International Journal of Environment and Climate Change

Volume 13, Issue 10, Page 693-701, 2023; Article no.IJECC.104357
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Effect of Irrigation Levels and Straw Mulching on Yield and Water Use Efficiency of Papaya under Drip Irrigation System

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJECC/2023/v13i102705

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/104357

Original Research Article

Received: 03/06/2023
Accepted: 07/08/2023
Published: 21/08/2023

ABSTRACT

Papaya (*Carica papaya* L.) is a significant fruit crop cultivated worldwide in tropical and subtropical regions. However, its cultivation is often constrained by limited water availability and soil moisture stress, which may significantly affect its yield and quality. This study aimed to explore the effects of

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irrigation levels and straw mulch on the growth and yield of papaya under a drip irrigation system. The experiment encompassed six treatments: three different irrigation levels (100%, 75%, and 50% of crop water requirement) and two mulch levels (straw mulching and no mulch). The effect of mulch levels on plant growth, yield, and water use efficiency was statistically significant. The results revealed that applying 100% of crop water requirement along with straw mulch resulted in the maximum plant height, stem girth, crown diameter, and yield compared to the no mulch treatment. The study also evaluated irrigation water use efficiency, an essential aspect of sustainable farming practices. The results indicated that the maximum irrigation water use efficiency (58.47 kg m^{-3}) was recorded when 50% of the crop water requirement was met alongside straw mulch. Conversely, the minimum irrigation water use efficiency was observed when 100% of the crop water requirement was completed without any mulch under the drip irrigation system.

Keywords: Mulching; irrigation levels; irrigation water use efficiency; drip irrigation; papaya.

1. INTRODUCTION

Papaya (*Carica papaya* L.) is an important tropical fruit crop widely grown in many countries, including India, Thailand, Brazil, and Mexico. Papaya is a rich source of vitamins A, C, and E. It has been shown to have many health benefits, such as reducing the risk of cancer, digestive disorders, and cardiovascular disease. The global demand for papaya has increased due to its nutritional and medicinal properties. However, papaya production is constrained by various biotic and abiotic factors, including water shortage stress.

Irrigation is crucial in papaya production as it affects growth, yield, and fruit quality. Insufficient irrigation can reduce growth, profit, and fruit quality, while excessive irrigation can lead to water logging, root rot, and reduced fruit quality. Therefore, applying appropriate irrigation levels is essential to optimize papaya production. Drip irrigation, which has an irrigation efficiency of more than 90%, is one of the most modern and effective irrigation techniques. Comparing the drip irrigation technique to the conventional one, crop production is often increased by 25–30%, and irrigation water is saved by 50–60% [1].

Mulching is another critical cultural practice that can improve soil moisture conservation, reduce weed growth and improve soil fertility [2]. Mulching can also regulate soil temperature, thereby influencing plant growth and development. Straw mulching is a common agricultural practice to improve soil quality and increase crop yield. It involves the application of a layer of straw on the soil surface to reduce water loss through evaporation, maintain soil moisture and suppress weed growth. Straw mulch is a barrier between the soil surface and the atmosphere, reducing water loss through evaporation. This reduces the need for frequent irrigation, leading to significant water savings. Additionally, straw mulching can improve soil structure, aeration, and nutrient availability, leading to healthier and more productive fruit trees. Several studies have reported positive effects of straw mulching on fruit crops [3,4,5].

Several studies have investigated the effect of different irrigation and mulch levels on various crops such as tomato, cucumber and wheat [6,7,8]. However, limited research has been conducted on the effect of irrigation and mulch levels on papaya. Therefore, the present study aimed to investigate the effect of different irrigation and mulch levels on the growth, yield, and water use efficiency of papaya.

2. MATERIALS AND METHODS

The experiment was carried out at the research field of Deendayal Upadhyay Centre of Excellence for Organic Farming, Chaudhary Charan Singh Haryana Agricultural University, Hisar ($29^0$08'09.3" N, $75^0$42'16.0" E and 215.2 m above sea level) during 2021-22. Hisar falls under the subtropical zone with a semi-arid climate, situated approximately 1600 kilometers away from the ocean at the outer edges of the monsoon region. The region receives an average of 459 mm of annual rainfall, with 75 to 80% occurring during the South-West Monsoon season from June to September. The average yearly temperature in Hisar is 25.1°C. Meteorological parameters such as pan evaporation, pan coefficient, and rainfall for the experimental period were obtained from the Department of Agricultural Meteorology, COA, CCS Haryana Agricultural University, Hisar. The soil of the practical site was found to be sandy loam with a pH of 6.5. The present investigation was laid out in a split-split plot design and replicated three times. The experimental treatment consisted of three irrigation levels, *viz.,* 100, 75, and 50% of crop water requirement in the main plot, and two mulch levels, straw mulch and no mulch in the subplot. The details of treatment combinations of different irrigation and mulch levels are shown in Table 1.

Irrigation levels:

I_1 - 100 % of crop water requirement
I_2 - 75 % of crop water requirement
I_3 - 50 % of crop water requirement

Mulch levels:

M_1 - 5 cm thick straw mulch in two-meter diameter around the plant
M_2 - No mulch

In the first week of March, papaya seedlings of the variety "Red Lady" that were 45 days old were transplanted at a spacing of 2 m X 2 m. The laterals equipped with drippers are placed on both sides of the plants with 60 cm spacing. Each plant consists of four drippers of a 2 liter per hour discharge rate with 30 cm spacing on laterals. The experimental field was irrigated as per treatment by using a climatological approach. The amount of irrigation water to be applied was calculated by following formula [9].

$$V=\frac{W_a \times PE \times P_C \times K_C}{EU} \quad (1)$$

Where,

V = amount of water applied (Litre per plant)
W_a = Wetted area
PE = sum of pan evaporation of last two days (mm)
K_C = crop coefficient of papaya [10]
P_C = pan coefficient (0.7)
EU = Emission uniformity of the system (considered as 90%)

Soil samples were collected periodically (90, 120 and 150 days after transplanting (DAT)) to determine the soil moisture on a dry basis. Soil samples were collected by using a tube auger at 0-30 cm depth below the soil surface and 30 cm away from the dripper, perpendicular to lateral. The mass of soil samples was observed before and after drying the samples, and the moisture content (dry basis) was determined using equation 2.

$$\text{Moisture content (\%)}=\frac{M_1-M_2}{M_2}\times 100 \quad (2)$$

Where,

M_1 = mass of soil sample before drying (g)
M_2 = mass of soil sample after drying (g)

The correlation between irrigation water and yield is expressed as irrigation water use efficiency (IWUE). IWUE was determined by comparing the fruit yield per hectare to the amount of water utilized in each treatment.

$$\text{IWUE}\left(\text{kg m}^{-3}\right)=\frac{\text{Total curd yield}\left(\text{kg ha}^{-1}\right)}{\text{Amount of irrigation water applied}\left(\text{m}^3\text{ ha}^{-1}\right)} \quad (3)$$

The different parameters, such as plant height, crown diameter, stem girth, number of fruits per plant, yield per plant, yield per hectare, and irrigation water use efficiency, were recorded during the crop period. The collected data were analyzed for statistical significance using the split-split plot design with the help of OPSTAT software [11]. The treatment differences were tested using the 'F' significance test based on the null hypothesis. For each case, the standard error of the mean was calculated, and the critical difference (C.D.) at a 5% probability level was computed for significant results.

Table 1. Details of treatment combinations of different irrigation and mulch levels

Sr. no.	Irrigation levels	Mulch levels	Symbol
1	**100 % of crop water requirement**	Straw mulch	$\mathbf{I_1M_1}$
2		No mulch	$\mathbf{I_1M_2}$
3	**75 % of crop water requirement**	Straw mulch	$\mathbf{I_2M_1}$
4		No mulch	$\mathbf{I_2M_2}$
5	**50 % of crop water requirement**	Straw mulch	$\mathbf{I_3M_1}$
6		No mulch	$\mathbf{I_3M_2}$

3. RESULTS AND DISCUSSION

3.1 Soil Moisture Content

The soil moisture content on a dry basis was recorded at 90, 120, and 150 DAT using the gravimetric method shown in Fig. 1. Soil samples were taken using a tube auger 0-30 cm below the soil surface and 30 cm from the plant. The soil moisture content was recorded as maximum (16.44, 16.88, and 18.54%) for I_1M_1 and minimum (9.11, 10.18, and 10.58%) for I_3M_2 at 90, 120, and 150 DAT, respectively.

3.2 Plant Height (cm)

The interaction of irrigation and mulch levels on average plant height at harvesting is shown in Fig. 2. Although the statistical analysis showed that the exchange of irrigation and mulch levels on average plant height was not significant, it was observed that treatment I_1M_1 resulted in the maximum average plant height (237.67 cm) at harvesting. In comparison, treatment I_3M_2 had the minimum average plant height (186.27 cm). On the other hand, the effect of different irrigation levels on average plant height was statistically significant. Treatment I_1 resulted in the maximum average plant height (232.07 cm), followed by I_2 (214.60 cm), and I_3 showed the minimum average plant height (193.63 cm) at harvesting. Similarly, the effect of mulch levels on average plant height was also found to be statistically significant. Treatment M_1 showed the maximum average plant height (219.67 cm) at harvesting, while M_2 had the minimum average plant height (207.20 cm).

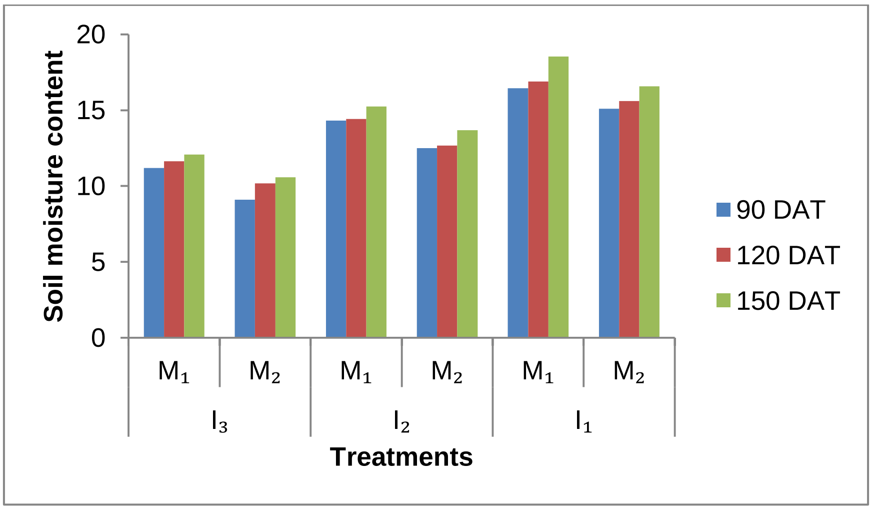

Fig. 1. Soil moisture content for different treatments at 90, 120, and 150 DAT

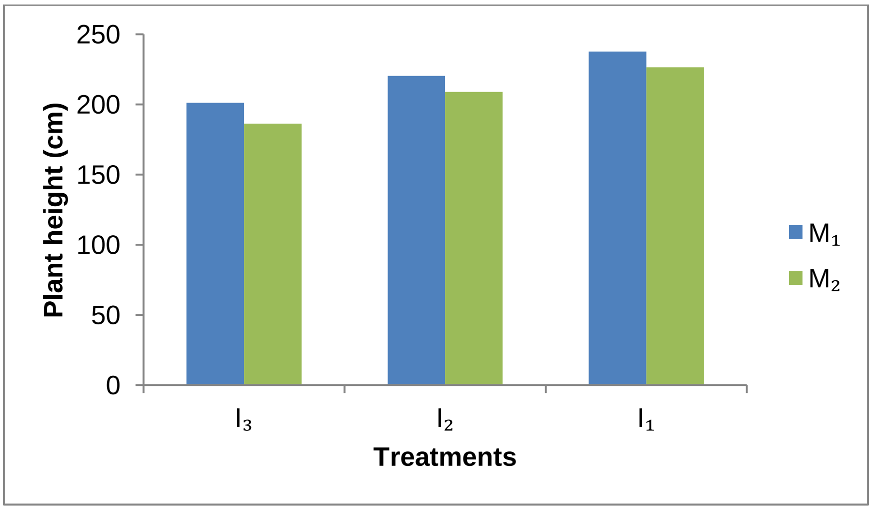

Fig. 1. Average plant height of different treatments at harvesting

3.3 Stem Girth (cm)

The interaction of irrigation and mulch levels on average stem girth at harvesting is shown in Fig. 3. Although the statistical analysis showed that the exchange of irrigation and mulch levels on average stem girth was not significant, it was observed that treatment I_1M_1 resulted in the maximum average stem girth (45.63 cm) at harvesting. In comparison, treatment I_3M_2 had the minimum average stem girth (32.97 cm). On the other hand, the effect of different irrigation levels on average stem girth was statistically significant. Treatment I_1 resulted in the maximum average stem girth (44.15 cm), followed by I_2 (39.82 cm), and I_3 showed the minimum average stem girth (34.85 cm) at harvesting. Similarly, the effect of mulch levels on average stem girth was also found to be statistically significant. Treatment M_1 showed the maximum average stem girth (41.22 cm) at harvesting, while M_2 had the minimum average stem girth (37.99 cm).

3.4 Crown Diameter (cm)

The interaction of irrigation and mulch levels on average crown diameter at harvesting is shown in Fig. 4. Although the statistical analysis showed that the exchange of irrigation and mulch levels on average crown diameter was not significant, it was observed that treatment I_1M_1 resulted in the maximum average crown diameter (242.33 cm) at harvesting. In comparison, treatment I_3M_2 had the minimum average crown diameter (190.93 cm). On the other hand, the effect of different irrigation levels on average crown diameter was statistically significant. Treatment I_1 resulted in the maximum average crown diameter (236.73 cm), followed by I_2 (219.27 cm), and I_3 showed the minimum average crown diameter (198.30 cm) at harvesting. Similarly, the effect of mulch levels on average crown diameter was also found to be statistically significant. Treatment M_1 showed the maximum average crown diameter (224.33 cm) at harvesting, while M_2 had the minimum average crown diameter (211.87 cm).

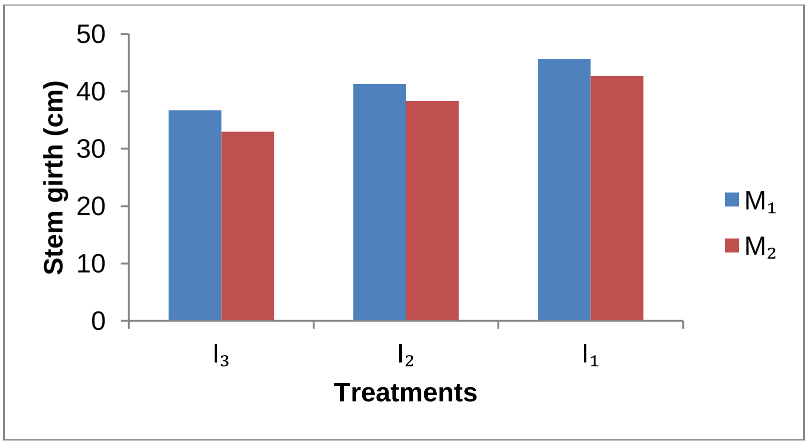

Fig. 3. Average stem girth of different treatments at harvesting

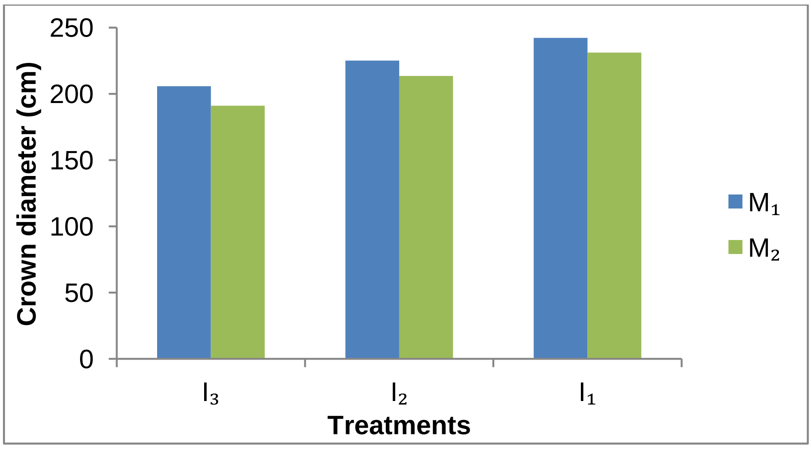

Fig. 4. Average crown diameter of different treatments at harvesting

3.5 Number of Fruits

The interaction of irrigation and mulch levels on an average number of fruits at harvesting is shown in Fig. 5. Although the statistical analysis showed that the exchange of irrigation and mulch levels on average number of fruits was not significant, it was observed that treatment I_1M_1 resulted in the maximum average number of fruits (42) at harvesting. In contrast, treatment I_3M_2 had the minimum average number of fruits (32.33). On the other hand, the effect of different irrigation levels on the average number of fruits was statistically significant. Treatment I_1 resulted in the maximum average number of fruits (41), followed by I_2 (37), and I_3 showed the minimum average number of fruits (33.33) at harvesting. Similarly, the effect of mulch levels on average number of fruits was also found to be statistically significant. Treatment M_1 showed the maximum average number of fruits (38.11) at harvesting, while M_2 had the minimum average number of fruits (36.11).

3.6 Yield per Plant (kg)

The interaction of irrigation and mulch levels on average yield per plant at harvesting is shown in Fig. 6. Although the statistical analysis showed that the exchange of irrigation and mulch levels on average yield per plant was not significant, it was observed that treatment I_1M_1 resulted in the maximum average yield per plant (53.60 kg) at harvesting. In comparison, treatment I_3M_2 had the minimum average yield per plant (35.83 kg). On the other hand, the effect of different irrigation levels on average yield per plant was statistically significant. Treatment I_1 resulted in the maximum average yield per plant (51.78 kg), followed by I_2 (44.78 kg), and I_3 showed the minimum average yield per plant (36.27 kg) at harvesting. Similarly, the effect of mulch levels on average yield per plant was also found to be statistically significant. Treatment M_1 showed the maximum average yield per plant (46.20 kg) at harvesting, while M_2 had the minimum average yield per plant (43.02).

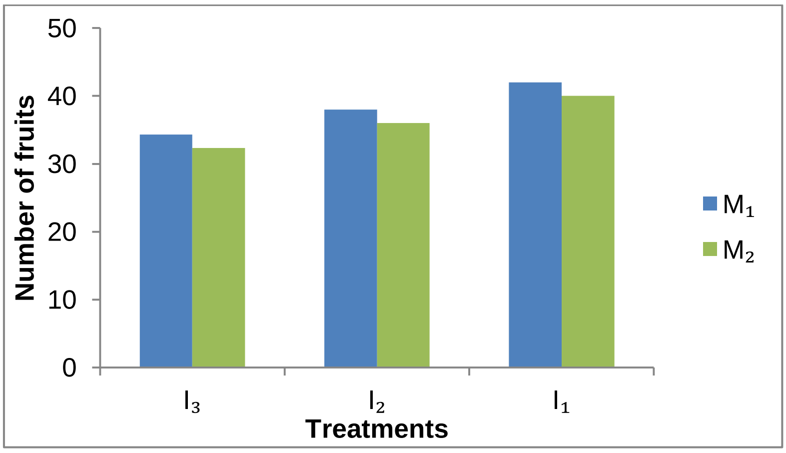

Fig. 5. Average number of fruits for different treatments at harvesting

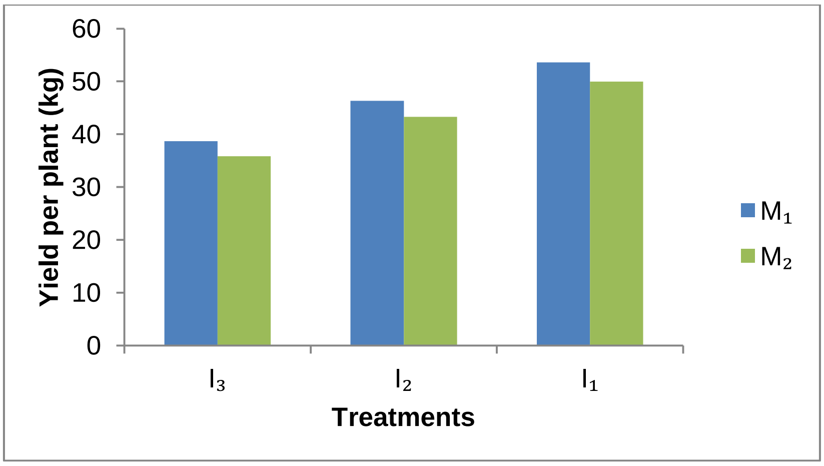

Fig. 6. Average yield per plant for different treatments

3.7 Yield (t ha^{-1})

The interaction of irrigation and mulch levels on average yield per hectare is shown in Fig. 7. Although the statistical analysis showed that the exchange of irrigation and mulch levels on average yield per hectare was not significant, it was observed that treatment I_1M_1 resulted in the maximum average yield per hectare (133.96 t ha^{-1}). In comparison, treatment I_3M_2 had the minimum average yield per hectare (89.58 t ha^{-1}). On the other hand, the effect of different irrigation levels on average yield per hectare was statistically significant. Treatment I_1 resulted in the maximum average yield per hectare (129.44 t ha^{-1}), followed by I_2 (111.96 t ha^{-1}), and I_3 showed the minimum average yield per hectare (93.17 t ha^{-1}). Similarly, the effect of mulch levels on average yield per hectare was also found to be statistically significant. Treatment M_1 showed the maximum average yield per hectare (115.49 t ha^{-1}) at harvesting, while M_2 had the minimum average yield per hectare (107.56 t ha^{-1}).

- The influence of different irrigation levels on plant growth and yield parameters was statistically significant, with the maximum values observed for I_1 and the minimum values for I_3. This outcome can be attributed to higher irrigation levels maintaining optimal water availability, thereby creating stress-free conditions for continuous growth and development of plants throughout the crop growth period. This outcome with previous studies reported by [12,13,14,15].
- The influence of mulchi levels on plant growth and yield parameters was statistically significant, with the maximum values recorded for M_1 and minimum values for M_2. This result can be attributed to the use of mulch at the soil surface, which reduced evaporation losses and maintained higher soil moisture availability in the straw mulched treatments compared to the no mulched treatments. This observation is consistent with the findings of [14].

3.8 Irrigation Water Use Efficiency

The interaction of irrigation and mulch levels on average irrigation water use efficiency was statistically insignificant. Still, average irrigation water use efficiency was recorded as maximum (58.47 kg m^{-3}) for treatment I_3M_1 and minimum (42.64 kg m^{-3}) for treatment I_1M_2. The interaction of irrigation and mulch levels on average irrigation water use efficiency is shown in Fig. 8. The influence of different irrigation levels on average irrigation water use efficiency was found to be statistically significant, and maximum average irrigation water use efficiency was observed for I_3 (56.30 kg m^{-3}), followed by I_2 (48.85 kg m^{-3}) and minimum for I_1 (44.19 kg m^{-3}). Similarly, the influence of mulch levels on average irrigation water use efficiency was statistically significant. Treatment M_1 showed the maximum average irrigation water use efficiency (51.57 kg m^{-3}), while M_2 had the minimum average irrigation water use efficiency (47.99 kg m^{-3}). The reason for this could be that using straw mulch during the early stages of growth resulted in a reduction in moisture loss through evaporation, leading to a decrease in water usage. This observation is consistent with [16 and 17] findings.

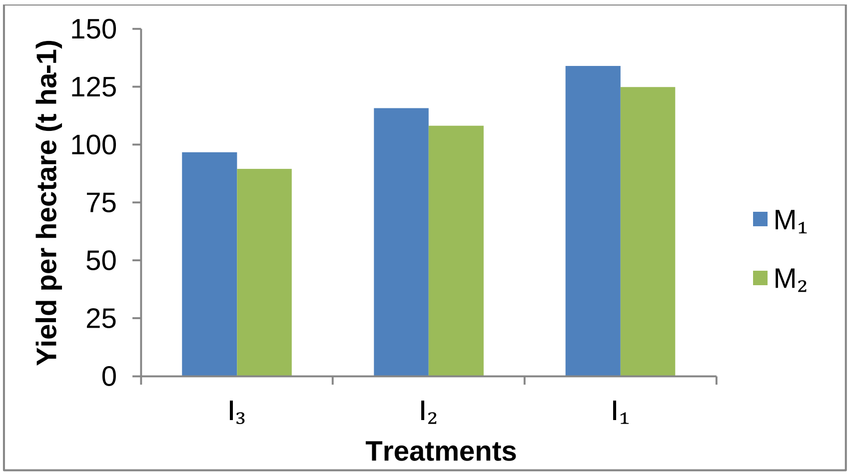

Fig. 7. Average yield per hectare for different treatments

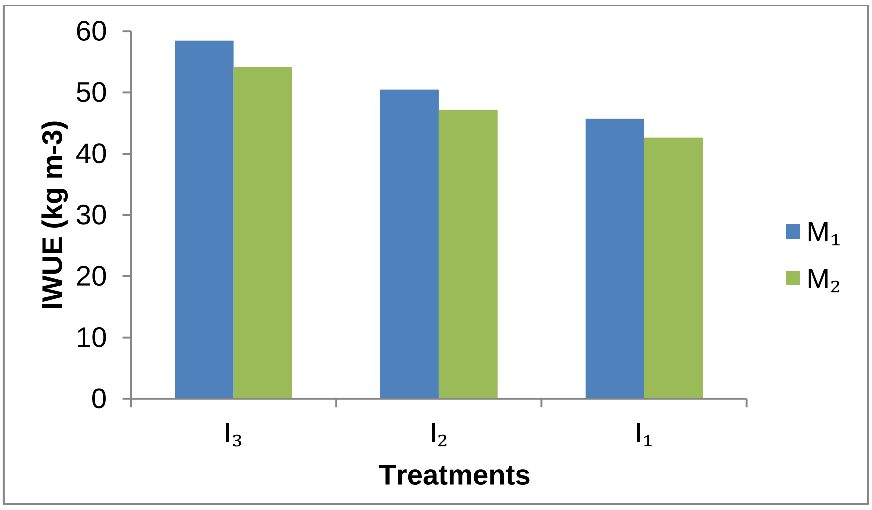

Fig. 8. Irrigation water use efficiency for different treatments

4. CONCLUSION

From the results it can be concluded that

- Regarding soil moisture content, the straw mulched treatments showed the highest levels while the no mulched treatments had the lowest soil moisture content. Therefore, straw mulch can be beneficial in areas with higher evaporation losses.
- When using straw mulch to supply all of the crop's water needs, it was discovered that plant growth and yield parameters were at their highest levels. On the other hand, the minimal values were seen when 50% of the crop's water needs were met without mulch.
- It was discovered that the efficiency of irrigation water consumption was highest when 50% of the crop's water needs were met with straw mulch and lowest when 100% of the crop's needs weren't met. This implies that combining drip irrigation with straw mulch at 50% of the crop's water need will successfully increase irrigation water use efficiency and decrease papaya's overall irrigation requirements.
- So, proper irrigation management is essential to ensure sufficient soil moisture for optimal plant growth and to avoid negative effects on agricultural productivity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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