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The response of irrigation, fertigation, and mulching on water and fertilizer use efficiency of capsicum grown under polyhouse

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Abstract

Efficient water and fertilizer management are vital for sustainable capsicum cultivation inside polyhouse. The study was conducted at RPCAU, Pusa, in Samastipur and aimed to evaluate the impact of irrigation, fertigation, and mulching on water and fertilizer use efficiency for capsicum cultivation inside polyhouse environment. The experiment was carried out from October 2017 to April 2018 using a factorial randomized block design (FRBD) involving three levels of irrigation (100%, 80%, and 60% of WR), fertigation (120%, 100%, and 80% of the recommended dose of fertilizer (RDF)), and mulch. The results revealed that there was significant improvement in yield water and fertilizer use efficiencies of capsicum under drip irrigation and fertigation. The treatment combination of 100% WR through drip and 120% recommended NPK through fertigation with mulch registered maximum fruit yield (93.74 kg/ha). The highest water and fertilizer use efficiency (62.49 kg/ha-cm) and (101.67 kg/ha-kg), respectively, was observed with the treatment combination of 100% ET through drip + 120% recommended NPK through fertigation. The study highlights the valuable insights for optimizing agricultural practices, and enhancing the sustainability of capsicum cultivation inside polyhouse. In conclusion, optimal irrigation, fertigation, and mulching practices significantly increase yield and enhance water and fertilizer use efficiencies in capsicum cultivation inside polyhouse.

Keywords: Drip irrigation, fertilizer, mulch, water use efficiency, fertilizer use efficiency, polyhouse

1. Introduction

Capsicum (*Capsicum annum* L. var. *grossum*) is an economically significant crop worldwide due to its nutritional value, culinary versatility, and high market demand. It is also known as sweet pepper, bell pepper or Shimla mirch. It is highly remunerative vegetable and a high-value, low-volume crop in polyhouse cultivation (Nikki *et al.*, 2017) ^[11]. It belongs to Solanaceae family and is believed to be originated in the Tropical South America (Shoemaker and Tesky, 1995) ^[18]. Water is a vital component for successful vegetable production (Gupta *et al.*, 2010) ^[2]. In vegetable production, water is most critical input, and their efficient management is important not only for higher productivity but also for maintaining quality. The increased competition for water between agricultural, industrial, and urban consumers creates the need for continuous improvement of irrigation practices in commercial vegetable production (Sezen *et al.*, 2006) ^[17]. Development of water management technology that improve water use efficiency is the key to guaranteeing sustainable cultivation of facilities vegetable (Yang, 2013) ^[22]. However, the efficient utilization of water through irrigation is becoming progressively crucial, and alternative methods of water application, such as drip irrigation, may significantly enhance the optimal utilization of water for agricultural purposes and improve irrigation efficiency (Nagaz *et al.*, 2012) ^[8]. Drip irrigation delivers water directly to the root zone of plants, reducing evaporative losses and ensuring precise water application. This targeted irrigation method optimizes water uptake by Capsicum plants, minimizing wastage and enhancing overall efficiency. Fertilizer plays an important role in agriculture by contributing to enhanced crop yields and improved soil fertility.

However, efficient management of fertilizers is paramount for maximizing their benefits while minimizing environmental impact and resource wastage.

The challenge facing agriculture in the forthcoming decades will be the sustainable use of plant nutrients. Achieving sustainability in any system necessitates the optimal use of resources such as water and fertilizers. Among agricultural techniques, fertilizer management stands out as crucial, as it governs the development, yield, and quality of crops. Therefore, every effort is essential in attaining the goal of improved water and fertilizer use efficiency (Chand, 2014) [7]. Under these circumstances, drip fertigation in a controlled environment, such as a polyhouse, emerges as a modern technology. Polyhouse is capital-intensive, less dependent on the environment, and has the capacity to improve the productivity and quality of produce in a controlled environment. It provides a controlled environment and helps to improve crop production throughout the year. The efficient application of fertilizer through a drip irrigation system as a carrier and distributor of crop nutrients holds bright promise (Magen, 1995) [4]. Maximizing crop yield and quality while minimizing nutrient leaching below the rooting zone can be achieved by precisely managing fertilizer concentrations in measured quantities of irrigation water through drip irrigation (Hagin and Lowengart., 1995) [6]. When fertilizer is applied through drip irrigation, it was observed that the yield has been increased and about 30 per cent of the fertilizer could be saved (Sivanappan and Ranghaswami., 2005) [14]. Locascio (2005) [10] observed that by employing drip irrigation for fertigation directly to the root rhizosphere, precision, uniformity, and nutrient use efficiency are achieved. Drip irrigation adoption increases water use efficiency (60-200%), fertilizer use efficiency (20-33%), and saved water as well as fertilizer (Kaushal *et al.*, 2012) [9]. Mulching also plays a pivotal role in reducing water loss through evaporation from the soil surface, thereby improving water use efficiency. It is gaining momentum in recent modern farming. The response of mulching on water use efficiency and fertilizer use efficiency is multifaceted and significant in enhancing agricultural sustainability. A field study was conducted to investigate the effect of drip irrigation and black polyethylene mulch Improve water-use efficiency and economics of tomato (*Lycopersicon esculentum* Miller). A study investigated the combined effects of drip irrigation and mulches on yield, water-use efficiency and economic return of tomato. Varughese and Habeeburrahman (2015) [21] observed that when plastic mulching is used along with drip irrigation and fertigation, it controls weeds and further increases the efficiency of the system. Moreover, mulching contributes to improved fertilizer use efficiency by reducing nutrient leaching and runoff. By preventing the displacement of applied fertilizers due to rainfall or irrigation, mulch helps retain nutrients within the root zone, maximizing their availability to plants and minimizing losses to the environment. In response, agricultural practices are evolving to embrace sustainable and efficient methodologies aimed at optimizing resource use while maximizing yields. Among these methodologies, drip irrigation and fertigation, coupled with mulching in controlled environments, have emerged as promising strategies to enhance water and fertilizer use efficiency in crop production. The present study was conducted to determine water and fertilizer use efficiency of capsicum grown under polyhouse.

2. Material and Methods

2.1 Description of experimental site and soil characteristics

The experimental site is located at RPCAU, Pusa, Samastipur

district of Bihar. It is situated on the southern and western bank of the River Burhi Gandak, at 25°59'N latitude and 85°48'E longitude, at an elevation of 52.92 meters above mean sea level. The experimental site falls under a humid subtropical climate, heavily influenced by the southwest monsoon. The average annual rainfall is 1270 mm, with approximately 1026 mm received during the monsoon season. The experimental plot exhibits uniform topography. The soil is well-drained with good tilth and manageable characteristics. It is classified as sandy clay loam with an average available moisture content of 12.01%. The other physio-chemical properties of the soil were outlined in Table 1

Table 1: Soil physical and chemical properties of the experimental field

Sl. No.	Particulars	Characteristics
1.	Soil type	Sandy clay loam
	pH	8.4
	EC (dS/m)	0.36
2.	Bulk density (g/cc)	1.56
3.	Particles distribution (%)	Sand- 63.02
		Silt- 23.25
		Clay- 13.73
4.	Hydraulic conductivity (cm/day)	130
5.	Basic infiltration rate (cm/hr)	2.5
6.	Wilting point (%)	7.2
7.	Field capacity (%)	22

2.2 Treatments and experimental design:

The experiment was carried out from October 2017 to April 2018. In this experiment factorial randomized block design (FRBD) with eighteen treatments and three replication was used. In order to increase resources, use efficiency on capsicum through different drip irrigation and fertigation along with incorporate mulch. The design details are mentioned in Table 2

Table 2: Treatments details

T ₁	120% RDF with 100% WR through drip without plastic mulch
T ₂	120% RDF with 100% WR through drip with plastic mulch
T ₃	100% RDF with 100% WR through drip without plastic mulch(control)
T ₄	100% RDF with 100% WR through drip with plastic mulch
T ₅	80% RDF with 100% WR through drip without plastic mulch
T ₆	80% RDF with 100% WR through drip with plastic mulch
T ₇	120% RDF with 80% WR through drip without plastic mulch
T ₈	120% RDF with 80% WR through drip with plastic mulch
T ₉	100% RDF with 80% WR through drip without plastic mulch
T ₁₀	100% RDF with 80% WR through drip with plastic mulch
T ₁₁	80% RDF with 80% WR through drip without plastic mulch
T ₁₂	80% RDF with 80% WR through drip with plastic mulch
T ₁₃	120% RDF with 60% WR through drip without plastic mulch
T ₁₄	120% RDF with 60% WR through drip with plastic mulch
T ₁₅	100% RDF with 60% WR through drip without plastic mulch
T ₁₆	100% RDF with 60% WR through drip with plastic mulch
T ₁₇	80% RDF with 60% WR through drip without plastic mulch
T ₁₈	80% RDF with 60% WR through drip with plastic mulch

2.3 Crop Evapotranspiration

The standard USWB Class-A pan evaporimeter is widely used worldwide for measuring the evaporation rate from a free surface. It is made of 20-gauge galvanized iron sheet with a diameter of 121.5 cm and a depth of 25.4 cm, equipped with a stilling well. The evaporimeter was installed inside a polyhouse for measuring the daily evaporation rate for capsicum crops following specific guidelines. The monthly pan evaporation data

shown in fig1.

The crop evapotranspiration (ET_C) for irrigating capsicum inside the polyhouse was calculated using the following formula:

$$ET_C = E_p \times K_p \times K_c \times W_p \times A_p$$

Where, ET_C = Evapotranspiration rate in mm/day, E_p = Pan evaporation in mm/day, K_p = Pan coefficient (taken 0.7 as suggested for class-A pan), K_c = crop coefficient (taken based on the FAO-56 curve methods), W_p = Wetted area factor (taken as 0.8 for capsicum), A_p = Area of Plant [(spacing between rows (m) $\times$ spacing between plants, (m))].

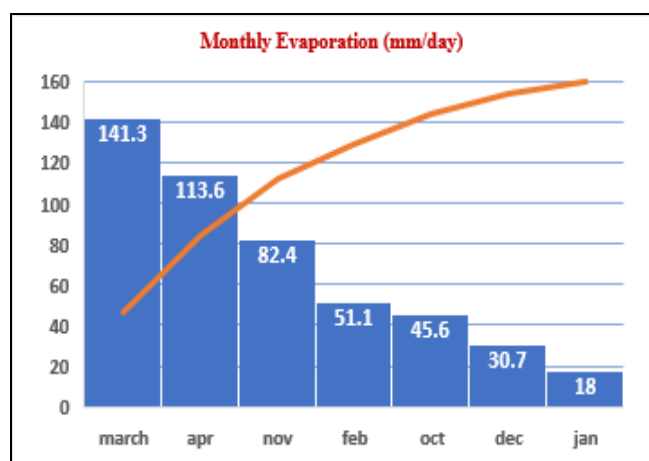


Fig 1: Monthly pan evaporation inside polyhouse during the entire growth period

2.4 Fertilizer dose and application

The amount of fertilizer used in this study was the same as the recommended dose of fertilizer used in the polyhouse for capsicum cultivation. The recommended dose of fertilizer (RDF) is in the ratio of 80:40:30 NPK (grams/square meter), with 25% of the fertilizer applied to each plot as a basal dose at the time of planting, and the remaining 75% applied through fertigation in a total of six split doses using water-soluble liquid fertilizers. Specifically, nitrogen was supplied using urea and DAP (Diammonium phosphate), phosphate (P_2O_5) using DAP, and potassium (K_2O) using muriate of potash (MOP). Table 3 shows the nutrients used to meet the crop's NPK requirements. Furthermore, Table 4 details the quantities of fertilizers used to provide nutrients (N, P, and K) at the recommended dose under different treatments.

Table 3: Different fertilizer sources and their nutrients content

Nutrients	Source	Nutrient availability (%) per 100 kg
Nitrogen (N)	FYM	0.5%
	DAP	18%
	Urea	46%
Phosphorus(P_2O_5)	FYM	0.3%
	DAP	46%
Potassium(K_2O)	FYM	0.4%
	MOP	60%

Table 4: Quantity of fertilizers used as basal dose before planting

Fertilizers	Treatment		
	120% RDF	100% RDF	80% RDF
DAP (kg/ha)	1042.32	868.6	694.89
Urea (kg/ha)	1678.92	1399.1	1119.28
MOP (kg/ha)	598.08	498.4	398.72

2.5 Irrigation and fertigation schedule

Capsicum is highly sensitive to moisture stress and waterlogging, with even slight variations in moisture levels significantly affecting plant growth and branch development (Ou, 2011) ^[12]. Considering this, irrigation was scheduled on daily basis to meet the crop water requirements. In the present study, fertilizer (NPK) was applied according to the recommended dose for different treatments, using a fertigation unit integrated into the drip irrigation system.

Fig 2 illustrates the use of a venture-type fertigation system with a fertilizer tank for the application of fertilizers. The required amount of fertilizer for each treatment was applied through this system.



Fig 2: General view of drip system and fertigation unit

2.6 Water-use efficiency

According to (Farooq *et al.*, 2019) ^[24] Water-use efficiency (WUE) is an important characteristic that delineates the ability of crop plants to utilize accessible water for carbon assimilation. It is defined as the ratio of crop yield to the amount of water depleted by the crop in the process of evaporation. The total fruit yield obtained for each treatment was divided by the quantity of water used for each treatment by this method. Different expressions (WUE have been proposed and discussed (Pereira *et al.*, 2002; Zwart and Bastiaanssen., 2004; Hsiao *et al.*, 2007) ^[13, 23, 5]. In general, WUE can be written as follows:

$$WUE = \frac{Y}{\text{Total crop water use}}$$

Where

WUE = Water use efficiency (kg/ha-cm)

Y = Total crop yield (kg/ha)

2.7 Fertilizer use efficiency

Fertilizer use efficiency (FUE) represents the overall efficiency of nutrient uptake and utilization, taking into account multiple nutrients (N, P, K) applied to the crop. It refers to the effectiveness with which plants absorb and utilize nutrients from applied fertilizers to support growth and development while minimizing nutrient losses to the environment. It is the ratio of

$$FUE = \frac{Y}{\text{Total amount of fertilizer use}}$$

Where

FUE = Fertilizer use efficiency (%)

Y = Total crop yield (kg/ha).

2.8 Data analysis

Data were statistically analyzed by a factorial randomized model using SAS software. Tukey's test was employed to determine any statistically significant differences between the treatments at 5% significance level.

3. Results and Discussion

3.1 Crop Evapotranspiration

Fig: 3 shows the monthly crop evapotranspiration (ET_c) inside the polyhouse during the growth period. The variation in evapotranspiration (ET_c) values inside the polyhouse follows seasonal changes, with a minimum ET of 11.2 mm in January during winter due to low temperatures and less solar radiation, and a maximum ET_c of 90.5 mm in April during summer due to high temperatures and more solar radiation trapped by the polyhouse. During the summer season, crop coefficient (K_c) value for initial, development, middle and end stages were higher compared to the winter season. This result was supported by Arunadevi *et al* (2022) [25]. Additionally, higher ET_c reflects increased water demand by plants as they actively develop and transpire more in warmer and brighter conditions, resulting in greater overall moisture loss.

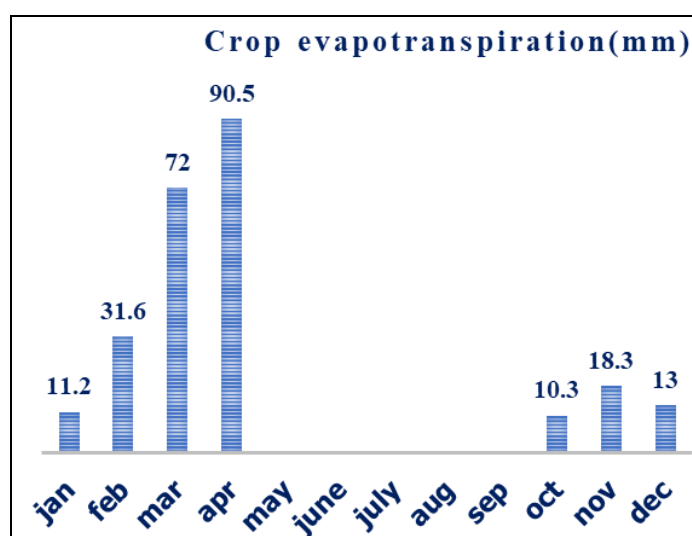


Fig 3: Monthly evapotranspiration inside Polyhouse

3.2 Total Yield

The effect of irrigation, fertigation, and mulching on capsicum yield was analyzed as presented in Table 5 and fig.4 revealing statistically significant differences among the treatments at the 5% significance level. The highest yield of 93.74 kg/ha was achieved in T₂ (120% recommended dose of fertilizer (120% RDF with 100% WR through drip with plastic mulch), followed by T₄ and T₈, with no statistically significant difference observed between both T₄ and T₈. Conversely, the lowest yield of 40.5 kg/ha was recorded in T₁₈ (80% RDF with 60% WR through drip irrigation with plastic mulch), followed by T₁₇ with no significant difference observed between both treatments. The synergistic effect of combining optimum levels of fertilizer, water, and mulching in treatment T₂ likely created favorable conditions for capsicum growth and development, leading to higher yields compared to other treatments.

Similar findings have been reported in previous studies on maximized capsicum yield through specific treatment combinations. In accordance with Joshi *et al.* (2012), higher yields of capsicum were obtained for treatment in combination

with Mulch + drip irrigation at 100% WR + 125% RDF. Similarly, Gupta *et al.* (2010) [2] also reported that the highest yield of capsicum was obtained by applying 80% of ET and 80% of RDF NPK. Furthermore, Muhhamad *et al.* (2015) (2017) [26] also found that the maximum capsicum yield was achieved with 100% RDF combined with plastic mulch. Similarly, observed that the maximum yield per plant was obtained with black polyethylene mulching and fertigation in capsicum under polyhouse conditions. These findings are consistent with the results reported by Tiwari *et al.* (2013) [27]. These findings indicate the optimal combination of irrigation, fertilizer application (RDF) and the use of plastic mulch for maximizing capsicum yield. It concludes that the best management practices for maximizing capsicum yield can vary based on specific factors such as water, nutrient application rates, and the use of mulching. However, efficient use of water, nutrients and soil moisture conservation consistently emerge as critical factors in achieving high yields in capsicum cultivation. Further research and experimentation may help refine these management strategies and adapt them to different agro-climatic conditions for optimal crop performance.

Table 5: Effect of irrigation, fertigation, and mulching on capsicum yield.

Treatments	Total Yield (kg/ha)	Treatments	Total Yield (kg/ha)
T ₁	65.5 ^{cd}	T ₁₀	67.4 ^c
T ₂	93.74 ^a	T ₁₁	49.23 ^{ij}
T ₃	58.64 ^{ef}	T ₁₂	52.96 ^{ghi}
T ₄	74.79 ^b	T ₁₃	54.57 ^{fg}
T ₅	49.9 ^{hij}	T ₁₄	54.08 ^{gh}
T ₆	61.64 ^{de}	T ₁₅	48.83 ^{ij}
T ₇	46.5 ^j	T ₁₆	48.03 ^j
T ₈	73.37 ^b	T ₁₇	41.13 ^k
T ₉	50.3 ^{g-j}	T ₁₈	40.5 ^k

Treatments means with the same letter are not statistically significantly different ($p < 0.05$).

3.3 Water use efficiency (WUE)

The study investigates the effect of irrigation, fertigation, and mulching on water use efficiency (WUE) for each treatment, as detailed in Table 6. The highest WUE of 62.49 kg/ha-cm was observed in Treatment T₂ (120% RDF with 100% WR through drip with plastic mulch; this was closely followed by T₈ and T₁₀ at 61.14 kg/ha-cm and T₁₀). In contrast, the control treatment T₃ (120% RDF with 80% WR through drip with plastic mulch) exhibited WUE of 39.09 kg/ha-cm. These findings emphasize the significance of specific irrigation, fertigation, and mulching practices in increasing water use efficiency (WUE) in agricultural systems. Similar findings have been reported by several researchers in previous studies on maximized WUE of capsicum through specific treatment combinations. Reported that the maximum water use efficiency was observed with 60% of the requirement ET_c combined with 100% recommended dose of fertilizer (RDF). These findings align with the results reported by Gupta *et al* (2010) [2]. Furthermore, also observed that drip irrigation and polyethylene mulch resulted in the highest water use efficiency in tomato cultivation. This results accordance with in capsicum cultivation. The study highlights the importance of adopting and adapting drip irrigation and mulching techniques to meet crop water needs and enhance water use efficiency.

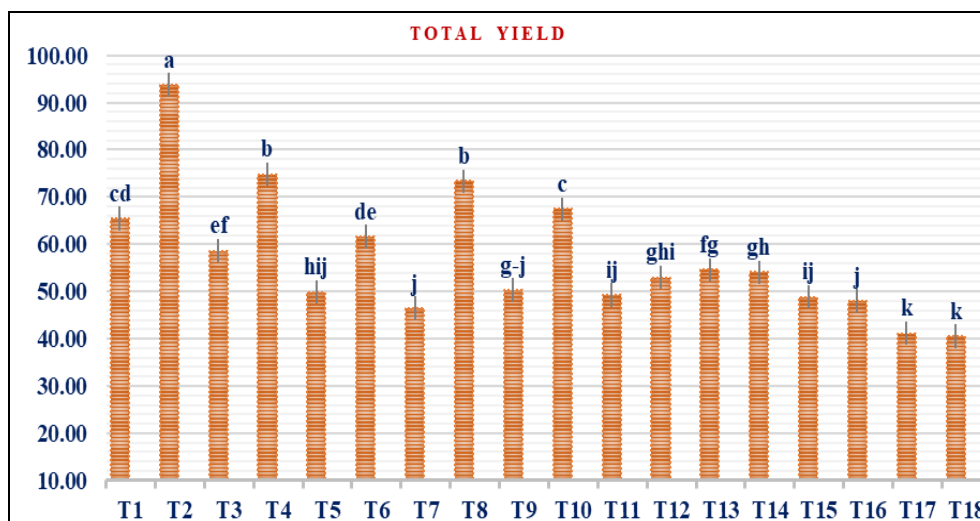


Fig 4: Treatments effect on capsicum yield

3.4 Fertilizer use efficiency (FUE)

The study investigates the effect of irrigation, fertigation, and mulching on water use efficiency (WUE) for each treatment, as detailed in Table 6. Among the all treatments, the highest FUE of (101.67kg/ha-kg) was observed in Treatment T₂ (120% RDF with 100% WR through drip with plastic mulch) followed by T₄ (81.11 kg/ha-kg).

In contrast, treatment T₁₈ (80% RDF with 60% WR through drip with plastic mulch) exhibited lower FUE of (45.7 kg/ha-kg). Higher fertilizer use efficiency indicates that more of the applied fertilizer is utilized by the crop. Furthermore, an increase in fertilizer use efficiency was observed with the higher fertilizer dose applied through drip irrigation. These results are in accordance with who reported that Nitrogen use efficiency increased considerably increased with the application of Nitrogen through Drip irrigation.

Table 6: Effect of irrigation, fertigation and mulching on water use efficiency on capsicum.

Treatments	Water use efficiency(kg/ha-cm)	Treatments	Water use efficiency (kg/ha-cm)
T ₁	43.67	T ₁₀	61.14
T ₂	62.49	T ₁₁	41.03
T ₃	39.09	T ₁₂	44.13
T ₄	49.86	T ₁₃	60.63
T ₅	33.27	T ₁₄	60.09
T ₆	41.09	T ₁₅	54.26
T ₇	37.64	T ₁₆	53.73
T ₈	61.14	T ₁₇	45.38
T ₉	41.92	T ₁₈	45.7

Table 7: Effect of irrigation, fertigation and mulching on fertilizer use efficiency on capsicum.

Treatments	Fertilizer use efficiency (kg/ha-kg)	Treatments	Fertilizer use efficiency (kg/ha-kg)
T ₁	71.04	T ₁₀	79.58
T ₂	101.67	T ₁₁	53.4
T ₃	63.6	T ₁₂	57.44
T ₄	81.11	T ₁₃	59.18
T ₅	54.12	T ₁₄	58.66
T ₆	66.85	T ₁₅	52.96
T ₇	48.99	T ₁₆	52.45
T ₈	79.58	T ₁₇	44.29
T ₉	54.55	T ₁₈	40.61

4. Conclusions

It can be concluded that proper management of drip irrigation and fertigation, along with mulching with an appropriate amount of water and fertilizer, significantly enhances the yield of capsicum with maximum water and fertilizer use efficiency. The results showed that optimized practices significantly enhanced crop yield and resource use efficiencies.

The treatment combination of 100% water requirement (WR) through drip irrigation and 120% recommended NPK through fertigation with mulch produced the maximum yield 93.74 kg/ha. Furthermore, Water use efficiency (WUE) was substantially improved by specific treatments, with the highest WUE of 62.49 kg/ha-cm observed in the treatment combining 100% WR with 120% RDF and plastic mulch. Similarly, there was a significant improvement in fertilizer use efficiency (FUE), with the highest FUE of 101.67 kg/ha-kg attained under the same treatment conditions. The findings highlight here offer valuable insights for growers and policymakers seeking to adopt efficient strategies in protected agriculture. In a nutshell, efficient use of irrigation, fertigation, and mulching techniques offers enormous potential for maximizing capsicum yield while conserving water and nutrients.

Further research and adaptation of these strategies to diverse agro-climatic conditions are essential for farmer to improve crop performance in commercial capsicum cultivation while conserving natural resources.

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