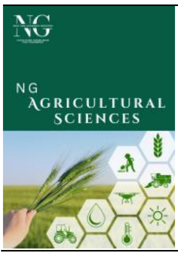

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Analysis of Water Use Efficiency in Zucchini Cultivation under Protected and Open Field Irrigation

Vadada Vinay Kumar* and Naveen Enugula

College of Horticulture, Dr. Y. S. R. Horticultural University, Anantharajupeta, Annamayya, Andhra Pradesh, 516105, India

*Corresponding author email ID: vinaysainik341@gmail.com

HIGHLIGHTS

- Zucchini grown under plastic mulch required 32% less irrigation water compared to open field cultivation.
- Polyhouse cultivation reduced water needs by up to 30% compared to shadenet house conditions.
- Reference evapotranspiration (ET0) peaked in May and was lowest in December, highlighting the need for adaptive irrigation scheduling.

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ABSTRACT

Zucchini (*Cucurbita pepo* L.) represents a highly polymorphic vegetable from the Cucurbitaceae family that thrives throughout the year in Indian agriculture under protection through both drip irrigation and plastic mulch systems and polyhouses and shadenet houses. The study examines Zucchini squash (*Cucurbita pepo* L.) irrigation water needs in four cultivation settings consisting of open fields and plastic mulch and polyhouse and shadenet house cultivation. This study employs the FAO-56 Penman-Monteith equation with data from 2021-2023 to determine water conservation levels brought about by protected cultivation systems. Plastic mulch cultivation of Zucchini needs only 68% of the irrigation volumes that Zucchini requires when grown in open fields. Water needs decrease up to 30% under polyhouse cultivation as compared to shadenet house cultivation. Protected cultivation methods demonstrate a remarkable ability to optimize water use efficiency, thus helping sustainable agriculture in water-scarce areas with challenging climatic conditions. Research should expand into the full economic and environmental assessment of these methods through studies of various vegetable cultivation and climate zones.

1. INTRODUCTION

Local residents in India refer to Zucchini (*Cucurbita pepo* L.) as summer squash which belongs to the plant family Cucurbitaceae and originated in tropical America. The fast-growing exotic vegetable crop is slowly gaining fame in Indian territories. Zucchini serves consumption in two ways either as an edible vegetable following cooking or in its immature form used with salad preparations. The vegetable contains high levels of vitamin C and minerals according to Kannaujia et al. (2019). Year-round cultivation of Zucchini demands only minor yield reductions under severe weather situations. Protected cultivation methods along with drip irrigation and plastic mulch and poly house and shadenet houses

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enable Zucchini cultivation during extreme weather conditions to achieve better productivity (Shrestha et al., 2021).

A drip irrigation system distributes water and nutrients specifically to the plant root area while improving yield production while conserving water supply through enhanced irrigation practices (Wang et al., 2021). A combination of environmental factors including alive and nonalive elements affect the production level of exotic vegetables. Under various climatic conditions (Abdrabbo et al., 2018) plastic mulches serve as an effective practical solution for Zucchini cultivation. The controlled cultivation of vegetables inside polyhouses as well as shadenet houses allows partial manipulation of structure-based micro climatic conditions to achieve early and off-season harvests (Reddy et al., 2021). The implementation of plastic mulch, particularly silver on black, has been recognized as an effective strategy for enhancing vegetable production in the designated research area (Regmi et al., 2021). It helps in weed control by blocking sunlight penetration and modifying the spectral composition of reflected light, which confuses certain insect pests, thus reducing their ability to locate host plants (Goud et al., 2021). These mulches reduce soil water evaporation by suppressing the direct contact of soil and atmosphere helps to improve plant growth, increases the productivity and quality of the produce.

The exact quantity of irrigation water needed for zucchini cultivation stands as a crucial element to obtain higher yields under distinct protected farming techniques. The FAO-56 Penman-Monteith equation enables farmers to calculate Zucchini irrigation needs when using different protected cultivation approaches (Saji et al., 2022). Three successive years spanning 2021 to 2023 served to measure and record data that would enable the calculation of crop water demands. The research focuses on determining how much irrigation water Zucchini plants need when grown under drip, plastic mulch, poly house and shadenet house conditions.

2. MATERIALS AND METHODS

The study evaluated irrigation water requirements of Zucchini cultivated with various protection methods through measurements at the Meteorological Department of College of Horticulture within Dr. Y. S. R. Horticultural University Anantharajupeta.

The crop needs irrigation according to the water amounts that plants use for transpiration and water lost through soil surface evaporation. The daily irrigation water need of Zucchini crops under different protected cultivation systems requires evaluation through this mathematical method.

$$WR = ET0 \times Kc \times Wp \times A$$

where,

WR = Crop water requirement (L day-1)

ET0 = Reference evapotranspiration (mm day-1)

Kc = Crop coefficient (Table 1)

Wp = Wetting fraction (taken as 1 for close growing crops)

A = Plant area, m2 (i.e. spacing between rows, m x spacing between plants, m).

Daily weather records obtained from 2021 through 2024 served as the basis for reference evapotranspiration (ET0) calculations. The scientists at Allen et al. (1998) proposed changes to the Penman-Monteith method for reference evapotranspiration (ET0) calculations.

The crop evapotranspiration (ETc) values for Zucchini cultivation under plastic mulch will decrease between 10% to 30% with each additional irrigation cycle. According to Allen et al. (1998) the Kc value for Zucchini crop under initial growth stages reaches a minimum of 0.10. A table showing Kc values appeared in Table 1 both during growth phases and while implementing different protective measures. The combination of daily reference evapotranspiration value (ET0) and Kc values in relation to crop development stages calculates the daily ETc values.

3. RESULTS

ETc values were determined through averaging yearly FAO-56 Penman Montieth equation-based estimates of ET0 for three different years (2021, 2022, 2023). The tabulated reference evapotranspiration (ET0) values can be found in Table 2. Yearly trends showed that ET0 reached its maximum in May while December recorded its lowest values for all examined years. The season of May marks the beginning of dry wind conditions while maintaining high temperature levels. The reference evapotranspiration (ET0) attains its yearly minimum value of 2.2 mm day-1 throughout December within the winter season. Reference evapotranspiration declines because of the cooler temperatures and decreased solar radiation which prevail throughout December. ET0 averages rise steadily throughout the first five months of the year from 2.5 to 5.2mm whereas the trend descends from June to December from 4.3mm to 2.2mm. Zucchini crop can be grown throughout the year so the water requirement for irrigation can be established for all seasons by researchers. A mature zucchini plant requires 90 days for completion while being suitable for all twelve months of the year. The chart in Figure 1 illustrates the seasonal ET0 measurements across numerous years. The figure demonstrates that February- April and May- July crop seasons show the highest ET0 values.

Table 1. Crop coefficients and plant spacing of a Zucchini crop under drip, plastic mulch poly house, and shadenet house

Sl. No.	Protected cultivation measures	$K_{c\ ini}$	$K_{c\ mid}$	$K_{c\ end}$
1	Open field condition	0.50	0.95	0.70
2	Plastic mulch	0.10	0.81	0.60
3	Polyhouse	0.50	0.95	0.70
4	Shadenet house	0.50	0.95	0.70

The combination of ET0 with Kc allows calculation of ETc and further multiplication with plant area yields WR. Table 3 illustrates daily ETc and WR averages of the Zucchini crop during various major growing seasons when planted in fields without plastic mulch cover or with plastic mulch cover. Open field Zucchini crop required irrigation water amounting to 40.1 L day-1, 65.9 L day-1 and 74.6 L day-1 and 51.4 L day-1 in each of the November-January, February-April, May-July and August-October crop periods. The total WR estimation for Zucchini crops with plastic mulch reached 27.5 L day-1 in November-January, 49.2 L day-1 in February-April, 50.7 L day-1 in May-July, and finally 35.2 L day-1 in August-October. Application of plastic mulch on Zucchini crops resulted in 32 percent lower water requirements than establishing cultivation of Zucchini in open fields without plastic mulch. Research on Padmaja et al. (2021) established water conservation through plastic mulch application for different crops.

Table 2. Monthly average of daily reference evapotranspiration (ET0) during the study years (2021-2023) for open field condition

Month	Reference evapotranspiration ET_0, mm			
	2021	2022	2023	Average
January	2.5	2.5	2.4	2.5
February	3.2	3.0	2.9	3.0
March	4.2	4.0	3.3	3.8
April	5.1	5.2	4.8	5.0
May	5.3	5.4	5.0	5.2
June	4.4	4.4	4.3	4.3
July	3.6	3.6	4.0	3.7
August	3.4	3.4	3.6	3.5
September	3.3	2.8	3.2	3.1
October	3.0	2.8	2.8	2.9
November	2.9	2.6	2.7	2.7
December	2.2	2.2	2.3	2.2

Table 3. Crop reference evapotranspiration (ETc), mm day-1 and irrigation water requirement, L day-1 of Zucchini crop for different crop seasons in open field conditions

Months	Open field		Plastic mulch	
	ET_c, mm day^{-1}	Irrigation water requirement, L day^{-1}	ET_c, mm day^{-1}	Irrigation water requirement, L day^{-1}
November - January season				
November	1.3	0.34	0.3	0.07
December	2.1	0.53	1.8	0.45
January	1.7	0.43	1.5	0.37
Total	160.3	40.1	110.0	27.5
February - April season				
February	1.5	0.38	0.3	0.08
March	3.6	0.91	3.1	0.77
April	3.5	0.88	3.0	0.74
Total	263.7	65.9	196.7	49.2
May - July season				
May	2.6	0.65	0.5	0.13
June	4.5	1.12	3.8	0.95
July	2.6	0.65	2.2	0.55
Total	298.5	74.6	202.7	50.7
August - October season				
August	1.7	0.43	0.3	0.09
September	2.9	0.74	2.5	0.63
October	2.0	0.50	1.7	0.43
Total	205.4	51.4	140.9	35.2

Table 4. Crop reference evapotranspiration (ETc), mm day-1 and irrigation water requirement, L day-1 of Zucchini crop for different crop seasons under polyhouse and shadenet house conditions

Months	Shadenet house		Polyhouse	
	ET_c, mm day^{-1}	Irrigation water requirement, L day^{-1}	ET_c, mm day^{-1}	Irrigation water requirement, L day^{-1}
	November - January season			
November	1.6	0.41	1.2	0.30
December	2.3	0.57	1.8	0.44
January	2.2	0.54	1.5	0.37
Total	187.4	46.8	137.7	34.4
	February - April season			
February	2.1	0.52	1.4	0.34
March	5.2	1.29	3.5	0.87
April	4.4	1.11	3.1	0.77
Total	355.5	88.9	241.7	60.4
	May - July season			
May	3.0	0.75	2.3	0.57
June	5.0	1.25	4.4	1.10
July	3.9	0.97	3.0	0.76
Total	365.6	91.4	298.5	74.6
	August - October season			
August	2.5	0.63	1.9	0.49
September	4.9	1.23	3.7	0.93
October	2.9	0.73	2.4	0.60
Total	318.1	79.5	248.6	62.1

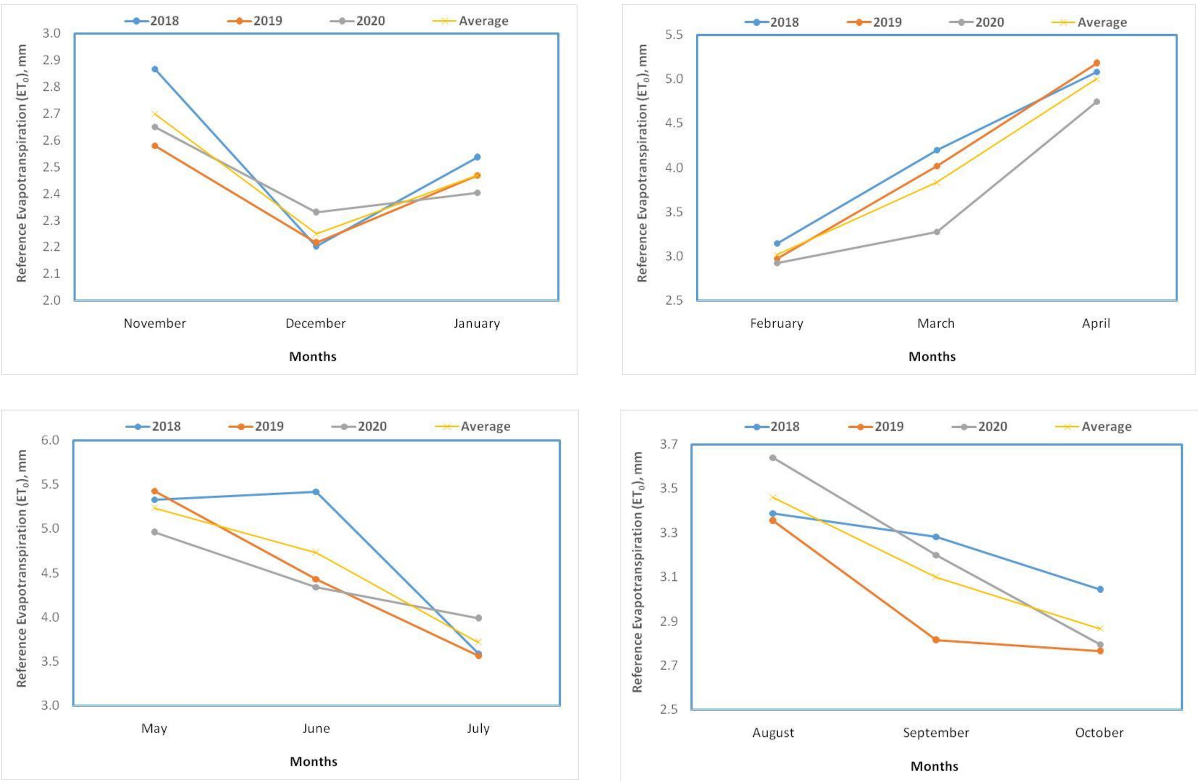

Figure 1. Monthly average daily reference evapotranspiration (ET0) of different Zucchini crop duration (November-January, February-April, May-July and August-October)

Table 4 contains monthly average values of daily ETc and WR measurements related to Zucchini production in polyhouse and shadenet structures across different growing seasons. Under shadenet house conditions Zucchini crop irrigation requirements amounted to 46.8 L day-1 in November-January and 88.9 L day-1 in February-April and 91.4 L day-1 in May-July and 79.5 L day-1 in August-October. The polyhouse cultivation of Zucchini resulted in an estimated total WR of 34.4 L day-1 during November-January and 60.4 L day-1 from February-April and 74.6 L day-1 during May-July and 62.1 L day-1 throughout August-October. Growing Zucchini in shadenet houses requires of up to 30 percent additional water consumption when compared to zucchini cultivation under polyhouse conditions. The findings of these researchers match those identified by Martim et al. (2018) and Poornima et al. (2017).

4. DISCUSSION

Results showed that Zucchini under plastic mulch needs only 32% of irrigation water compared to open field Zucchini. The decrease in water usage becomes possible through mulching because the plastic material keeps soil evaporation low while sustaining moisture levels in the ground (Oliveira et al., 2020). The employment of plastic mulch produces two benefits - moisture conservation and effective temperature management while minimizing weed outbreaks, which promotes healthier plant growth and eventual yield increases (Kishore et al., 2022). The implementation of plastic mulch emerges as a crucial strategy for optimizing crop production in the face of climate change and recurrent drought occurrences (Tegenu, 2021). The investigation demonstrates that polyhouse cultivation of Zucchini consumes thirty percent less water than shadenet houses do. The controlled environment of polyhouses enables managers to regulate temperature as well as humidity levels and lighting standards, which together affect evapotranspiration rates (Khapte et al., 2021). Polyhouses demonstrate their ability to reduce water requirements for vegetable cultivation during production periods because of controlled environment agriculture (Chavan et al., 2022). Employing plastic mulch in combination with subsurface drip irrigation resulted in significant improvements in melon production, including greater average fruit mass, increased plant production, enhanced yield, faster daily growth rates for plant height and crown diameter, larger fruit distal diameter (Wang et al., 2020).

Seasonal changes in reference evapotranspiration (ET0) demonstrate that optimized irrigation schedules need to consider specific conditions in different seasons. Maximum ET0 readings appeared during the dry May season because of hot weather conditions and windy conditions, but minimum readings appeared during the cooler months of December. The year-round changes in water demand require irrigation systems that adapt their strategies to optimize overall water efficiency (Supapo et al., 2024). The synergistic application of plastic mulching alongside drip irrigation enables meticulous management of the crop's microclimate, leading to enhanced yields and superior quality attributes through a combination of factors such as moderated soil temperatures, improved soil moisture retention, reduced soil erosion, enhanced soil organic matter content, and augmented microbial activity within the soil (Pimpale et al., 2020). Research on the advantages of protected cultivation systems for vegetable crop water conservation bears out in this investigation. Tiwari et al. (2014) established that plastic mulch techniques led to substantial water conservation in multiple crops, thus proving to lower irrigation needs effectively. According to Santosh et al. (2017), polyhouses effectively decrease water needs for lettuce cultivation as part of their evaluation of protected cultivation methods. The strategic integration of advanced water management technologies, such as subsurface drip irrigation in conjunction with plastic mulching, presents a viable solution for simultaneously enhancing crop productivity and minimizing water consumption, particularly in regions characterized by water scarcity, through the targeted delivery of water directly to the root zone, thereby curtailing evaporative losses and optimizing water utilization by plants (Vidyashree et al., 2018).

5. CONCLUSIONS

The research conducted on Zucchini squash water optimization through protected cultivation versus open field irrigation showed valuable information about sustainable farming methods. Cultivation of Zucchini under protected systems through plastic mulch and polyhouse environment reduced irrigation needs by substantial amounts in comparison to standard open field farming methods. Plastic mulch implementation reduced water consumption for crops by 32% but polyhouse cultivation produced less water usage than shadenet house irrigation by 30%. Protected cultivation demonstrates its ability to save water while improving soil water maintenance and boosting production results for crops. The periodic changes in reference evapotranspiration (ET0) demonstrate that water management strategies must adapt because they improve yearly water use efficiency. Protected cultivation methods must become integral to agricultural systems because the research shows their value for water-shortage regions dealing with climate-related concerns. Researchers should explore deep economic and environmental outcomes of these techniques while determining their universal potential for various vegetable crops across different climate zones.

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