



INFLUENCE OF DEFICIT IRRIGATION AND SOIL MULCH ON CHILI PEPPER PRODUCTION AND WATER-SAVING UNDER PULSE DRIP IRRIGATION

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ABSTRACT

This study was performed to maximize Field Water Use Efficiency (*FWUE*), optimize water-saving, and achieve economic benefits for chili pepper crop in Northern Sinai Peninsula, Egypt. The treatments of irrigation water regimes were (W1,100%; W2,80%; W3,60% of Crop Evapotranspiration *E_c*), three pulse drip irrigation treatments (P1, one continuous drip irrigation pulse; P2, two irrigation pulses with 30-min intervals; and P3, three irrigation pulses with 15-min intervals) the irrigation was applied every 48 h, and two soil cover conditions: bare soil with no-mulch (NM), and olive pomace mulch (M). The experimental design was split split plots with three replications. The results showed that chili pepper Marketable Yield (*MY*) was negatively affected in a linear relationship ($R^2 \geq 0.8773$) by water stress conditions. The highest value of *FWUE* was 6.4 kg.m⁻³, it was achieved by W2MP2 treatment. Furthermore, applying W2MP2 treatment had no significant reduction in the *MY* and economic return of chili pepper compared to full irrigation treatment W1MP2. Therefore, W2MP2 treatment is recommended to use for achieving 20% water-saving (148,928.57 mm/season $\approx$ 1,489.8 m³/ha/season) with proper economic Benefit Cost ratio (BC) of 6.0 under North Sinai conditions for chili pepper production. This research highlights the significance of irrigation water savings strategy using pulse drip irrigation, for other crops, irrigation treatments, and geographic locations under arid conditions.

1.INTRODUCTION

Several setbacks have existed in Egypt causing water shortage in recent years like: shortage and misuse of water resources, and inefficient irrigation techniques (Ouda and Zohry, 2022). The Northern Sinai region is an important agricultural region for Egypt's economic return (Abou Rayan et al., 2001; Abd-Elsalam, 2014). North Sinai is an arid region; with a low annual precipitation rate

of 61.0mm per year - limited to winter (CCKP, 2025). Some Dry areas as coastal and Mediterranean regions suffer poor water quality and quantity. The Sinai Peninsula is far from the Nile with restricted underground water resources (Abd-Elsalam, 2014). Thus, it is critical to consider the quantities of irrigation water and application methods for any irrigation water management practices.

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The combination of water scarcity and drought influences food security, it can raise and lead to more water drawing from the Nile River or underground salty aquifers as widely used in North Sinai to sustain agricultural production. Hence, water rationalization has become an absolute necessity, especially in agriculture, as the major consumer of universal freshwater resources; it consumes about 75 % of total water diverted for human use (**Eisenhauer *et al.*, 2021**). Using untraditional irrigation techniques is mandatory for better water saving and agricultural production. Under North Sinai conditions; the drip irrigation system is usually regarded as the most favorable system when used with saline groundwater (**Rafie and El-Boraie, 2017**). Pulse irrigation is a widely used practice globally, as it improves yield production and quality, more water saving, and reduces emitter plugging and energy consumption among other benefits (**Prats and Pico, 2016; Ray *et al.*, 2023; Abdelraouf *et al.*, 2024**). It has been widely used in arid Arab countries with several cultivated crops such as soybean in Egypt (**Eid *et al.*, 2013**), tomato in Saudi Arabia (**Elnesr *et al.*, 2015**), and potato in Egypt (**Abdelraouf *et al.*, 2012**). It refers to applying water for a short time then cutting off irrigation for another short time, and repeating this on-off irrigation cycle until all the desired irrigation water is completely applied (**Ramadan, 2009; Almeida *et al.*, 2015; Almeida *et al.*, 2018; Lozano *et al.*, 2020**). Successive irrigation events tend to form larger wet bulbs and superficial water cumulation areas. Moreover, the increase in the repetition of irrigation events associated with a reduction in applied water depth is a requirement for irrigation management in sandy soils, since this strategy tends to lessen water seepage under the effective root zone. In this case, pulse irrigation is recommended (**Maller *et al.*, 2019; Rank and Vishnu, 2019; Cruz *et al.*, 2021; Rank and Vishnu, 2024**). Pulse irrigation

enhances soil water distribution in the active root zone, and increases the lateral movement of soil water (**Allam *et al.*, 2011**). There are several studies on the advantages and constraints of this irrigation technique, for instance, using pulse treatments on potatoes increased water productivity by 63.90% with 25% savings each crop cycle (**Zamora *et al.*, 2019**). Also, Deficit Irrigation DI can be applied by pulses without reducing the vegetative growth of Japanese cucumbers. The grain yield production was raised by 11.8% with pulse drip irrigation compared to continuous or/ traditional drip irrigation (**Zin El-Abedin, 2006; Rank and Vishnu, 2021**). In contrast, a higher irrigation frequency could keep the soil surface wet with first-stage evaporation continuing for a long time, which causes extreme water loss (**Meshkat *et al.*, 2000**). In addition to the pulse irrigation technique, DI is a water-rationalization technique (**Chai *et al.*, 2016**) in which crops are subjected to relative water stress either during a specific stage or overall growing season (**Bhakar *et al.*, 2019**). This would help to keep the soil water at a limit that does not significantly minimize crop production, while not filling the crop root zone depth of soil. Regulated DI has recently become an essential water-saving strategy in irrigated agriculture, which raises water production and improves water use efficiency (**Colak, 2021; Mohammed and Hussen, 2023**). Therefore, DI is strongly recommended for overcoming significant yield decreases and securing weak yield levels (**Abu-hashim and Negm, 2018; Akarsh *et al.*, 2020**). The effect of DI on crop production and physiology caused significant differences in crop quality, physiology, and productivity. While other production factors are among their optimal level, crop response is a crop yield that continuously decreases when the applied water decreases in DI (**Amer, 2011**).

Furthermore, policymakers and growers were supported in improving water management and irrigation water resources; by raising awareness of Water Use Efficiency WUE concepts and the substantial correlation between soil water shortage and crop yield. According to studies, WUE is a crucial indicator of water-saving irrigation also, estimating the relevance between crop yield and WUE is a fundamental indicator. Additionally, the correlation between plant water consumption and productivity is expressed by WUE; its value is larger in drought circumstances in contrast to humid conditions (Ye *et al.*, 2020). WUE and irrigation technologies should be taken into account in agricultural production. Meanwhile, using soil mulch could improve water saving (Jadav *et al.*, 2020), reusing olive mill waste has been demonstrated to be a viable approach for increasing water conservation during longer irrigation intervals in arid regions (Gholam *et al.*, 2023).

The small, pungent peppers belong to *Capsicum frutescens*, while most peppers planted are *Capsicum annum* (FAOSTAT, 2001). Pepper grows well in environments where daytime air temperature ranges 18 to 27°C and nighttime air temperature lows of 18 to 15°C are common during the growing season and it's one of the largest and most valuable vegetable crops globally. Capsicums are considered a commercial crop because of their high economic value

(Reddy *et al.*, 2016; Widuri *et al.*, 2020). The pepper plant is classified as sensitive to water stress; there was a large yield reduction of peppers under water stress conditions (Liu, *et al.*, 2012; Abdelkhalik *et al.*, 2020).

This study addresses the effect of deficit irrigation on chili pepper productivity with pulse drip irrigation, and olive pomace mulch in North Sinai. The substantial objective is to rationalize water under water scarcity conditions, by improving irrigation management practices that achieve the lowest water consumption, with a proper economic return.

2. MATERIALS AND METHODS

2.1. Experimental site and experimental design

The field experiments were implemented at the farm of Agricultural Research Station, Agricultural Research Center (ARC) at Al-Arish City, North Sinai Governorate, Egypt (latitude 31°11' N, longitude 33°82' E, altitude 31 m), during (2021) growing season. Chicken manure was added before cultivation. The soil at 0-90 cm depth was sampled before seedling sowing and subjected to physicochemical analyses. The soil of the research field was classified as sandy soil, with a flat topography. Some soil physical and chemical properties, irrigation water, and organic matter at the experimental plot are summarized in Table (1).

Table 1. a- Soil mechanical and chemical analyses, b- Chemical analysis of well water, c- Chicken manure (organic fertilizer), and d- Olive pomace (organic soil mulch) of the investigated farm before cultivation.

a- Some physical properties of the studied soil.

Soil depth	Particle size distribution%			Eex. Class	SP %	FC %	WP %	AW %	BD Gm/cm ³
	Sand	Silt	Clay						
0-30	98.55	0.97	0.48	sandy	29	15.3	6.11	9.19	1.30
30-60	98.79	0.68	0.53	Sandy	28	14.8	6.23`	8.57	1.35
60-90	98.84	0.61	0.55	sandy	29	15.1	5.73	9.37	1.38

SP: saturation percent, FC: field capacity, WP: wilting point, AW: available water, BD: bulk density.

b- Some chemical properties of the studied soil.

Soil depth cm	SAR	OM %	EC dS.m ⁻¹	pH	Soluble ions (meq.l ⁻¹)						
					CO ⁻³ +HCO ⁻³	SO ₄ ⁻²	Cl ⁻	Ca ⁺²	Mg ⁺²	Na ⁺	K ⁺
0-30	1.77	0.10	0.36	7.9	0.5	0.30	2.80	0.8	1.0	1.68	0.12
30-60	2.67	0.08	0.28	7.8	0.8	0.20	1.80	0.5	0.4	1.79	0.11
60-90	2.64	0.09	0.26	8.0	0.7	0.19	1.71	0.5	0.3	1.67	0.13

EC: electrical conductivity; dS.m⁻¹ (deci Siemens per meter)

c- The chemical analysis of well water (irrigation source); to evaluate water quality for irrigation.

pH	EC dS.m ⁻¹	SAR	Cations (meq.l ⁻¹)				Anions (meq.l ⁻¹)		
			Ca ⁺²	Mg ⁺²	Na ⁺	K ⁺	CO ₃ ⁻² +HCO ₃ ⁻	SO ₄ ⁻²	Cl ⁻
7.6	4.22	0.36	10.0	30.0	1.62	0.56	6.0	5.0	31.18

d-Chemical analysis of chicken manure (organic fertilizer) and olive pomace (organic soil mulch).

Item	Chicken manure	Olive Pomace
pH	6.90	7.90
EC (dS.m ⁻¹)	4.00	2.51
Organic carbon%	19.7	18.7
Organic matter %	33.94	32.16

2.2. Planting chili pepper in the nursery

The chili pepper seeds of *HUMMER F1*, a reputed variety were planted. The seedling soil components were a mixture of: (compost, vermiculite; peat moss) with rates of (3, 2; 3), respectively. Also, the soil was moistened with water before planting the seeds. Emergence irrigation was applied a few times after seed sowing using a sprinkler system for a uniform plant establishment.

Two bags of seeds (the average weight of the single bag is approximately 10grams) were planted in seedling trays on 16/02/2021, and germination began after 12 days of sowing. The seedlings were hardened for 10 days before planting in the field. Seedlings were grown in the experimental plots where the average seedling length was (17-20 cm) with a mean of 6 true leaves.

2.3. Soil preparation

Before planting, the experimental plot of virgin soil with an area of 627.1 m² (92.9 m length and 6.75 m width) was plowed with a chisel plow, at 30 cm depth. Furrows were opened in the plot by furrow opener and large sacks of chicken manure fertilizer were added (each sack is $\simeq$ 50 kg). The organic fertilizer was placed inside each furrow, with an application rate of 4.84 kg.m⁻². Furthermore, the olive pomace mulch was applied on the soil surface by rate of 3.4 kg.m⁻².

2.4. The experimental treatments

The experimental design was a split split plot with three replications (Figure 1). The factors were:

1. Three irrigation water treatments of 100% (W1), 80% (W2), and 60% (W3) of crop evapotranspiration (*ETc*). Where; W1 represents full irrigation, and W2 and W3

were deficit irrigation treatments by 80 and 60% of the full irrigation, respectively.

2. Three pulse drip irrigation treatments were applied: P1, one continuous drip irrigation pulse; P2, two drip irrigation pulses with 30-minute intervals; and P3,

three drip irrigation pulses with 15-minute intervals.

3. Two soil cover conditions were used: bare soil with no-mulch (NM) or control treatment, and olive pomace for soil mulching (M).

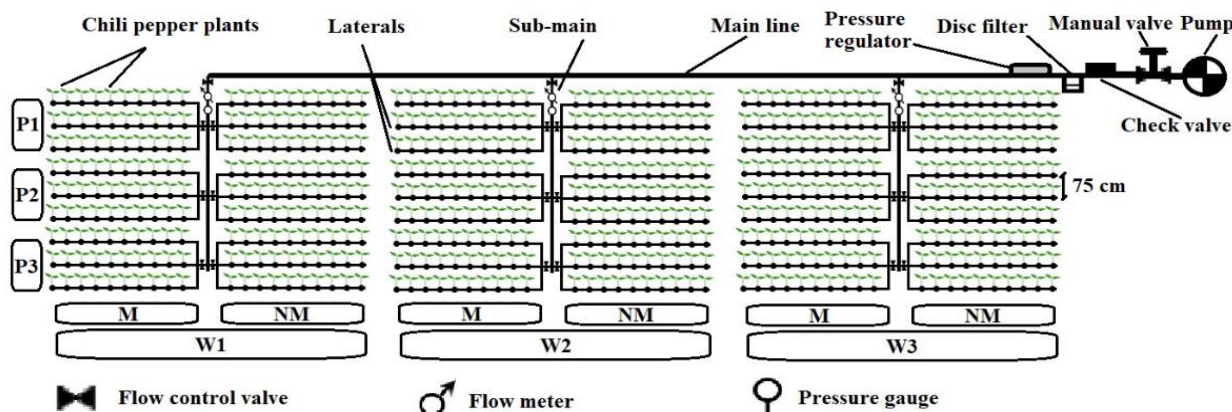


Figure 1. Schematic diagram of the distribution of the treatments between the experimental plots.

2.5. The description of the drip irrigation network

The drip irrigation network consisted of a pump, disc filter, check valve, pressure regulator, pressure gauges, water meters, ball valves, manifolds, drip lines (laterals), mini valves, and fittings and accessories (Figure 1). Laterals consist of 16mm diameter polyethylene (United Plast) with 75cm lateral spacings, the laterals carrying on-line emitters with a water discharge rate of 3.8 l.h^{-1} with 50cm emitter spacing. Chili pepper seedlings were sown on April 15, 2021. The seedlings were sown manually using a small shovel with 75cm furrow spacing and 50cm on-row spacing.

There were 18 experimental plots; every traditional irrigation plot has three dripper lines for three plant rows. The lateral length was 15m. After the experimental plots were formed, planting the seedlings procedures were performed, with a plant density range of 26,667.2 plants per hectare.

2.6. E_{tc} calculation

Water requirements for the chili pepper crop were estimated via the Penman method using agricultural meteorological station data of the Central Laboratory for Agricultural Climate (CLAC), in El-Arish city.

Crop evapotranspiration, E_{tc} , is calculated using the following equation (Allan *et al.*, 1998):

$$E_{tc} = K_c E_{To} \quad (1)$$

Where:

E_{tc} = crop evapotranspiration [mm.d^{-1}],

K_c = crop coefficient [dimensionless], and

E_{To} = reference crop evapotranspiration [mm.d^{-1}].

E_{To} can be calculated using climatic data. The FAO Penman-Monteith method is now recommended as the only standard method for computing reference evapotranspiration.

2.7. Harvesting

Harvesting data were gathered by handpicking the chili fruits against the direction of the neck growth, taking into account that the branches of pepper were easy to break, where the crop collection

began on June 29th until August 17th of 2021 year, for a harvesting period of about 52 days, and a total growing season of 125 days. The marketable yield and the total water applied were measured for each plot to calculate the field water use efficiency.

2.8. Field water use efficiency

Field water use efficiency (*FWUE*, kg.m⁻³) is an indicator of the effective use of irrigation water to maximize crop yield. The amount of chili peppers yield (*Y*, kg.ha⁻¹) that was recorded and the total amount of water applied (*WR*, m³.ha⁻¹) were used to calculate *FWUE*; as indicated in Equation 1 (James, 1988; Bilalis *et al.*, 2009).

$$\text{Field Water use efficiency} = \frac{Y}{WR} \quad (2)$$

2.9. Crop response to applied water

A linear model was utilized to determine the crop response between yield and water use under deficit irrigation (Doorenbos and Kassam, 1986; Wu and Barragan, 2000). A slope straight line was generated from the linear response model for deficit water application. With uniform water application, the crop's response to deficit irrigation is shown in Equation 2:

$$\left(1 - \frac{Y_a}{Y_m}\right) = K_y \left(1 - \frac{W_a}{W_m}\right) \quad (3)$$

Where *Y_m* and *W_m* represent the maximum yield and corresponding maximum water application; *Y_a* and *W_a* are the production and corresponding irrigation water applied under deficit irrigation conditions and *K_y* is a production reduction coefficient considered as a constant for a crop under deficit irrigation.

2.10. Economic analysis

The economic estimation was carried out under current pricing for equipment and installation based on the 2021 Egyptian pound (LE) price level and chili pepper production costs. The overall cost for unit area had been classified as: (fixed costs and variable or operational costs). The

appreciated fixed expenses were depreciation, interest on investment, taxes, and insurance. While, the assessed variable expenditures included electricity, repairs and maintenance, and other costs. The data were analyzed using Microsoft Excel Worksheet (2019) and summarized in equations 3 and 4.

$$T.C = F.C + V.C \quad (4)$$

Where; T.C. is the total costs per season, F.C. fixed costs, and V.C. is the variable costs.

$$BC = \text{Total return} / T.C \quad (5)$$

Where; BC is the benefit cost ratio.

2.11. Statistical analysis

Various periodic measurements were recorded from each plot of treatments, including (weights of chili pepper *MY*, and plant height). Before completing the statistical analysis, all data were checked for variance's normality and homogeneity. Statistical analysis test was done by Analysis of Variance (ANOVA), Least Significant Difference (LSD) at 5% significance level, means were separated using "CoStat" statistics (version 6.451) software (CoHort Software, Monterey, CA, USA).

3. RESULTS

3.1. Yield and plant height

The plant height (cm) was measured at the beginning of mid-season stage on June 19, 2021. The plant height was affected by irrigation water treatments (*W1*, *W2*, and *W3*), pulse drip irrigation (*P1*, *P2*, and *P3*), and olive pomace mulch (*M*, and *NM*). The water stress negatively affected plant growth, where the measured plant height means were (54.5 cm), (51.85cm) and (43.25 cm) for the irrigation water regimes (*W1*, *W2*; *W3*), respectively, Figure 2. The plant height under full irrigation (*W1*) treatments were higher than those in deficit irrigation treatments (*W2*, and *W3*). Figure 2 also indicates the impact of using pulse drip irrigation; the plant height means were

(46.25 cm), (53.5 cm), and (49.0 cm) under (P1, P2; P3), respectively. Where the highest and lowest plant height were with W1MP2 and W3NMP1 treatments,

respectively. There wasn't a significant difference between plant height values for W1MP2 and W2MP2 treatments.

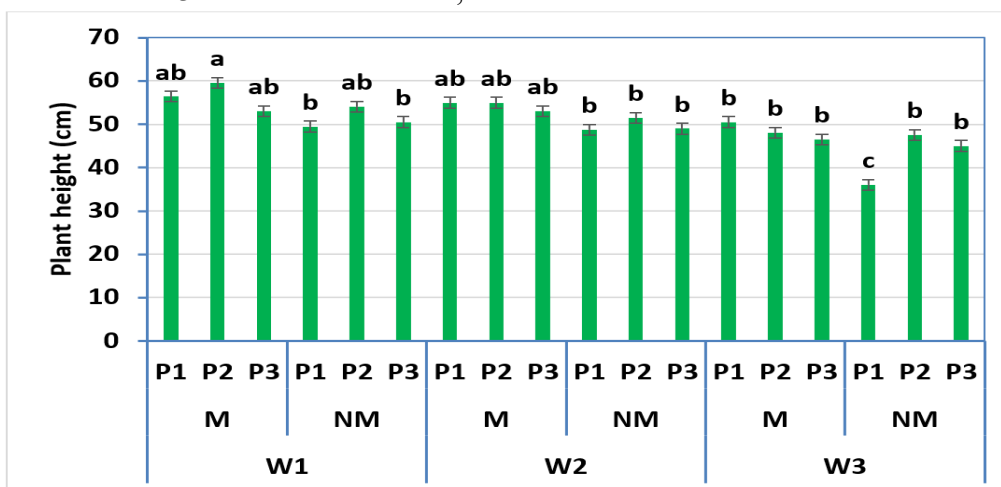


Figure 2. Plant height (cm), interaction affected by irrigation water regimes (W1, W2, and W3), pulse drip irrigation (P1, P2, and P3), and soil mulching (M, and NM). Bars represent $\pm$ S.E. Bars with the same letters are not significantly different ($P \leq 0.05$ level).

The Marketable Yield (MY) of chili pepper (t.ha^{-1}) under three pulse drip irrigation treatments (P1, P2; P3), soil mulching (M; NM) and irrigation water regimes (W1, W2; W3), are present in Figure 3. Where, yields varied from (34.1-17.6 t.ha^{-1}), (41.0- 20.6 t.ha^{-1}), and (36.2-17.8 t.ha^{-1}) in (P1, P2; P3) treatments, respectively. The lowest mean yield was

(25.85 t.ha^{-1}) under one continuous pulse drip irrigation P1 treatment. While the application of the P2 treatment recorded the highest chili pepper MY (30.8 t.ha^{-1}) for all treatments. The MY of chili pepper (t.ha^{-1}) was raised owing to P2 treatment by (18.6 %), and (14.5 %) compared with P1 and P3, respectively.

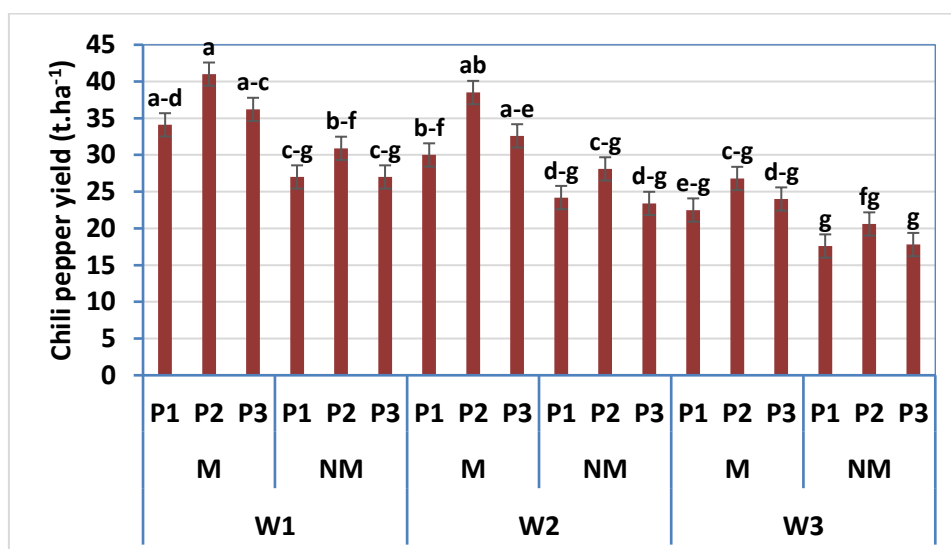


Figure 3. Chili pepper yield (t.ha^{-1}) interaction affected by irrigation water regimes (W1, W2, and W3), pulse drip irrigation (P1, P2, and P3), and soil mulching (M, and NM). Bars represent $\pm$ S.E. Bars with the same letters are not significantly different ($P \leq 0.05$ level).

Table 2. Statistical analysis's output of chili pepper *MY*, plant height, and and *FWUE* under different experimental treatments.

Characters		MY Ton/ha	Plant hight cm	FWUE
Treatments		Means		
Irrigation water regimes	W1	32.67 a	53.17 a	4.36
	W2	29.49 b	53.06 a	4.91
	W3	21.54 c	46.78 b	4.79
P value		.0000***	.0000***	.0530(ns)
Olive pomace mulch	M	31.75 a	53.26 a	5.33 a
	NM	24.05 b	48.74 b	4.04 b
P value		.0000***	.0000***	.0000***
Drip irrigation pulses	P1	25.89 b	50.00 b	4.35 b
	P2	30.98 a	52.94 a	5.20 a
	P3	26.83 b	50.06 b	4.50 b
P value		.0013**	.0164*	.0017**

The values represent means. For a given variable; means followed by the same letter have no significant difference, and mean values not sharing common letters are significantly different., *MY*: marketable yield.

The statistical analysis in Table 2 indicates a significant effect of P2 drip irrigation pulses on raising the plant height and chili pepper *MY* compared with (P1, and P3). The *MY* values of chili showed no significant differences between P1 and P3 drip irrigation pulses. The maximum *MY* of chili pepper were measured as 41.0t.ha⁻¹ for W1MP2 treatment, followed by W2MP2 with 38.5 t.ha⁻¹, Figure 3. There wasn't a significant difference between *MY* values for W1MP2 and W2MP2 treatments. Also, a significant effect of using olive pomace for soil organic mulching was found in maximizing both plant height and chili *MY*. A significant low of *MY*, and growth was also observed when the chili pepper plant

was subjected to maximum water stress W3 (60% of *ETc*) compared to W1, and W2 irrigation water regimes, Table 2. Intensive water deficit significantly reduced chili pepper *MY*, and plant growth ($P \leq 0.05$).

3.2. Field water use efficiency

Maximum *FWUE* value means the highest production with the least applied irrigation water (Abdelkhalik *et al.*, 2020). Applying olive pomace mulch significantly raised the *MY* of chili pepper and *FWUE* (Figure 4, and Table 2). The highest two values of *FWUE* were (6.4 and 6.0 kg.m⁻³) by W2MP2 and W3MP2 treatments, respectively, Figure 4.

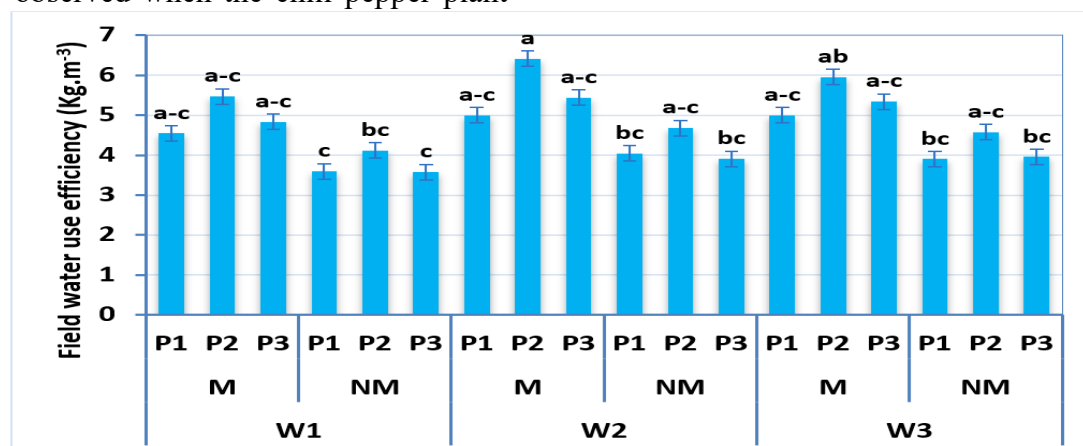


Figure 4. Field water use efficiency (kg.m⁻³) interaction affected by irrigation water regimes (W1, W2, and W3), pulse drip irrigation (P1, P2, and P3), and soil mulching (M, and NM). Bars represent $\pm$ S.E. Bars with the same letters are not significantly different ($P \leq 0.05$ level).

The statistical analysis indicated that *FWUE* of chili pepper were not significantly different in the irrigation water regimes treatments. But W2 achieved highest *FWUE* of 4.91 kg.m⁻³. Applying two drip irrigation pulses P2 significantly raised *FWUE* compared with (P1 and P3). Also, applying P3 slightly increased *FWUE* compared with P1, Table 2.

3.3. Chili pepper response

Chili pepper was affected by irrigation regimes with three pulse drip irrigation

treatments (P1, P2; P3), (Figure 5). The full irrigation W1 (100% *ETc*) achieved maximum yield (*Ym*) of (34.1, 41.0; 36.0 t.ha⁻¹) for (P1, P2; P3) respectively. Yields for W2 (80 % *ETc*) were (30.0, 38.5; 32.6 t/ha) and W3 (60% *ETc*) had a minimum yield of (22.5, 26.8; 24.0 t.ha⁻¹) for (P1, P2; P3), respectively. A relative yield (*Ya/Ym*) was found as a linear relationship with a uniform water-applied ratio (*Wa/Wm*) in deficit irrigation conditions, Figure 5.

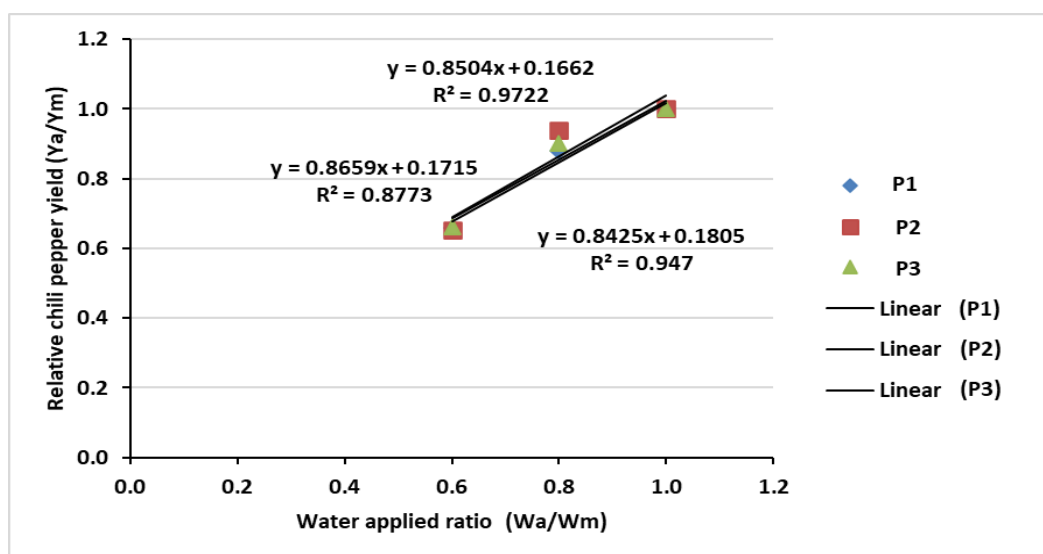


Figure 5. Relative chili pepper yield versus water applied ratio at different irrigation regimes.

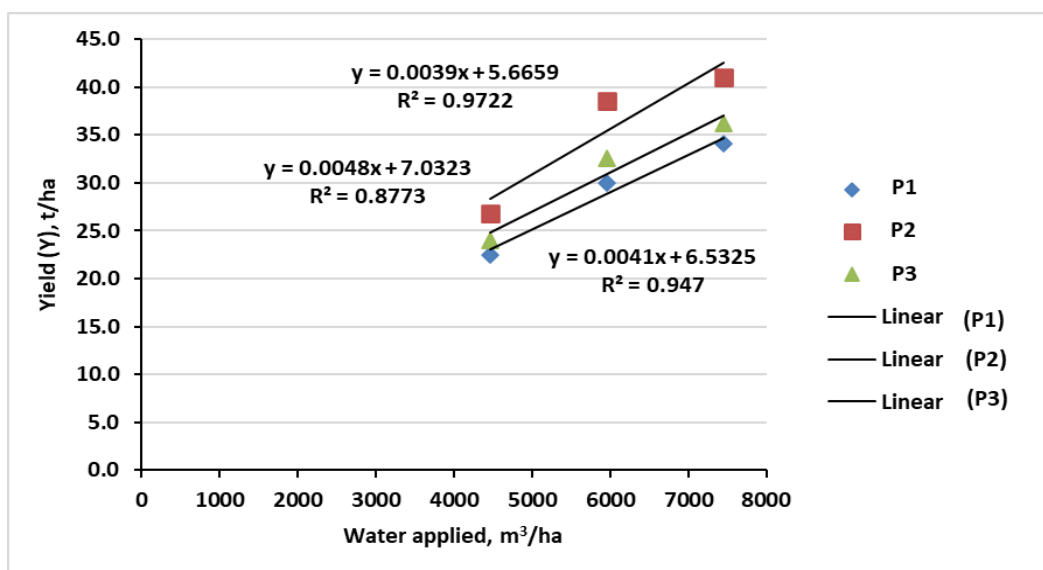


Figure 6. Relationship between chili pepper yield and water applied under different irrigation regimes.

The results showed that chili pepper yield increased linearly with increasing irrigation water application up to $7451.9 \text{ m}^3 \cdot \text{ha}^{-1}$ (W1) where the maximum yield was $41.0 \text{ t} \cdot \text{ha}^{-1}$ under two drip irrigation pulses P2. When water applied was reduced to $4471.2 \text{ m}^3 \cdot \text{ha}^{-1}$ (W3), the yield decreased to $26.8 \text{ t} \cdot \text{ha}^{-1}$. The result from Figure 6 found a linear relationship for the whole growth period:
 $y = 0.0039x + 5.6659$ with $R^2 = 0.9722$ for P1,
 $y = 0.0048x + 7.0323$ with $R^2 = 0.8773$ for P2,
 $y = 0.0041x + 6.5325$ with $R^2 = 0.947$ for P3;
 Where Y (y) is in $\text{t} \cdot \text{ha}^{-1}$ and Water applied (x) is in $\text{m}^3 \cdot \text{ha}^{-1}$.

Chili pepper yield related to its corresponding uniform irrigation water applied depth was found under the pulse drip irrigation technique, Figure 6. It decreased as water applied decreased in deficit irrigation due to plant stress caused by drier soil. However, yield reduction ($1 - Y_a/Y_m$) was found in a linear relationship with uniform water applied fraction in small experiment plots in either deficit irrigation conditions ($1 - W_a/W_m$) as shown in Figure 7.

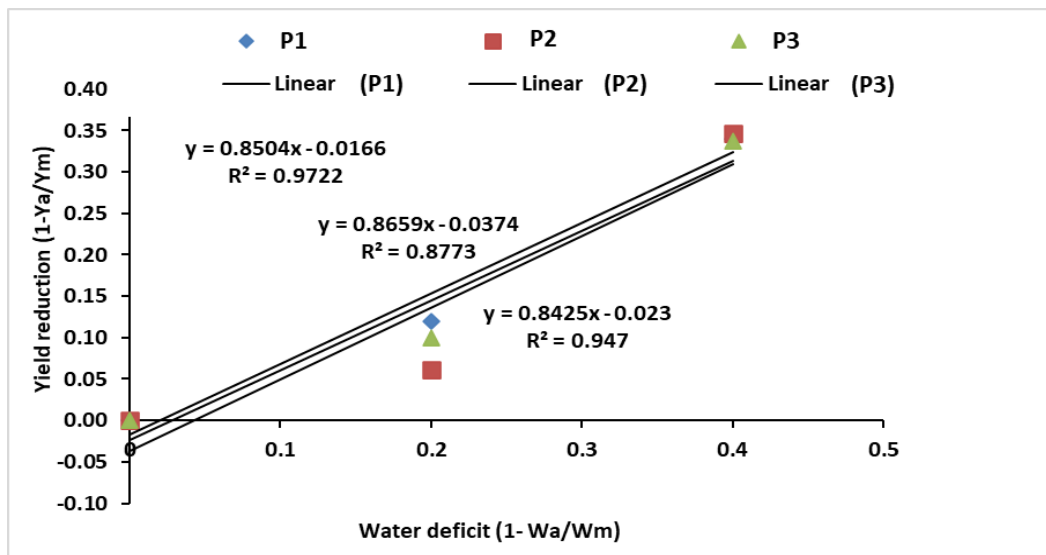


Figure 7. Chili pepper yield reduction versus water deficit.

Expressing yield and application of water (W_a) in relative terms by dividing Yield (Y_a) by Maximum Yield (Y_m) and W_a by W_m for every treatment and subtracting from results in functions of relative deficit water production. So, the yield reduction coefficients (K_y) were expressed as:

$$\left(1 - \frac{Y_a}{Y_m}\right) = 0,60 \left(1 - \frac{W_a}{W_m}\right) \quad \text{For W2 with P1}$$

$$\left(1 - \frac{Y_a}{Y_m}\right) = 0,30 \left(1 - \frac{W_a}{W_m}\right) \quad \text{For W2 with P2}$$

$$\left(1 - \frac{Y_a}{Y_m}\right) = 0,50 \left(1 - \frac{W_a}{W_m}\right) \quad \text{For W2 with P3}$$

$$\left(1 - \frac{Y_a}{Y_m}\right) = 0,85 \left(1 - \frac{W_a}{W_m}\right) \quad \text{For W3 with P1}$$

$$\left(1 - \frac{Y_a}{Y_m}\right) = 0,87 \left(1 - \frac{W_a}{W_m}\right) \quad \text{For W3 with P2}$$

$$\left(1 - \frac{Y_a}{Y_m}\right) = 0,84 \left(1 - \frac{W_a}{W_m}\right) \quad \text{For W3 with P3}$$

From the previous equations; the coefficients of 0.60, 0.30, 0.50, 0.85, 0.87, and 0.84 are crop deficit coefficients and relate the relative yield reduction to the relative water applied. The yield reduction coefficient (K_y) was calculated as (0.6, 0.3; 0.5) for (P1, P2; P3), respectively for W2 irrigation regime, on the other hand when applying W3 the yield reduction coefficient

(Ky) was determined as (0.85, 0.87; 0.84) for (P1, P2; P3), respectively. Therefore, chili pepper yield reduction coefficients (Ky) using regression, see Figure 7, and equations were for W2 (80% *ETc*) treatment, they were calculated as 0.60 ($R^2 = 0.9722$), 0.30 ($R^2 = 0.8773$), and 0.50 ($R^2 = 0.947$) for P1, P2, and P3 treatments, respectively. Therefore, W2P2 treatment was recommended for saving water with a minimum yield reduction coefficient of (0.3).

3.4. Economics

The treatment W1MP2 with full irrigation W1, olive pomace mulch M, and two drip irrigation pulses P2, achieved the highest Benefit Cost ratio (BC) of 6.3; due to its maximum chili pepper *MY*, which offset its high initial cost. Also, the treatment W2MP2 with deficit irrigation W2 (20% water saving), achieved high

benefit cost ratio (BC) of 6.0, Figure 8. There was not a significant economic difference between W1MP2 and W2MP2 treatments.

Table 3 presents the statistical analysis of BC ratio for the experimental treatments. The mulching treatment (M) achieved significantly higher economic values of BC than the non-mulching (NM). While, the lowest irrigation regime (W3) had a significantly lowest BC ratio. Applying two drip irrigation pulses P2 significantly raised BC economic parameter compared with P1, and P3. Furthermore, using three drip irrigation pulses P3, relatively maximized BC ratio compared with the traditional one-continuous pulse P1. So, the significantly positive effect of drip irrigation pulses on maximizing the economic return could be arranged in the following descending order ($P2 > P3 > P1$).

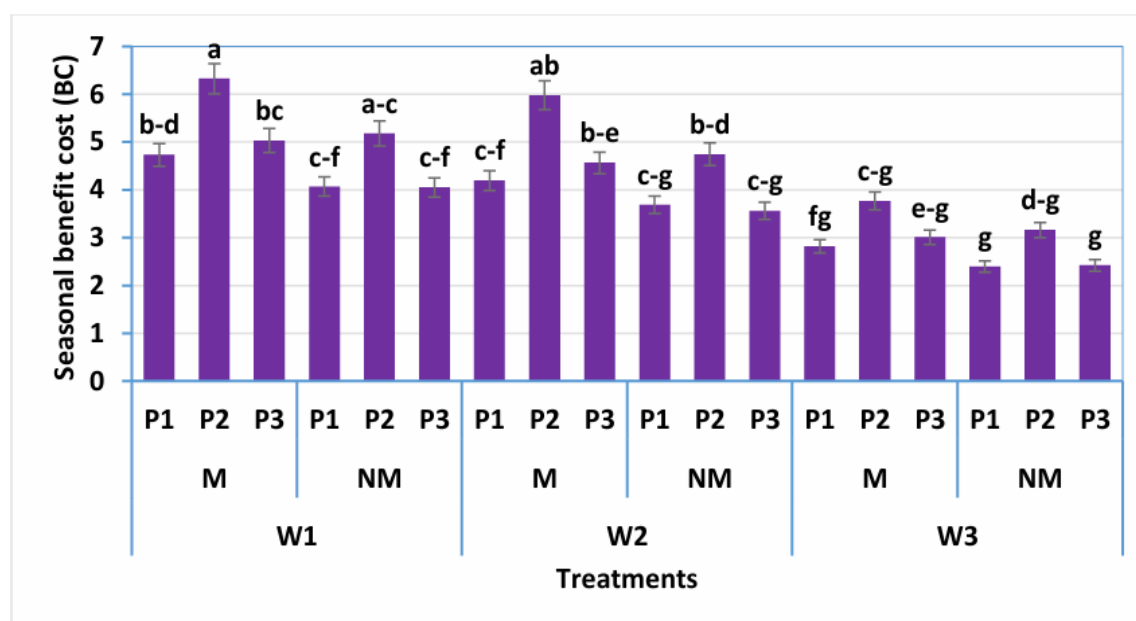


Figure 8. Seasonal benefit cost ratio BC interaction, affected by irrigation water regimes (W1, W2, and W3), pulse drip irrigation (P1, P2, and P3), and soil mulching (M, and NM). Bars represent $\pm$ S.E. Bars with the same letters are not significantly different ($P \leq 0.05$ level).

Table 3. Statistical analysis of BC ratio as an economic parameter for the experimental treatments.

Characters		BC
Drip irrigation layouts	<i>L1</i>	4.09 a
	<i>L2</i>	2.94 b
P value		<0.001**
Irrigation water regimes	<i>W1</i>	4.27 a
	<i>W2</i>	3.83 b
	<i>W3</i>	2.46 c
P value		<0.001**
Olive pomace mulch	<i>M</i>	3.84 a
	<i>NM</i>	3.20 b
P value		<0.001**
Drip irrigation pulses	<i>P1</i>	3.14 b
	<i>P2</i>	4.24 a
	<i>P3</i>	3.18 b
P value		<0.001**

The values represent means. For a given variable; means followed by the same letter have no significant difference, and mean values not sharing common letters are significantly different., BC: Seasonal benefit cost ratio.

4. DISCUSSION

Our study aimed to address one of the major challenging issues for agriculture production and food security in Northern Sinai, Egypt. Applying modern irrigation approaches with proper water management could play an important role in water-saving and crop production.

The previous results showed that *MY* of chili pepper was negatively affected in a linear relationship ($R^2 \geq 0.8773$) by water stress conditions. W2P2 treatment was recommended for saving water with a minimum yield reduction coefficient of 0.3. Although the negative effect of water deficit on plant height and yield, there was a positive effect of applying deficit irrigation (W2) combined with pulse drip irrigation (P2) and olive pomace mulch (M). The application of two drip irrigation pulses P2 raised the *MY* of chili pepper (t.ha^{-1}) by ranges (18.6 %), and (14.5 %) compared with P1 and P3, respectively. Moreover, applying P2 maximized the *FWUE* under deficit irrigation circumstances. Where, the highest two *FWUE* values were (6.4 and 6.0 kg.m^{-3}) by W2MP2 and W3MP2 treatments, respectively. Furthermore, applying two drip irrigation pulses P2 significantly raised *FWUE* compared with one continuous pulse P1, which indicated

more production per water unit. Also, the highest economic returns were achieved by W1MP2 and W2MP2 treatments with benefit cost BC ratios of (6.3 and 6.0), respectively. There was no significant economic difference between W1MP2 and W2MP2 treatments.

These findings align with (Colak, 2021) who found a reduction in chili pepper yield production under water deficit treatments due to soil drying which decreased the root absorption below the transpiration rate by the plant resulting in reduced plant growth. In contrast under full irrigation, there were more fresh-weight fruits resulting from a longer ripening period, which allowed a higher accumulation of water, compared to water-stressed fruits. Also, many studies reported the effect of drought on reducing the total yield of capsicums and the yield reduction was primarily due to a decline in macro-nutrition, leaf relative water content, leaf area, stomatal conductance, plant growth, assimilation rate, WUE, fruit quantity, and quality (Reddy *et al.*, 2016). Moreover, many studies found that the yield parameters of pepper were negatively affected by water stress (Ramadasan and Vasantha, 1994; Krishnamurthy *et al.*, 2016).

The rate of water applied for plants can be decreased by around 20% for water management in regions that suffer water shortage in agreement with (Mardani *et al.*, 2017).

Soil mulch significantly influenced chili pepper behavior, including yield production, and *FWUE* in accordance with (Michelon *et al.*, 2020). Applying pulse irrigation significantly increased crop growth in agreement with Levin *et al.*, (1979); El-Mogy *et al.*, (2012); Júnior *et al.*, (2020); Rank and Vishnu, (2021). Also, pulse drip irrigation upgraded productivity and *FWUE* in accordance with (Carroll *et al.*, 2024).

A study in sandy soil found that; there were significant differences in Net Income NI between pulse drip irrigation and continuous drip irrigation (Ramadan, 2009), which indicated the positive effect of applying pulse drip irrigation technique on economic benefit in agreement with our study. In this context, our study findings could improve the production of chili pepper yield and save water which is one of the strategic goals of the country and even worldwide. Applying pulse drip irrigation could be one of the good water management practices for farmers and local producers in Northern Sinai, and arid regions which suffer water scarcity.

5. CONCLUSIONS

Applying pulse drip irrigation (P2), and olive pomace mulch (M) achieved higher growth, Marketable Yield *MY*, Field Water Use Efficiency *FWUE*, and economic return. The intermitted application of irrigation water with two pulses (P2) gives big volume of water pulse with enough break time (30 minute) for the soil to absorb the water doses, which enhances aeration in the soil profile, optimum absorption of essential nutrients from the effective root zone, helps the plant to improve photosynthesis, better plant growth, and production, in addition to more horizontal

spread of soil moisture in sandy soil; that minimize water loss by percolation under rootzone and save water. The olive pomace is a widely available residue from olive pressing in North Sinai, it has a suitable price. This organic mulch gradually decomposed in the soil, adding more nutrients and organic matter to the soil profiles, and improving the soil quality. It is essential for increasing vegetable production in arid environments; it enhances the soil micro-environment around the root-zone, and soil moisture conservation by less evaporation from soil.

Deficit irrigation conditions negatively affected chili pepper *MY* in a linear relationship ($R^2 \geq 0.8773$). Any significant decline in soil water directly impacts the available water for a crop, and consequently the actual yield. However, applying W2MP2 treatment (with 20% water saving) did not significantly reduce chili pepper *MY* and economic benefits (BC ratio) compared with full irrigation treatment W1MP1. Furthermore, W2MP2 treatment achieved the highest *FWUE* value of 6.4 kg.m⁻³. Therefore, it is recommended to apply an irrigation water deficit of 80% from *ETc* (W2) combined with two drip irrigation pulses (P2) of 30 minutes off-time between pulses- the main irrigation every 48 hours and use olive pomace as a soil organic mulch (M). Hence W2MP2 treatment is the most identical treatment to save water, where it could save 20% from *ETc* (148,928.57mm/season $\simeq$ 1,489.8 m³/ha/season) with proper economic return (BC ratio $\simeq$ 6.0) when cultivating chili peppers with chicken manure organic fertilization in sandy soil under dry climate conditions.

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الملخص العربي

تأثير الري المتناقص وتغطية التربة على إنتاج الفلفل الحار وترشيد المياه باستخدام الري بالتنقيط النبضي

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تم إجراء هذه الدراسة لزيادة كفاءة استخدام المياه في الحقل ($FWUE$) وزيادة توفير المياه مع تحقيق منافع اقتصادية لمحصول الفلفل الحار في شمال شبة جزيرة سيناء- مصر. كانت معدلات إضافة مياه الري ($W1, 100\%$ ؛ $W2, 80\%$ ؛ $W3, 60\%$) من البخر نتج المحصول ($ETc\%$) واستخدم ثلاث نبضات ري بالتنقيط ($P1$) نبضة ري بالتنقيط مستمرة واحدة؛ $P2$ نبضتان بفاصل ٣٠ دقيقة؛ $P3$ ثلاث نبضات بفاصل ١٥ دقيقة) حيث تم إجراء الري كل ٤٨ ساعة واستخدم نوعين لتغطية التربة: تربة بدون ملش (NM) واستخدام مخلف تفل الزيتون كغطاء عضوي للتربة (M). كان التصميم التجريبي عبارة عن "القطع المنشقة الثنائية" بثلاث مكررات. أظهرت النتائج تأثير المحصول التسويقي MY للفلفل الحار سلبياً بالإجهاد المائي بعلاقة خطية ($R^2 \geq 0.8773$). حققت معاملة $W2MP2$ أعلى قيمة كفاءة استخدام للمياه في الحقل ($FWUE$) بقيمة ٦,٤ كجم للمتر المكعب. علاوة على أن استخدام معاملة $W2MP2$ لم يكن لها تأثير معنوي على خفض المحصول التسويقي MY والعائد الاقتصادي للفلفل الحار مقارنة بمعاملة الري الكامل $W1MP2$. لذا يوصى باستخدام معاملة $W2MP2$ لتحقيق ٢٠٪ توفير في مياه الري بما يعادل (١٤٨,٩٢٨.٥٧ مم في الموسم ~ ١,٤٨٩.٨ متر مكعب للهكتار في الموسم) بعائد إقتصادي مناسب ($BC = 6.0$) لإنتاج الفلفل الحار في ظروف شمال سيناء. هذا البحث يلقي الضوء على أهمية ترشيد المياه باستخدام الري بالتنقيط النبضي لمحاصيل أخرى، معاملات ري، ومواقع جغرافية تحت ظروف الجفاف.

الكلمات الاسترشادية: الري بالتنقيط النبضي، نقص المياه، التحليل الاقتصادي، كفاءة استخدام المياه الحقلية، تغطية التربة

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