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Effect of Different Furrow Irrigation Methods on Growth and Productivity of Onion Crop

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Abstract

The present study was conducted to investigate the effect of different furrow irrigation techniques on the growth and productivity of the onion crop at Taluka Kotdiji, District Khairpur Mir's, Sindh, Pakistan. The experiment was conducted in a plot size of 161.5 m^2. The plot was further divided into 9 subplots, each have size of 12.5m^2. The treatment was T_1 = Conventional furrow, T_2 = Plastic mulched furrow, T_3 = Alternative mulched furrow. The results of water saving showed 20% and 46.67% under T_2 and T_3, respectively. The CWP was 1.13 kg m^{-3},1.49 kg $m^{-3,}$ and 2.94 kg m^{-3} under $T_{1,}$ T_2 and $T_{3,}$ respectively. Moreover, the bulb size 4.56 cm, 5.19 cm and 5.58 cm, the biomass was 93.49 kg, 97.96 kg and 103.00 kg, the bulb weight was 70.54 g, 95.76g, and 130.00 g, and the plant height was 39.74 cm, 43.63 cm, and 49.83 cm under $T_{1,}$ T_2 and $T_{3,}$ respectively. Furthermore, the yield of onion was16808 kg ha^{-1}, 17856kg ha^{-1} and 23488 kg ha^{-1}, under $T_{1,}$ T_2 and T_3 respectively. It is concluded that the highest yield was obtained under T_3, as compared to T_1 and T_2. Water saving was highest under T3 as compared with T_1 and T_2. The bulb size, biomass and plant height were higher under T_3 compared with T_1 and T_2. In the present study, T_3 performed better crop water productivity than T_1 and T_2.

Keywords: Onion; Furrow-Irrigation; Water-Productivity; Mulching; Biomass;

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Introduction

Onion (*Allium cepa* L.) is a vital horticultural crop grown worldwide for its culinary and economic importance (Ivanova & Andonov, 2017; Mallor et al., 2018). Due to its shallow root system, onion growth and bulb formation are highly sensitive to soil moisture fluctuations, requiring consistent and well-managed irrigation throughout the growing season (Shanmugasundaram & Kalb, 2001). Water availability is one of the most critical factors determining crop yield and productivity (Rockström & Falkenmark, 2000), and in regions with limited water resources, improving irrigation efficiency has become essential for sustainable agricultural development (Mekonen, 2011). Traditional furrow irrigation, though widely practised, often leads to uneven water distribution, excessive percolation, and nutrient leaching, especially in sandy or semi-arid soils (Shock et al., 2015). To overcome these issues, modified furrow irrigation methods such as Alternate Furrow Irrigation (AFI) and Fixed Furrow Irrigation (FFI) have been introduced as water-saving alternatives. Studies have demonstrated that AFI can maintain comparable yields to conventional furrow irrigation while using significantly less water by irrigating every other furrow, thereby improving transpiration and nutrient water use efficiency (Ma et al., 2000; Gudeta et al., 1999; Gudeta et al., 2020). Moreover, integrating mulching practices with efficient irrigation systems further enhances soil moisture conservation, minimises evaporation losses, and stabilises soil temperature, contributing to improved onion growth and bulb quality (Sheikh et al., 2016; Olayinka et al., 2017; Singh et al., 2016). In Pakistan, onion cultivation, particularly during the Rabi season, requires approximately 5,000–6,000 m^3 of water per hectare (Hafeez et al., 2016), highlighting the need for adopting water-efficient irrigation systems like furrow irrigation combined with mulching to optimise yield and water productivity (Aziz et al., 2021; Mebrahtu, 2018). Hence, different furrow irrigation methods significantly influence onion growth, yield, and water productivity. Among them, alternate and fixed furrow irrigation techniques offer substantial advantages in conserving water and enhancing resource-use efficiency without sacrificing crop performance. The integration of these improved methods supports sustainable onion production, particularly under conditions of water scarcity, contributing to agricultural resilience and food security.

1.2 Problem Statement

Sustaining high levels of agricultural productivity requires a great deal of water. There is a need for better irrigation management based on crop requirements in order to minimise water delivery to the crop while still maintaining good yield. Furrow irrigation is one of the common methods accepted by many farmers. Mulching practices have been a common activity in vegetable production for better growth and good yield of most horticultural crops. Justifying the usage of furrow irrigation systems is the potential for higher yields and earlier market access for growers of onions using this method of cultivation in the spring (Al-Jamal et al., 2001). Making the right irrigation technique choice can help to manage the limited water resources and boost crop profitability. In this situation, there can be no doubt about the need of making wise use of the water supply.

1.3 Objectives

1. To determine the growth parameters of the onion crop under different furrow irrigation methods
2. To determine water saving and

productivity under different furrow irrigation methods

Materials and Methods 2.

2.1 Experimental site

The experiment was conducted at the agricultural field of Village Muhammad Bux Dahar (27.36° N 68.74° E), Taluka Kotdiji, District Khairpur Mir's, Sindh, Pakistan (Figure 2.1).

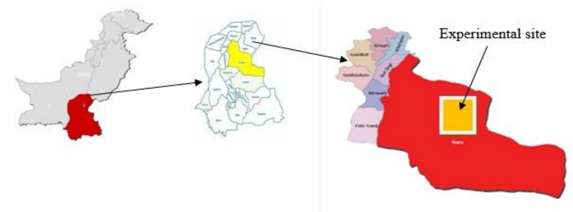

Figure 2.1 Experimental site

2.1 Experimental design and layout

The experiment was conducted in a Randomised Complete Block Design (RCBD) with three replications. The whole experimental space was 161.5 square meters. There was a total of 9 individual plots inside the larger area. The average size of a plot was 12.5 m^2 (Figure 3.2). There were three replications for each treatment.

2.3 Treatments and replications

There were three treatments: T_1 (Conventional furrow irrigation), T_2 (Mulched furrow irrigation), and T_3 (Alternate mulched furrow irrigation). Conventional furrows were irrigated with a traditional interval, mulched furrows were irrigated on the availability of moisture on ridges and alternate furrows were irrigated with the method: first water was applied in odd furrows, and second water was applied in even furrows with the same interval as in conventional furrows. The experiment was replicated three times (R_1, R_2 and R_3).

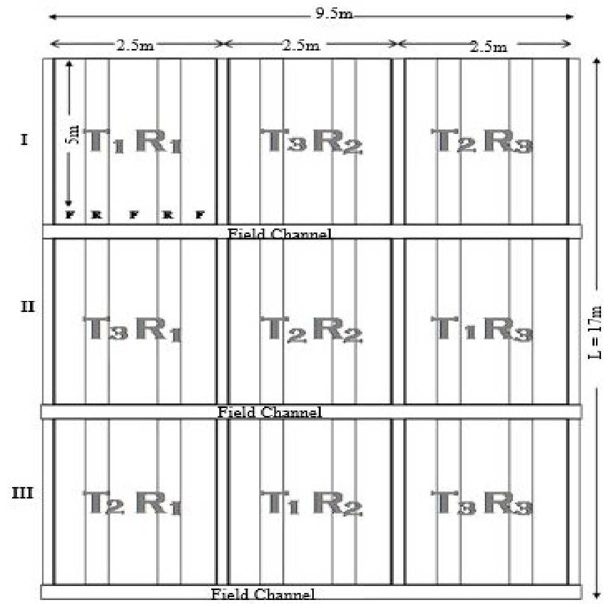

Figure 2.2 Layout of the experimental field

2.4 Preparation of the experimental field

The soil in the experimental plots was deep ploughed before it was broken up with a disc harrow. Then, six rows of alternate furrows were manually constructed. With the assistance of a cultivator and leveller, the soil was prepared. Each ridge's width and length in each sub-plot were 0.5 m and 5 m, respectively. In each sub-plot, a total of 100 mm of water was administered during the soaking dose.

2.5 Use of fertiliser

Recommended urea for one hectare is 250 kg. For the experimental plot of area 161.5 m^2, urea was applied at 2.8125 kg. The DAP for one hectare is recommended to be 125 kg, and for the experimental area, 1.4 kg DAP was applied. The DAP was applied at the time of sowing, and urea was applied at the 2^{nd} watering.

2.6 Selection and sowing of seed

For the study, seeds of the Local onion variety were planted. The seeds were sown throughout the furrows on both sides. The planting depth was 2.5 cm. To keep the necessary space, the unhealthy plants were

Field Channel

removed.

2.7 Irrigation

Irrigation water was taken from module number R-12, on the right bank of Khan Wah minor, which is taken from Mir Wah canal at Sukkur barrage. Onion needs irrigation at the time of transplanting, after transplanting, the irrigations were applied with 20 days interval. A total of 5 irrigations were applied over the whole crop period without a soaking dose. Table 2.1 shows the depth of water applied per furrow.

Table 2.1 Depth of water (mm) applied per furrow

Irrigation No.	Date	Depth of water applied (mm) per furrow		
		T_1	T_2	T_3
0	04-01-2022 Soaking Doze	100	100	100
1	24-01-2022	100	100	----
2	13-02-2022	100	100	100
3	05-03-2022	100	100	-----
4	04-04-2022	100	100	100
5	24-04-2022	100	--------	-----
Total		600	500	300

2.8 Soil Physical Properties

The soil samples were collected from the depths 0-15, 15-30 and 30-45 cm, before sowing the seed.

2.8.1 Soil texture

The hydrometer technique was used to analyse soil texture (Bouyoucos, 1962). In this experiment, the data indicated that the soil texture under T_1 was Silt Loam, under T_2 and T_3 was Loam, respectively, as shown in Table 2.2.

Table 2.2 Textural class of experimental site

Treatment	Sand (%)	Silt (%)	Clay (%)	Total	Texture class
T_1	23	52	25	100	Silt loam
T_2	30	46	24	100	Loam
T_3	26	48	26	100	Loam

2.8.2 Dry density

The soil samples were collected with a core cutter, and the dry density was determined using the following formula (McIntyre & Loveday, 1974). In this research, the dry density was 1.32, 1.36 and 1.33g/cm³ at depths of 0-15, 15-30 and 30-45 cm.

$$\rho d = \frac{M}{V}\ (\frac{g}{cm^3})$$

Where:

ṗd = Dry density

M = Dry mass of soil sample

V = Volume of soil sample

2.8.3 Field capacity

The field capacity was determined by the gravimetric method as described by Veihmeyer & Hendrickson (1931). Before irrigation, the soil samples were collected, and the field capacity was determined. In this study, the field capacity was 28, 30 and 30 % respectively, at depths of 0-15, 15-30 and 30-45 cm.

2.9 Chemical properties

Before sowing the seed, the soil samples were collected at depths of 0-15, 15-30 and 30-45 cm to determine the following parameters.

2.9.1 Electrical conductivity (dS/m)

The electrical conductivity of the soil-extract paste was determined by using a digital EC meter. The extract was prepared with a 1:2 ratio. In this research, the electrical conductivity of 0.29, 0.34 and 0.38 (dS/m) at the depths of 0-15, 15-30 and 30-45 cm.

2.9.2 pH

pH of the soil extract was determined by using a digital pH meter. The extract was prepared with a 1:2 ratio. In this study, the pH was 7.00, 7.05 and 7.10, respectively, at depths of 0-15, 15-30 and 30-45 cm.

2.10 Discharge measurement

The discharge of the field channel was measured with a Parshall flume of size 54 inches in length and 3 inches in width. The following formula was used for discharge. The discharge was taken from the following table after the height of flow of water (Abt and Staker, 2019).

$$Q = 0.96\ H^{1.72}$$

Where:

H = Height (ft)

Q = Discharge (ft^3/sec)

2.11 Time to irrigate each plot

Time to irrigate the plots was determined with the following formula.

$$T = \frac{AD}{Q}$$

Where:

Q = discharge (cumec)

T = time of application (sec)

A = area to be irrigated (hectare)

D =depth of irrigation water to be applied (cm)

2.12 Bulb size, bulb weight, biomass, plant height, and yield

The diameter of the bulbs was determined by a vernier calliper. Ten samples of onion bulbs were selected from each treatment. The average bulb size was calculated. The weight of the bulb was determined by a weight balance. The weight biomass was determined by a weight balance. The height of each plant was measured with a measuring tape from the root to the leaves. The yield of onion was estimated per plot and per-hectare basis.

2.13 Water saving

The water saving was determined by comparing the conventional furrow irrigation. The following relations were used to determine the water saving.

$$WSa = \frac{Wc - Wa}{Wc} \times 100$$

$$WSm = \frac{Wc - Wm}{Wc} \times 100$$

Where:

WS_a = Water saving in alternate furrow (%)

WS_m = Water saving in mulched furrow (%)

W_c = Water used in conventional furrow (m^3)

W_a = Water used in alternate furrow (m^3)

W_m = Water used in mulched furrow (m^3)

2.14 Water productivity

Crop water productivity on per hectare basis was determined with the following formula.

$$CWP = \frac{Y}{W}$$

Where:

CWP = Crop water productivity (kg/m^3)

Y = Yield (kg/ha)

W = Water consumed (m^3/ha)

2.15 Irrigation scheduling

The irrigation scheduling of the onion crop was done using the following formula.

$$d_{net} = TAW \times P$$

Where:

D_{net} = Net depth of water (m)

P = Soil moisture depth (m)

TAW = Total available moisture (mm/m)

$$IF = {d_{net}}/{ETc}$$

Where:

IF = Irrigation frequency (days)

d_{net} = Net depth of water required (mm)

ETc = Crop evaporation (mm/day)

Kc = Crop coefficient

2.16 Statistical Analysis

The statistical analysis was done with statistical computer software Statistix 8.1. Analysis of variance and least significant differences were calculated with the same software.

Results and Discussions 3.

3.1 Growth parameters of onion

Results of the bulb size of onion under conventional furrow, mulched furrow and alternative mulched furrow are mentioned in Figure 3.1. The bulb size (cm) was significantly affected by different furrow irrigation methods. Maximum bulb size (5.58 cm) was recorded from the alternative mulched furrow irrigation, followed by mulched furrow irrigation (5.19 cm), and minimum bulb size (4.56 cm) was recorded from the conventional furrow irrigation method.

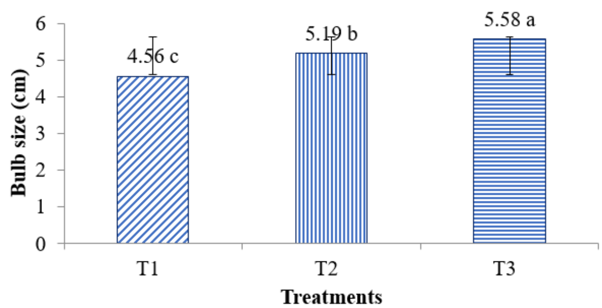

Figure 3.1 Bulb size (cm) of onion crop under different treatments

Results on the biomass of onion are mentioned in Figure 3.2. The biomass was significantly affected by different furrow irrigation methods. The biomass was obtained at 56464 kg/ha, 76640 kg/ha and 104000 kg/ha under T_1, T_2, and T_3, respectively.

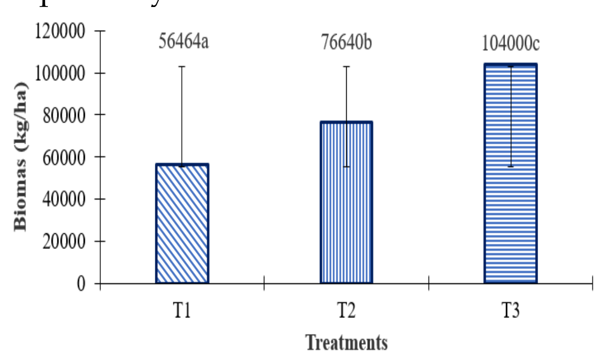

Figure 3.2 Biomass (kg /ha) of onion crop under different treatments

Results of the bulb weight of the onion are mentioned in Figure 3.3. The bulb weight (g) was significantly affected by different furrow irrigation methods. Maximum bulb weight (103.01 g) was recorded from the alternative mulched furrow irrigation followed by conventional furrow (93.49 g) and mulched furrow irrigation (98.00 g), and minimum bulb weight (93.49 g) was recorded from the conventional furrow irrigation method.

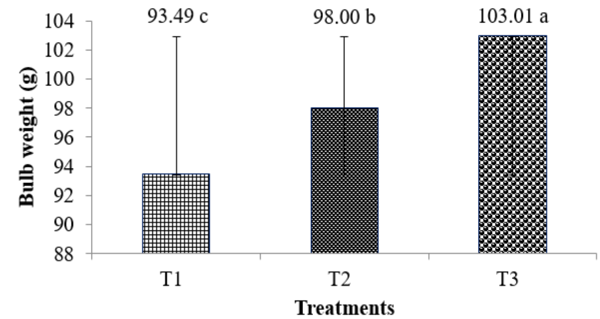

Figure 3.3 Bulb weight (g) of onion crop under different treatments

Results on the plant height of onion are mentioned in Figure 3.4. The plant height (cm) was significantly affected by different furrow irrigation methods. Maximum plant height (49.83 cm) was recorded from the alternative mulched furrow irrigation, followed by mulched furrow irrigation (43.63 cm), and minimum plant height (39.74 cm) was recorded from the conventional furrow irrigation method.

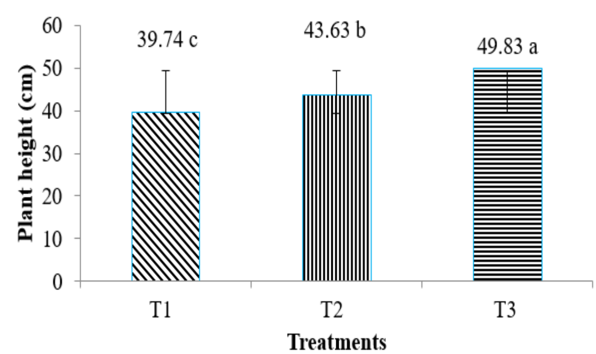

Figure 3.4 Plant height (cm) of onion crop under different treatments

Results on the yield of onions are presented in Figure 3.5. The yield was significantly affected by different furrow irrigation methods. Maximum yield (23488 kg ha^{-1}) was recorded from the alternative mulched furrow irrigation, followed by mulched furrow irrigation (17856 kg ha^{-1}), and minimum yield (16808 kg ha^{-1}) was recorded from the conventional furrow irrigation method.

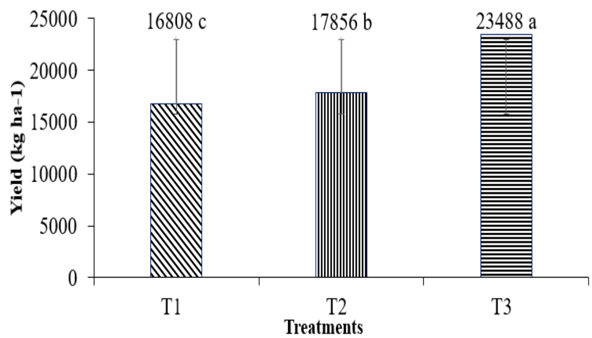

Figure 3.5 Yield (kg ha^{-1}) of onion crop under different treatments

The present study shows that the onion crop irrigated with alternative mulched furrow irrigation (T_3) resulted in a 5.58 cm bulb size, 103.01 g bulb weight, 130.00 kg biomass, 49.83 cm plant height and 29.36 kg plot^{-1} yield. Mulched furrow (T_2) resulted in 5.19 cm bulb size, 98.00 g bulb weight, 95.80 kg biomass, 43.63 cm plant height and 17856 kg plot^{-1} yield. The conventional furrow (T_1) resulted 4.56 cm bulb size, 93.49 g bulb weight, 70.58 kg biomass, 39.74 cm plant height and 16808 kg plot^{-1} yield.

The collective findings of earlier studies consistently demonstrate that irrigation water availability plays a decisive role in determining onion growth and yield. Kloss et al. (2012) confirmed that increasing irrigation volume directly enhances crop productivity. Similarly, Oweis et al. (2000) reported that supplying 100% of the crop's water requirement at all growth stages ensures the highest attainable commercial yield, irrespective of plant age. This positive relationship between irrigation levels and marketable yield is further supported by Dalorima et al. (2017) and Mebrahtu (2018), who observed that greater irrigation depths produced larger bulb sizes. Li et al. (2015) added that adopting water-saving strategies to achieve 75% ETc can still generate large, high-value bulbs without compromising quality, emphasising the efficiency of optimised irrigation. Such evidence underscores the importance of maintaining adequate soil moisture throughout the crop cycle, as this promotes healthy vegetative growth and supports the formation of commercially acceptable bulb sizes. Maity et al. (2017) also noted that water stress significantly affects bulb mass; heavier bulbs (103 g) were recorded under sufficient irrigation, whereas severe stress reduced bulb weight to 67 g and 57 g. Their results indicate a linear improvement in bulb mass with reduced stress, highlighting the sensitivity of onions to moisture levels. Our findings align with those of Bayisa et al. (2021), Kumar et al. (2017), and Anisuzzaman et al. (2009), confirming that precise, frequent irrigation applied in small amounts minimises evaporation losses compared to surface irrigation and eliminates foliage wetting by applying water below or at ground level. Under alternate irrigation systems, onion bulbs achieved greater equatorial (6.15 cm and 5.15 cm) and polar (5.15 cm and 3.35 cm) diameters than those under surface irrigation during both Rabi and Kharif seasons. Consistent soil moisture also contributes to increased photosynthetic area, enhancing plant height, leaf production, and ultimately bulb diameter and overall yield.

3.2 Water saving

Findings of the water saving of the onion crop as affected by conventional furrow, mulched furrow and alternative mulched furrow are mentioned in Figure 3.6. Maximum water saving (46.67%) was recorded from the alternative mulched furrow irrigation, and minimum water saving (20%) was recorded from the mulched furrow irrigation method.

The findings of the present study indicate that T_3 achieved the highest water savings at 46.67%, while mulched furrow irrigation (T_2) contributed to a 20% reduction in water use. These results closely align with the work of Mebrahtu (2017), who described alternative furrow irrigation (AFI) as an effective water-saving strategy wherein only alternate furrows are irrigated, thereby reducing overall water consumption without adversely affecting crop yield. The suitability of AFI for onion production has been supported by Temesgen et al. (2018) and Gelu (2023), who identified it as a feasible and efficient method for conserving water under limited-resource conditions. Further evidence from Abera et al. (2020) reinforces that onions, being a water-intensive crop typically grown in water-scarce environments, benefit significantly from AFI, which has been shown to reduce irrigation water use by up to 30% relative to conventional furrow irrigation. This reduction is attributed to decreased evaporation losses and lower water application per unit area. Additionally, studies by Sali et al. (2022) and Shahid and Abdul (2015) demonstrated that AFI not only conserves water but also enhances onion yield and quality by improving root-zone moisture availability, thereby reducing plant water stress and promoting overall growth. The literature further highlights ancillary benefits of AFI, such as mitigating soil erosion and nutrient depletion. Irrigating alternate furrows allows the dry furrow to absorb moisture and nutrients from adjacent wet furrows, resulting in gradual improvement of soil fertility over time. Nevertheless, the suitability of AFI varies across soil types and climatic conditions, necessitating expert consultation before adoption, as advised by Mugoro et al. (2020) and Bayisa et al. (2021). The present study also confirms that furrow irrigation techniques significantly influenced water savings. The highest water savings (55%) were achieved through alternative furrow irrigation, followed by mulched furrow irrigation (51%), while conventional furrow irrigation resulted in the lowest savings (47%). These trends correspond with Abdel Khalik et al. (2019), who reported that soil cover reduces evaporation by acting as a protective barrier, reflecting solar radiation, and lowering crop evapotranspiration, thereby further enhancing water conservation.

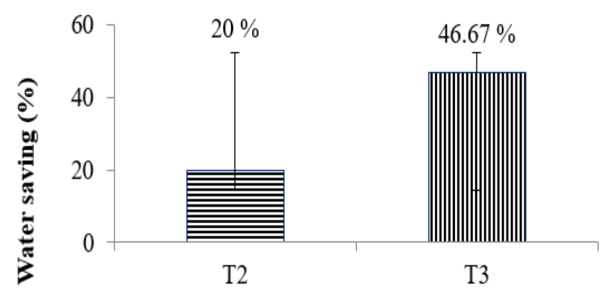

Figure 3.6 Water saving (%) of onion crop under different treatments

3.3 Crop water productivity

Results on the crop water productivity of onion are shown in Figure 4.7. The crop water productivity was significantly ($P<0.05$) affected by different furrow irrigation methods. Maximum crop water productivity (2.94 kg m^{-3}) was recorded from the alternative mulched furrow irrigation, followed by mulched furrow irrigation (1.49 kg m^{-3}) and minimum crop water productivity (1.13 kg m^{-3}) was recorded from conventional furrow irrigation.

The present study demonstrates that alternative mulched furrow irrigation (T3) produced the highest crop water productivity (2.94 kg m^{-3}), followed by mulched furrow irrigation (T2), which achieved 1.49 kg m^{-3}. These findings align with Kloss et al. (2012), who reported that controlled deficit irrigation has a direct and rapid effect on yield improvement and is fundamentally linked to enhanced water productivity. Similarly, Prasad and Mahmud (2017) emphasised that supplying 100% of crop water requirements at every growth stage consistently leads to maximum commercial yield, regardless of plant maturity. The positive relationship between irrigation water quantity and marketable bulb output has also been confirmed by Suthar et al. (2020), Muhammed et al. (2015), and Enciso (2015), who documented a linear increase in bulb yield with increased irrigation application. Mansouri (2015) further found that adopting water-saving adjustments to achieve 75% ETc can still produce large, high-value onion bulbs without sacrificing quality. These findings collectively highlight the importance of maintaining adequate soil moisture throughout the onion growth cycle, as it supports vegetative development and ensures the formation of commercially desirable bulb sizes. Gebeyehu (2020) also reported that deficit irrigation significantly affects fresh bulb mass ($p < 0.05$), with a high coefficient of determination ($R^2 = 0.943$). Treatments receiving the highest water levels produced the heaviest bulbs (103 g), whereas the lowest water treatments yielded bulbs weighing only 67 g and 57 g. This demonstrates that water stress adversely affects individual bulb weight and that bulb mass responds linearly to increasing water stress. These observations are consistent with the findings of Gelu (2020), Kumar et al. (2017), and Haile et al. (2021), who found similar trends in onion plant growth under varying irrigation regimes. Compared with traditional irrigation, optimised systems such as alternative and mulched furrow irrigation reduce water loss by supplying water in precise amounts at scheduled intervals and at or below the soil surface, thereby preventing unnecessary evaporation and foliage wetting. Under these improved irrigation methods, onion bulbs achieved maximum equatorial diameters of 6.15 cm and 5.15 cm and polar diameters of 5.15 cm and 3.35 cm, while surface irrigation resulted in the smallest bulb dimensions during both Rabi and Kharif seasons. Maintaining consistent soil moisture increases the photosynthetic area, enhancing plant height, leaf number, bulb diameter, and ultimately total production. The findings further indicate that different furrow irrigation methods significantly affected crop water productivity ($p < 0.05$). Alternative furrow irrigation achieved the highest productivity (2.94 kg m^{-3}), followed by mulched furrow irrigation (1.49 kg m^{-3}), while conventional furrow irrigation recorded the lowest productivity (1.13 kg m^{-3}). These results correspond with Ogunjobi (1999), who emphasised the importance of measuring efficiency as a key indicator of performance and a tool for analysing productivity variations. According to Amaza (2010), improved agricultural productivity contributes not only to economic development but also directly supports the livelihood of rural communities. However, lower onion yield may arise from factors such as inconsistent seed supply and inadequate seed processing techniques. Proper plant nutrition significantly enhances onion seed yield and quality, as noted by Maity and Basu (2017).

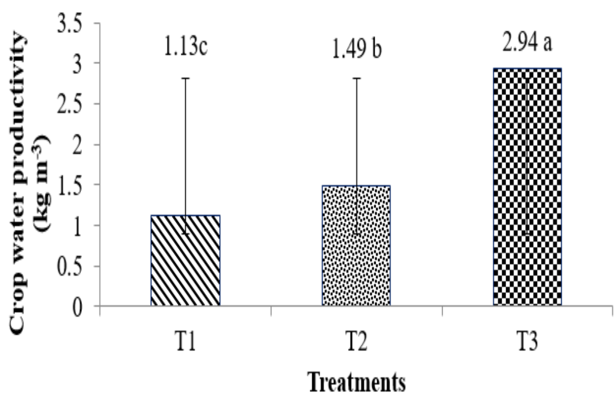

Figure 3.7 Crop water productivity (kg m^{-3})

3.4 Conclusions

The results of the present study collectively demonstrate that T_3 (alternative mulched furrow irrigation) is the most efficient and productive irrigation method for onion cultivation. This treatment consistently outperformed T_1 and T_2 across all major agronomic parameters, producing the maximum bulb size (5.58 cm), biomass yield (104,000 kg/ha), bulb weight (103.01 g), plant height (49.83 cm), and total bulb yield (23,488 kg/ha), highest water saving (46.67%) and maximum crop water productivity (2.94 kg m^{-3}). Optimised irrigation through alternative mulched furrows offers a viable, resource-efficient strategy that successfully decouples yield performance from water consumption.

3.5 Recommendations

Based on the findings of the present study, it is explicitly recommended that the alternative mulched furrow irrigation method be adopted in the study area. This method has proven to be both sustainable and scalable, offering substantial improvements in agricultural productivity while significantly enhancing water-use efficiency in onion production systems.

3.6 Innovation Statement

The innovation of this study lies in demonstrating that alternative mulched furrow irrigation (T_3) can simultaneously maximise onion yield and minimize water use, thereby decoupling high productivity from high water input, a challenge rarely addressed in traditional irrigation research. Unlike conventional methods, T_3 integrates alternate furrow wetting with soil mulching, creating a dual mechanism that enhances soil moisture retention, improves root-zone efficiency, and reduces non-beneficial water losses. This combined approach results in substantially higher bulb size, biomass, bulb weight, plant height, and total yield, while achieving unprecedented water savings (46.67%) and superior crop water productivity (2.94 kg m^{-3}). The study introduces a scalable, resource-efficient irrigation strategy that advances sustainable onion production and provides a practical solution for regions facing increasing water scarcity

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