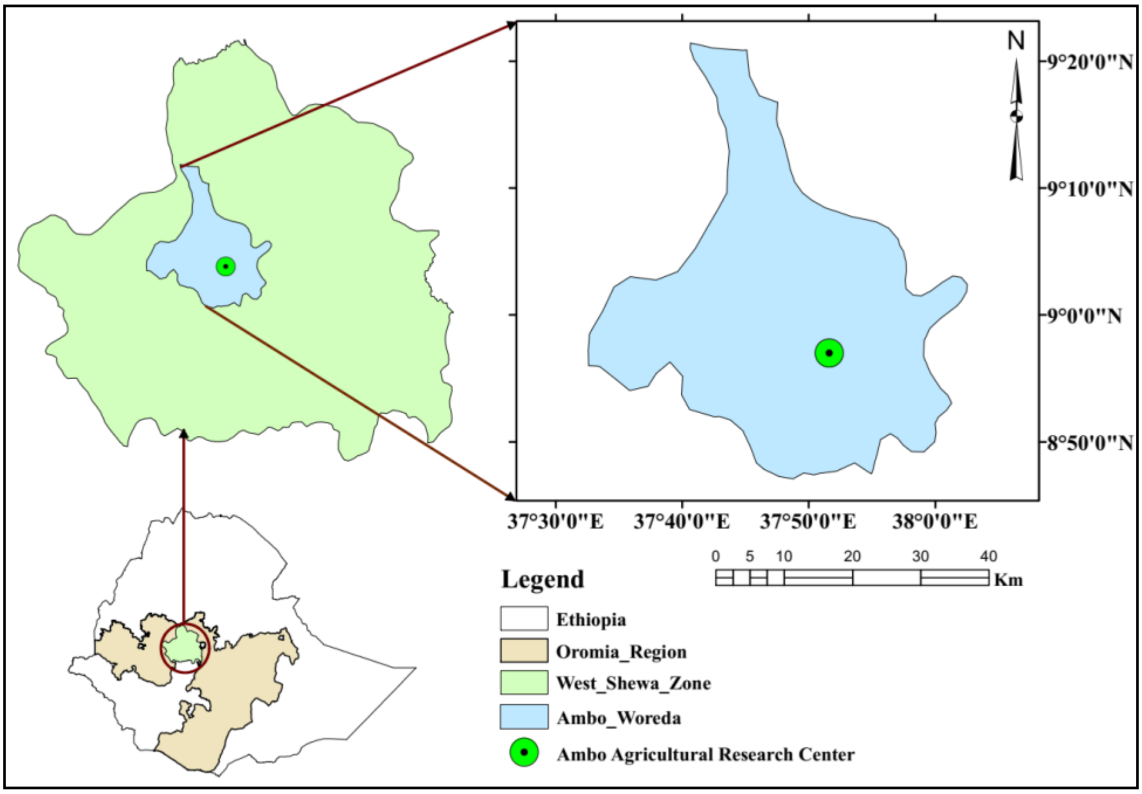

Figure 1. *Map of the study area.*

Table 1. *Treatment combination.*

Treatment	Irrigation level	Mulch material
T1		No mulch (NM)
T2	55% ETc (Evapotranspiration of a crop)	Straw mulch (SM)
T3		Plastic mulch (PM
T4		No mulch (NM)
T5	70% ETc (Evapotranspiration of a crop)	Straw mulch (SM)
T6		Plastic mulch (PM)
T7		No mulch (NM)
T8	85% ETc (Evapotranspiration of crop)	Straw mulch (SM)
T9		Plastic mulch (PM)
T10		No mulch (NM)
T11	100% ETc (Evapotranspiration of crop)	Straw mulch (SM)
T12		Plastic mulch (PM)

2.3. Crop Water Requirement Determination

The study area's climate data were used to compute reference evapotranspiration (Eto) and determine onion crop Evapotranspiration of Crop (ETc). Over 30 years, climatic data (including monthly maximum and minimum temperature, relative humidity, wind speed, and sunshine hours) were collected from the Ambo Agricultural Research Center methodology station. The study area's Eto represents the evapotranspiration from a grass reference crop computed using the CropWat 8.0 Windows model based on the long-year average data of the above climate variables. Subsequently, the ETc of onion was determined by this model using onion crop characteristic data (Table 2), soil data of the study area (Table 3), and long-year average climate data by considering drip irrigation efficiency as 90%. ETc of the crop can also be computed using (equation 1) with the formula developed by [25]. (Kc) crop coefficient value and growing date for the crop were obtained from FAO Irrigation and Drainage Paper No. 56.

$$ETc = ETo * Kc \quad (1)$$

Where: ETc = Evapotranspiration Crop, in mm, ETo = Reference evapotranspiration for a grass reference crop, mm KC = Crop coefficient.

2.4. Determination of Irrigation Amount and Application Time

The net irrigation depth needed to refill the soil moisture to field capacity was used to compute full irrigation application (100% ETc). The percentage of wetted area for a single emitter was calculated using the method outlined by Keller and Bliesner, as cited by [26, 27], and it was determined to be 0.8, as these researchers suggested. The amount of irrigation water applied to each plot (in m^3) for the experimental test was calculated using the equation proposed by [25] (equation 2).

$$V = A * (w.a) * dg \quad (2)$$

Where: V is the volume of irrigation water application (m^3), A is the plotting area (m^2), w.a. is a wetting area (0.8), and dg is gross irrigation depth (m).

The time required for each emitter to deliver the desired water depth per the treatment was calculated using the formula described by (equation 3). A stopwatch was used to record the application time for each irrigation application.

$$t = \frac{0.8\,Dr^2}{360q} \quad (3)$$

Where: t = application time (hour), D = depth of water applied (cm), r = radius of effective wetted area (m) and q = emitters discharge rate (1/sec).

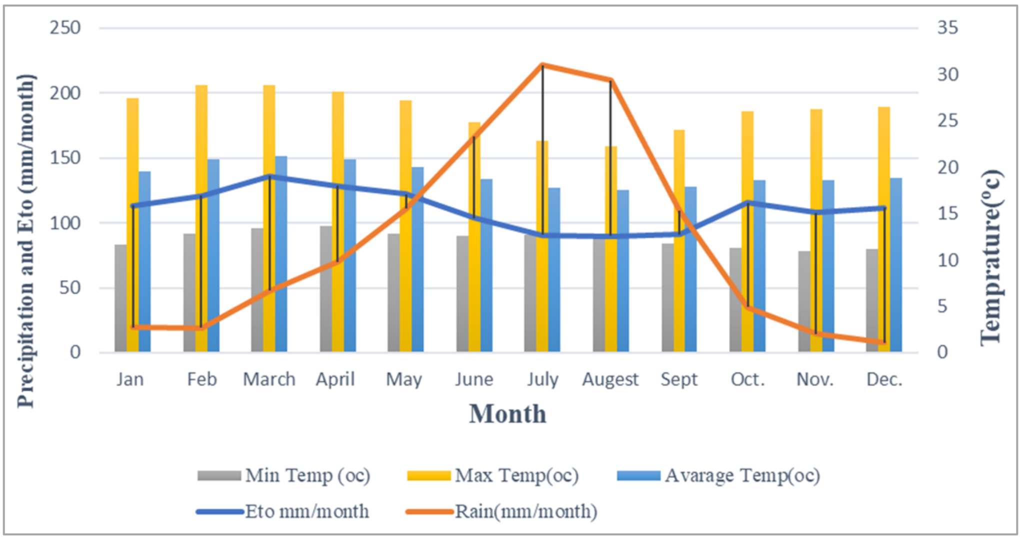

Figure 2. Long-year average monthly precipitation Reference Evapotranspiration and Temperature data.

Table 2. Onion crop data.

Growth Stages	Initial	Development	Mid	Late	Total
Stage Lengths [Days]	20	30	35	40	125
Crop Coefficients [K_c]	0.50		1.05	0.80	-
Rooting Depths [m]	0.30		0.50	0.50	-
Depletion Levels [P]	0.30	0.45	0.30	0.60	-
Yield Factors [K_y]	0.45		0.80	0.30	1.10

Table 3. *Soil physio-chemical characteristics of Ambo Agricultural Research Center Experimental site.*

Depth Cm	FC vol.%	PWP vol.%	TAW mm/m	Sand%	Silt%	Clay%	Texture	PH	OM%	Available P (ppm)
0-30	39.05	18.53	205.2	16	18	66	Clay	7.83	3.66	5.9
30-60	38.53	17.13	214.0	16	18	66	Clay	8.13	2.06	4.3
60-90	34.73	17.07	177.3	18	14	68	Clay	8.01	2.09	3.6
Average	37.44	17.58	198.6	16.7	16.7	66.7	Clay	8.0	2.6	4.6

2.5. Description of Agronomic Procedure

The Nasik Red onion variety was raised in a nursery bed at the Ambo Agricultural Research Center in mid-October and transplanted to field plots after eight weeks. To ensure proper plant establishment, 20.4 mm of irrigation water was applied to all plots according to the crop's water requirements before beginning the treatment applications. Each experimental plot measured 2.5 m in length and 1.5 m in width, with inter-row spacing of 30 cm and intra-row spacing of 10 cm, resulting in five rows per plot. The three central rows were designated experimental rows for data collection, while the two outer rows served as buffer rows to minimize border effects. The spacing between plots was 0.5 m, and the spacing between blocks was 1 m.

Nitrogen and phosphorus fertilization was applied in the form of Urea and DAP according to the recommended rates for the crop. Specifically, 200 kg/ha of DAP was applied at planting, and 150 kg/ha of Urea was used in a split application across all treatments.

2.6. Installation of Drip Irrigation System

An experimental field measuring 36.5 m in length and 7.5 m in width was prepared to install a drip irrigation system. The system was installed on a level plot to ensure uniform water distribution. Three water tanks, each with a capacity of 1000 liters, were mounted on a wooden stand 1.5 m high, with one tank allocated per block to regulate water flow. A 25 mm diameter main line was connected to the water tank through a 25 mm elbow and extended to a 20 mm sub-main line via a reducer elbow. To distribute water to each plot, the sub-main line was installed along each block and connected to manifolds by reducer T-connectors. A 16-mm-diameter lateral line was laid into each plant row and tied to the manifold using 16-mm-diameter nipples. Water was delivered to the crops' root zones via drip emitters, essential components of the drip irrigation system. The emitters used for this study were 0.3 m apart and discharged at one l/hr. The water tank's main valve regulated the water flow into the drip irrigation system. A mini valve mounted on each plot's manifold was used to control the water delivered to each plot per treatment requirements.

Figure 3. *Experimental field with different mulch treatment.*

2.7. Data Collection

2.7.1. Onion Bulb Yield and Yield Component

The three central rows were considered for the experimental data collection of onion bulb yield and yield component data. In comparison, the outer two rows served as a buffer to control the border effect. When the onion plants reached maturity, dry biomass and bulb yield of onion data were collected by harvesting the entire stand of onions in the three central rows. Average plant height, bulb diameter, and bulb height data of onion for each treatment were measured by taking five onion stands randomly from three central rows of mature onions. Bulb height was measured using measuring tape, while Bulb diameter and bulb height of selected onion bulbs were measured using a caliper.

2.7.2. Water Productivity

Water productivity was expressed in crop yield (kg) per applied water for the growing crop season. It was calculated by a ratio of total bulb yield (kg/ha) to the total water used through the growing season in (m^3 /ha) according to Zwart [28], using (equation 4).

$$WP = \frac{Y}{ETc} \tag{4}$$

Where: WP is water productivity (kg/m^3), Y is bulb yield (kg/ha), ETc is the seasonal crop water applied (m^3/ha).

2.7.3. Percent of Yield Reduction

According to the explanation of Hanssen and Seid [29], the percentage of yield reduction and water saved in the application of deficit irrigation was calculated using (equation 5).

$$YR(\%) = \left(\frac{Ym - Ya}{Ym} * 100\right) \tag{5}$$

Where: YR is the percent of yield reduction with deficit irrigation application,

Ym is the maximum crop yield in (kg/ha) obtained from full irrigation (conventional furrow irrigation), and Ya is the actual yield in (kg/ha) obtained from deficit irrigation.

2.7.4. Yield Response Factor

The yield response to the water stress approach adopted by [30], relates a reduction in evapotranspiration to a proportional decrease in yield. It is calculated by the relationship of water to yield reduction as described in (equation 6).

$$1 - \frac{Ya}{Ym} = K_y\left(1 - \frac{ET_a}{ET_m}\right) \tag{6}$$

Where: Ya is actual yield (kg/ha), Ym is maximum yield (kg/ha), ETa is actual evapotranspiration (mm), ETm is maximum evapotranspiration (mm), and Ky = yield response factor of onion to deficit irrigation.

2.8. Economic Analysis

The economic analysis of this experiment was conducted using a partial budgeting method as outlined by CIMMYT (International Maize and Wheat Improvement Center). The average cost of mulch material and labor cost for dressing mulch materials for the two consecutive cropping seasons were considered variable costs, and the average farm gate price of onion for these cropping seasons was considered a total return. According to the procedure stated by CIMMYT the adjusted mean bulb yield was calculated by deducting 10% of the total bulb yield from its total [31]. The average Man-day labor cost was 200.00 ETB (Ethiopian Birr), whereas the average farm gate price of onion was 50.00 ETB per kg taken for analysis. Considering that all other expenses were constant and were not altered by the treatment, all costs and returns were computed on an ETB/ha basis.

$$Ya = Y - (Y * 0.1) \tag{7}$$

$$TR = Ya * P \tag{8}$$

Where: Ya is the adjusted bulb yield (kg), Y is the total yield, TR is the total return and P is the average market price (ETB/kg).

Net income (NI) was calculated by subtracting the total variable costs (TVC) from the total return (TR) for a given treatment as described in (equation 9 &10):

$$NI = TR - TVC \tag{9}$$

$$TVC = MC + LC \tag{10}$$

Where: TVC is the total cost incurred, MC is the Mulching cost, and LC is the Labour cost.

The benefit-cost ratio is another economic analysis method that shows the financial feasibility of a treatment setup. It was estimated as the ratio between net income and TVC (equation 11). The total variable costs considered for this analysis were the cost of mulch material, Labour for applying the mulch, and labour for irrigating the field for each deficit level.

$$BCR = \frac{NI}{TVC} \tag{11}$$

Where: BCR is a benefit-cost ratio, NI is Net income, and TVC is the total cost.

Marginal rate of return (MRR) is another economic analysis parameter, and it was estimated as the ratio between the differences in the cost of the investment as described by [31] (equation 12):

$$MRR = \frac{\Delta NI}{\Delta TVC} * 100\% \tag{12}$$

Where: ΔNI is the difference between the net income, and ΔTVC is the additional expense unit between the two treatments.

2.9. Data Analysis

The data collected from each experimental plot on onion bulb yield, yield component, and water productivity data were subjected to Analysis of Variance (ANOVA) using SAS Software 9.4. The list significant difference (LSD) test was applied at a 5% significance level to compare means among the treatments. The economic results were analyzed using the marginal rate of return and net income.

3. Results and Discussion

3.1. Bulb Yield and Dry Biomass Onion as Influenced by Deficit Irrigation and Mulch

The findings of the two-season over-year study on onion bulb yield and dry biomass show a significant difference at ($p<0.05$) with applying different mulch materials and deficit irrigation levels. However, Onion bulb yield, dry biomass, growth parameter, yield attribute parameters, and water productivity of onion were not significantly impacted by the interaction of these factors, as presented in (Tables 4-6).

The treatment with irrigation application levels of 55% ETc produced the lowest value of 30913 kg/ha and 33151 kg/ha, respectively, while the treatment receiving 100% ETc produced the maximum onion bulb yield and dry biomass value, at 41038 kg/ha and 44072 kg/ha, respectively. Compared to 70% and 55% ETc levels, the statistical analysis showed that application at 100% ETc levels resulted in a considerable increase in bulb yield and dry biomass of onion. On the other hand, the treatment with 85% ETc levels and the application with 100% ETc levels were statistically similar. The results of this investigation were consistent with those of Enchalew *et al.*, & Biswas *et al.*, who observed that applying DI up to 20% deficiency levels reduces the gross onion irrigation water consumption by 45 to 108 mm with acceptable yield reduction [16, 32]. Also, it agreed with the findings of Sujeewa *et al.*, Abdelkhalik *et al.*, Mishra *et al.* & Sali *et al.*, who stated that irrigating onions at a 15% to 30% deficit level had no significant yield penalty compared to full irrigation application [13, 17, 33, 34].

The statistical analysis revealed that applying mulch material significantly increased bulb yield and dry biomass of onion compared to un-mulched treatment with all deficit levels. Maximum bulb yield and dry biomass value of 39450 kg/ah and 42039 kg/ha were obtained with the application of straw mulch. In contrast, treatment with no mulch application gives a minimum bulb yield and dry biomass value of 33969 kg/ha and 36733 kg/ha, respectively. Even if straw mulch has the highest bulb yield and dry biomass, the results are statistically equivalent to white plastic mulch. This result aligned with previous studies indicating that applying mulch material significantly improves onion productivity and bulb yield [19, 21, 35].

Table 4. Response of onion bulb yield and dry biomass to deficit irrigation and mulch application.

Treatments	Bulb yield (Kg/ha)	Dry Biomass (Kg/ha)
Irrigation application levels		
55% Etc	30913^{c}	33151^{c}
70% Etc	37769^{b}	40398^{b}
85% Etc	39524^{ba}	42243^{ba}
100% Etc	41038^{a}	44072^{a}
LSD (5%)	2868.7	2328.6
Mulch application		
No Mulch	33969^{b}	36733^{b}
Wheat Straw Mulch	39450^{a}	42039^{a}
White Plastic Mulch	38515^{a}	41125^{a}
LSD (5%)	2315.6	2437.4
CV (%)	10.6	10.4

*Values with the same letter are not statically significant, while with different letters, it is considered as a statistically significant 5% level of significance

3.2. Water Productivity of Onion as Influenced by Deficit Irrigation and Mulch

A deficit irrigation application greatly impacted onions' water productivity. Onions' water productivity and irrigation depth are inversely correlated; as irrigation depth increases, onions' water productivity declines and vice versa. Applying a 55% ETc level yielded the highest water productivity of 10.1 kg/m^3, while using a 100% ETc level produced the lowest result of 7.4 kg/m^3 (Table 5). According to the statistical analysis result, the application of 55% ETc level increased the water productivity of onions significantly compared to 85% and 100% ETc levels. However, applying a 70% ETc level produced statistically equivalent results with a 55% ETc level. This result was consistent with other research findings by Abdelkhalik *et al*., Matwally and Geries & Robi et al., that showed deficit irrigation application of up to 30% increases the water productivity of onions with a minimum yield penalty [17, 21, 26].

According to the over-year statistical analysis, the application of mulch materials significantly increased the water productivity of onions at all deficit levels. Applying straw and white plastic mulch produced significantly higher water productivity results, with respective values of 9.38 kg/m^3 and 9.2 kg/m^3. The lowest water productivity resulted from treatment with an un-mulch condition of 8.1 kg/m^3. This finding indicates that mulch application increases onion water productivity irrespective of deficit irrigation application levels. The study's findings are supported by other investigations, which found that applying mulch to onions increased water productivity by maintaining soil moisture [18, 21, 34, 35].

Table 5. *Response of onion water productivity to deficit irrigation and mulch application.*

Treatments Irrigation application levels	Water productivity (kg/m^3)	Treatments Mulch application	Water productivity (kg/m^3)
55% Etc	10.1^a	No Mulch	8.1^b
70% Etc	9.7^a	Wheat Straw Mulch	9.4^a
85% Etc	8.4^b	White Plastic Mulch	9.2^a
100% Etc	7.4^c		
LSD (5%)	0.61	LSD (5%)	0.61
CV (%)	11.4	CV (%)	11.4

*Values with the same letter are not statically significant, while with different letters are considered as a statistically significant 5% level of significance

3.3. Growth and Yield Attributing Parameters of Onion as Influenced by Deficit Irrigation and Mulch

This study considered plant height a plant growth parameter, whereas bulb diameter and height were yield-attributing traits. Based on the study's findings, these parameters were significantly affected by the amount of deficit irrigation and the mulch application; with increased irrigation water applied, plant height, bulb diameter, and bulb height also increased. The 100% ETc application gave the maximum values for these parameters, which is significantly differ from the 55% ETc level and is statistically comparable to the remaining deficit levels.

The Mulch application significantly affected these attributes, as indicated in (Table 6). Applying mulch material increases the bulb's height and diameter, directly affecting the onion bulb's weight. The results of this study supported those of other studies, Inusah et al., Robi et al.& Mubarek, and Altayeb, that showed mulch treatment improves yield-attributing factors such as bulb diameter and height [19, 26, 35].

Table 6. Response of growth and yield attribute parameters to deficit irrigation and mulch application.

Treatments	Plant Height (cm)	Bulb diameter (mm)	Bulb height (mm)
Irrigation application levels			
55% Etc	54.9[c]	56.2[b]	42.0[b]
70% Etc	56.9[ba]	56.9[ba]	45.5[a]
85% Etc	57.6[ba]	58.0[ba]	45.8[a]
100% Etc	59.8[a]	59.4[a]	47.7[a]
LSD (5%)	2.71	2.51	2.22
Mulch application			
No Mulch	57	56.2[b]	41.7[b]
Wheat Straw Mulch	58.3	58.9[a]	46.8[a]
White Plastic Mulch	56.6	57.9[a]	47.2[a]
LSD (5%)	NS	1.32	2.09
CV (%)	5.18	3.9	7.88

*Values with the same letter are not statically significant, while with different letters are considered as a statistically significant 5% level of significance

3.4. Yield Reduction Percentage

According to this study, using mulch significantly increased onion production, while the application of deficit irrigation significantly reduced the yield of onion. Compared to 100% ETc levels, 50% and 70% ETc levels resulted in a significant yield reduction of 24.7% and 8.0%, respectively, as shown in (Table 7). Compared to applying irrigation at full level, applying 85% ETc resulted in a 3.9% non-significant reduction in yield. Straw mulch and white plastic mulch showed a significant yield increment of 13.9% and 11.8%, respectively, compared to no mulch application. Therefore, at any deficiency level, mulch treatment improved considerably more yield than un-mulched conditions.

Table 7. Yield reduction with the application of deficit irrigation and mulch material.

Treatments	Actual yield (kg/ha)	Maximum yield (kg/ha)	Yield reduction (%)
Irrigation application level			
55% Etc	30913	41038	24.7
70% Etc	37769	41038	8.0
85% Etc	39524	41038	3.7
100% Etc	41038	41038	-
(mulch material)			
No mulch (Control)	33969	39450	13.9
Straw mulch	39450	39450	-
Plastic mulch	38515	39450	2.4

*Values with the same letter are not statically significant, while with different letters considered as a statistically significant 5% level of significance

3.5. Yield Response Factor

The yield response factor for each mulch treatment was calculated separately to analyze the influence of deficit application on the decline in onion bulb production. The yield response factor indicated a negative correlation with an increase in deficit level, as indicated by the computed result in (Table 8). The yield response factor is significantly lower when mulch application is used instead of un-mulched treatment. This implies that applying mulch could reverse the yield decrease caused by deficit irrigation application.

Table 8. *Result of yield response factor (Ky) for Onion.*

Mulch	Irrigation level	Ya kg/ha	Ym kg/ha	ya/ym	Eta m^3/ha	ETm m^3/ha	Eta/Etm	1-ya/ym	1-Eta/Etm	Ky
NM	55% Etc	24504	38251	0.64	3059	5562	0.55	0.36	0.45	0.80
NM	70% Etc	30842	38251	0.81	3894	5562	0.70	0.19	0.30	0.63
NM	85% Etc	36280	38251	0.95	4728	5562	0.85	0.05	0.15	0.33
NM	100% Etc	38251	38251	1.00	5562	5562	1	0.00	0.00	-
SM	55% Etc	33919	42970	0.79	3059	5562	0.55	0.21	0.45	0.47
SM	70% Etc	41234	42970	0.96	3894	5562	0.70	0.04	0.30	0.13
SM	85% Etc	42376	42970	0.99	4728	5562	0.85	0.01	0.15	0.07
SM	100% Etc	42970	42970	1.00	5562	5562	1	0.00	0.00	-
PM	55% Etc	32316	41893	0.77	3059	5562	0.55	0.23	0.45	0.51
PM	70% Etc	39933	41893	0.95	3894	5562	0.70	0.05	0.30	0.17
PM	85% Etc	40916	41893	0.95	4728	5562	0.85	0.02	0.15	0.13
PM	100% Etc	41893	41893	1.00	5562	5562	1	0.00	0.00	-

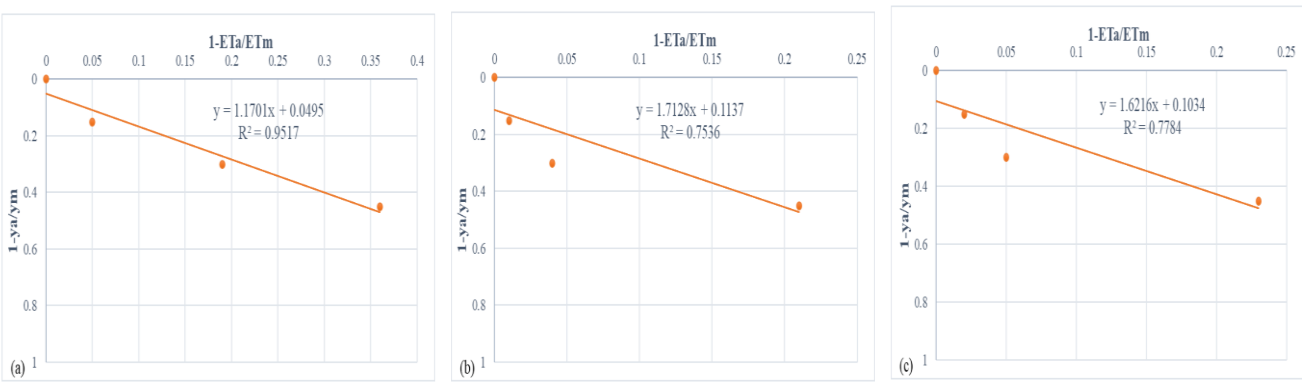

Figure 4. *Onion yield response function graph, (a) for un-mulch treatment, (b) for wheat straw mulch, and (c) for plastic mulch.*

3.6. Economic Analysis

According to the procedure stated by CIMMYT [31], the total variable cost was arranged in ascending order for the partial budgeting analysis. The average straw mulch and white plastic cost during the trial period was 40.00 ETB/10 kg and 23.00 ETB/m^2, respectively. The farm gate price of onions during harvesting was 50.00 ETB per kg taken, whereas the average daily labor cost was 200.00 ETB. For a single test plot with a plot size of 3.75 m^2, 2.01 kg of straw mulch and 6 m^2 of white plastic mulching material were used with corresponding costs of 8 ETB/plot and 138 ETB/plot. Dressing a single plot with straw and plastic mulch took an average of 27 minutes and 75 minutes per person, respectively. Thus, the total material cost and labor cost in a hectare base were computed from the cost required for a single plot; the total variable cost for plastic mulch was 451,128 ETB/ha, and for straw mulch application, it was 52,606 ETB/ha.

The results of the partial budgeting on the mulch material, as presented in Table 9, showed that applying plastic mulch and wheat straw increased the total revenue and bulb yield. However, the application of white plastic mulch had a higher variable cost than straw mulch; thus, even if the overall revenue from this treatment was comparable to that of straw mulch, the net income would be reduced due to the higher variable cost. Wheat straw mulch application gave a higher net income of 1,722,644 with a marginal rate of return value of 369% and a benefit-cost ratio of 32.8. The change in total variable cost of the plastic treatment with straw mulch gives a negative result; thus, plastic mulch treatment becomes dominant when calculating the marginal return. According to (CIMMYT), the minimum acceptable marginal rate of return (MRR%) should be between 50 and 100% and above [31]. As shown in Table 9, the application of straw mulch is economically important as the MRR value of 369% is greater than 100%. The finding of this study was also supported by other researcher findings, which stated that the application of straw mulch had high net income and economically acceptable MRR [19, 35].

Economic analysis on deficit irrigation application was calculated by considering the labor cost for irrigating the field at different irrigation levels as a total variable cost; from the analysis result described in Table 10, the application of 70% ETc level had a higher MRR value of 125% with a net income of 1,688,201.00 birrs. Thus, from this study's findings, applying 70% ETc levels with straw mulch was an economically feasible treatment for onion production under drip irrigation conditions for the study area.

Table 9. *Economic analysis results of Onion for the mulch material application.*

Treatment	TY (kg/ha)	AY (kg/ha)	TR (ETB/ha)	TC (ETB/ha)	NI (ETB/ha)	∆ NI (-)	∆ TC (-)	MRR (%)	BCR
NM	33969	30572	1528600	0	1528600	-	-	-	-
SM	39450	35505	1775250	52606	1722644	194044	52606	369	32.8
PM	38515	34664	1733200	451128	1282072	-440572	398522	D	2.8

Note: NM- No mulch, SM- Straw mulch, PM- plastic mulch TY- Total yield, AY-Adjusted yield, TR-Total revenue, TC- Total cost NI- Net Income, ∆ NI -change in net income, ∆ TC-change in total cost, MRR- Marginal Rate of Return, BCR benefit to cost ratio and D Dominant.

Table 10. *The economic analysis results of Onion deficit levels.*

Treatment	TY kg/ha	AY kg/ha	TR ETB/ha	TC ETB/ha	NI ETB/ha	∆ NI	∆ TC	MRR%	BCR
55% Etc	30913	27822	1391085	8961	1382124	-	-	-	154
70% Etc	37769	33992	1699605	11404	1688201	306077	2443	125	148
85% Etc	39524	35572	1778580	13847	1764733	76532	2443	31	127
100% Etc	41038	36934	1846710	16290	1830420	65687	2443	27	112

4. Conclusion

The warming brought on by climate change and population growth stresses freshwater resources. Therefore, it is crucial to promote sustainable water management and innovative irrigation techniques to improve the productivity of water and land units. This experimental study investigated the effects of deficit irrigation with mulch applications on bulb yield, water productivity, and the economic significance of onion production under drip irrigation. The analysis showed that applying plastic mulch and wheat straw considerably raised the water productivity and bulb yield of onions, with yield increments of 11.8% and 13.9%, respectively, compared to the un-mulched treatment. According to the analysis results, the application of deficit irrigation significantly reduced the onion yield. Compared to a 100% ETc level, applying a 55% and 70% ETc level had 24.7% and 8% respective yield reductions. According to the study's economic analysis, applying straw mulch increased net return value compared to plastic mulch and un-mulch by 25.6% and 11.3%, respectively, with a benefit-to-cost ratio of 32.8% and an MRR of 369%. Compared to other irrigation application levels, the application of a 70% ETc level yielded a higher MRR with a value of 125%. The study shows that straw mulch at 70% ETc levels produces comparable bulb yields with high water productivity and economic return. Therefore, straw mulch with 70% ETc levels is recommended for onion production in the study area.

Abbreviations

BCR	Benefit-cost Ratio
DI	Deficit Irrigation
ETB	Ethiopian Birr
Etc	Crop Evapotranspiration
Eto	Reference Evapotranspiration
FC	Field Capacity
Kc	Crop Coefficient
Ky	Yield Response Factor
LC	Laboure Cost
MC	Mulching Material Cost
MRR	Marginal Rate of Return
NI	Net Income
PWP	Permanent Welting point
TAW	Total Available Water
TC	Total Cost
TR	Total Return
TVC	Total Variable Cost

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Author Contributions

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Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Eshete DG, Sinshaw BG, Legese KG. Critical review on improving irrigation water use efficiency: Advances, challenges, and opportunities in the Ethiopia context. Water-Energy Nexus 2020 (3): 143–54. https://doi.org/10.1016/ j.wen.2020.09.001

[2] Yang P, Wu L, Cheng M, Fan J, Li S, Wang H, et al. Review on Drip Irrigation: Impact on Crop Yield, Quality, and Water Productivity in China. Water (Switzerland) 2023; (15): 1–18. https://doi.org/10.3390/w15091733

[3] Osman R, Ferrari E, Mcdonald S. Water Scarcity and Irrigation Ef fi ciency in Egypt. J Water Econ Policy 2016; (2): 1–28. https://doi.org/10.1142/S2382624X16500090

[4] Asres LA. Alternative Techniques of Irrigation Water Management for Improving Crop Water Productivity. J Agric Sci 2023; (11): 36–53. https://doi.org/10.7831/ras.11.0_36

[5] Ali A, Chunping X, Cheng J, Muhammad Faisal. Investment profitability and economic efficiency of the drip irrigation system : Evidence from Egypt *. J Irrig Drain 2020: 1–18. https://doi.org/10.1002/ird.2511

[6] Alcon F, Navarro N, Dolores M, Balbo AL. Drip Irrigation Technology : Analysis of Adoption and Diffusion Processes. J Sustain Solut Food Secur 2019: 269–85.

[7] Gebremicael GGTG, Hagos H, Teferi G, Kifl M. Farmers' perception towards the challenges and determinant factors in the adoption of drip irrigation in the semi-arid areas of Tigray, Ethiopia. Sustain Water Resour Manag 2018; (4): 527–37. https://doi.org/10.1007/s40899-017-0137-0

[8] Enius MAG, Oundouri PHK, Auges CÉN, Zouvelekas VAT. Information Transmission in Irrigation Technology Adoption and Diffusion: Social Learning, Extension Services, and Spatial Effects. Am J OfAgricultural Appl Econ 2013; (96): 328–44. https://doi.org/10.1093/ajae/aat054

[9] Zakhem BA, Ain FAL, Hafez R. Assessment of Field Water Budget Components for Increasing Water Productivity Under Drip Irrigation in Arid and Semi-Arid Areas, Syria. J Irrig Drain 2019: 1–12. https://doi.org/10.1002/ird.2286

[10] SK B, AR A, Rahman MS, MA H. Effect of drip irrigation and mulching on yield, water-use efficiency and economics of tomato. J Plant Soil Environ 2015; (61): 97–102. https://doi.org/10.17221/804/2014-PSE

[11] Berbel J, Expósito A, Gutiérrez-martín C, Mateos L. Effects of the Irrigation Modernization in Spain 2002 – 2015. J Water Resour Manag 2019; (33): 1835–49. https://doi.org/10.1007/s11269-019-02215

[12] Shock CC. Sustainable agriculture techniques Drip Irrigation : An Introduction. U. S: 2013.

[13] Sujeewa RM, Mikunthan T, Sayanthan S, Thushyanthi Y, Piraphaharan M. Effect of Deficit Irrigation on Growth and Yield of Red Onion (Allium cepa) in Drip Irrigation System. Sch J Agric Vet Sci 2020; (7): 144–50. https://doi.org/10.36347/sjavs.2020.v07i07.001

[14] Fereres E, Rabanales CU De. Deficit irrigation for reducing agricultural water use. J Exp Bot 2007; (58): 147–59. https://doi.org/10.1093/jxb/erl165

[15] Kirda C. Deficit irrigation scheduling based on plant growth stages showing water stress tolerance 2002; (22): 3–10.

[16] Enchalew B, Sl G, Rabo M, Hindaye B, Kedir M, Musa Y, et al. Irrigation & Drainage Systems Engineering Effect of Deficit Irrigation on Water Productivity of Onion (Allium cepal.) under Drip Irrigation. J Irrig Drain Syst Eng 2016; (5): 5–8. https://doi.org/10.4172/2168-9768.1000172

[17] Abdelkhalik A, Pascual-seva N, Nájera I, Domene MÁ, Baixauli C, Pascual B. Effect of Deficit Irrigation on the Productive Response of Drip-irrigated Onion (Allium cepa L.) in Mediterranean Conditions Effect of Deficit Irrigation on the Productive Response of Drip-irrigated Onion (Allium cepa L.) in Mediterranean Conditions. J Japanese Socity Hortic Sci 2019: 1–12. https://doi.org/10.2503/hortj.UTD-081

[18] El-Metwally IM, El-Wakeel MA. Comparison of safe weed control methods with chemical herbicide in potato field. Bull Natl Res Cent 2019; (43): 1–7. https://doi.org/10.1186/s42269-019-0053-6

[19] Inusah BIY, Wiredu AN, Yirzagla J, Mawunya M, Haruna M. Effect of different mulches on the yield and productivity of drip irrigated onions under tropical conditions. Int J Adv Agric Res 2013: 133–40.

[20] Lakew WJ, Anteneh BA, Ayalew LT. Yield and Water Use Efficiency of Mulched Drip-Irrigated Onion in Low Land Region of Amhara, North Central Ethiopia. Univers J Agric Res 2014; (2): 203–10. https://doi.org/10.13189/ujar.2014.020604

[21] Metwally I El, Geries L, Saudy H. Interactive effect of soil mulching and irrigation regime on yield, irrigation water use efficiency and weeds of trickle – irrigated onion. Arch Agron Soil Sci 2021: 1–13. https://doi.org/10.1080/03650340.2020.1869723

[22] Teame G, Tsegay A, Abrha B. Effect of Organic Mulching on Soil Moisture, Yield, and Yield Contributing Components of Sesame (Sesamum indicum L.). Int J Agron 2017: 1–7. https://doi.org/10.1155/2017/4767509

[23] Megersa HG. Onion (Allium cepa L.) Yield Improvement Progress in Ethiopia: A Review. Int J Ournal Agric Biosci 2018; (6): 265–71.

[24] Alemu D, Kitila C, Garedew W, Jule L, Badassa B, Nagaprasad N, et al. Growth, yield, and yield variables of onion (Allium Cepa L.) varieties as influenced by plantspacing at DambiDollo, Western Ethiopia. Sci Rep 2022: 1–9. https://doi.org/10.1038/s41598-022-24993-x

[25] Allen RG, Pereira LS, Raes D. Crop evapotranspiration guidelines for computing crop requirements. FAO Irrig. Drain. Report modeling and application Article. Rome, Italy: 1998.

[26] Robi AT, Gemeda F, Ahmed B, Bedaso N. Evaluating Water Productivity of Onion under Deficit Irrigation using Drip Irrigation System for Small Holder Farmers 2023; (7): 7–20.

[27] Yacoubi S, Zayani K, Slatni A, Playán E. Assessing Sprinkler Irrigation Performance Using Field Evaluations at the Medjerda Lower Valley of Tunisia 2012; (4): 682–91. https://doi.org/10.4236/eng.2012.410087

[28] Zwart SJ, Bastiaanssen WGM. Review of measured crop water productivity values for irrigated wheat, rice, cotton and maize. Agric Water Manag 2004; (69): 115–33. https://doi.org/10.1016/j.agwat.2004.04.007

[29] Hassene JN, Seid MT. Comparative Performance Evaluation of Alternate and Convectional Furrow Irrigation under Different Water Application Level on Cabbage Water Use Efficiency and Economic Analysis. Am J Environ Resour Econ 2017; (2): 123–31. https://doi.org/10.11648/ j.ajere. 20170203.15

[30] Doorenbos J, Kassam AH. Yield response to water. FAO Irrigation and Drainage, Paper 33 1979: 203.

[31] CIMMYT. From Agronomic Data to Farmer Recommendations: An Economics Training Manual. Completely revised edition. Mexico. D. F: 1988.

[32] Biswas SK, Roy DK, Sarker K, Mila A. Effects of Deficit Irrigation and Mulching on Seed Yield and Water Use of Onion Effects of Deficit Irrigation and Mulching on Seed Yield and Water Use of Onion (Allium cepa L.). Int J Plant Soil Sci 2017; (20): 1–11. https://doi.org/10.9734/ IJPSS/ 2017/36575

[33] Mishra S, Pyasi SK, Awasthi MK, Shrivastava RN. Improving water efficiency and crop yield of drip- irrigated onions through the application of deficit irrigation, mulching, and fertigation. Pharma Innov J 2023; (12): 2368–71.

[34] Sali AM, Alemayehu Y, Hordofa T. Effects Deficit Irrigation and Mulching on Yield and Water Productivity of Furrow Irrigated Onion (Allium Cepa L.) Under Haramaya Condition, Eastern Ethiopia. Turkish J Agric - Food Sci Technol 2022; (10): 360–7. https://doi.org/10.24925/turjaf.v10i2.360-367.4512

[35] Mubarak I, Altayeb H. Onion Crop Response to Regulated Deficit Irrigation Under Mulching in Dry Mediterranean Region. J Hortic Res 2018; (26): 87–94. https://doi.org/10.247/johr-2018-0010