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The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2023; 12(5): 4704-4709

www.thepharmajournal.com
Received: 07-02-2023
Accepted: 13-03-2023

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Crop water requirement, water use efficiency and economics of marigold (*Tagetes patula* L.) under groundwater-wastewater irrigation regimes

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Abstract
A field experiment was conducted for estimation of crop water requirement, water use efficiency and economics of marigold (*Tagetes patula* L. *cv.* Pusa deep) under groundwater-wastewater irrigation regimes at Water Technology Centre farm of ICAR-Indian Agricultural Research Institute, New Delhi during period of 2020-21. Eight treatments T-$_{1}$: Groundwater irrigation scheduled at 25% MAD (θv =27%); T-2: Groundwater irrigation scheduled at 50% MAD (θv=22.5%) T-3: Groundwater irrigation scheduled at 75% MAD (θv=18%); T$_{4}$: Groundwater irrigation scheduled as per farmers practice/recommended POP; T-5: Wastewater irrigation scheduled at 25% MAD (θv= 27%); T-$_{6}$: Wastewater irrigation scheduled at 50% MAD (θv= 22.5%); T-7: Wastewater irrigation scheduled at 50% MAD (θv=18%); T-8: Wastewater irrigation scheduled as per farmers practice/recommended POP were laid out in a randomized block design (RBD) with three replications. Results indicated that highest crop water requirement of marigold (647.04 mm) and lowest (434.42 mm) were found in the treatments where groundwater and wastewater irrigations scheduled at 75% MAD and 25% MAD, respectively. Maximum and minimum water use efficiency of marigold were observed as 7.05 kg/ha-mm and 4.27 kg/ha-mm under wastewater irrigations scheduled at 50% MAD and groundwater irrigations scheduled at 75% MAD, respectively. Highest and lowest economics in terms of benefit -cost ratio (BCR) of marigold was observed as 3.41 and 1.80 under wastewater irrigations scheduled at 50% MAD and groundwater irrigations scheduled at 25% MAD, respectively.

Keywords: Crop water requirement, economics, marigold, wastewater, water use efficiency

Introduction
The rise in population has led to urbanization and industrialization, resulting in a shortage of fresh water for irrigation. As a consequence, larger amounts of freshwater are diverted to domestic, commercial, and industrial sectors, producing higher volumes of wastewater (Qadir *et al.*, 2007a) [14]. In India, only 24% of wastewater produced by households and industries undergoes treatment before being used for agriculture or discharged into rivers (Minhas and Samra, 2003) [19]. In many developing countries, there is a lack of proper wastewater treatment plants and those in existence may function inadequately (Qadir *et al.*, 2007b). This situation poses significant challenges to the proper disposal of wastewater and results in severe water pollution as untreated wastewater is released into groundwater or natural drainage systems (CPCB, 2009; Kaur *et al.*, 2012) [6, 8]. Moreover, untreated sewage water from various industries in India may contain high levels of plant nutrients and heavy metals, leading to severe environmental problems (Gupta *et al.*, 1997; Radwan and Salama, 2006; Khan *et al.*, 2010; Khalwa *et al.*, 2019). Consequently, partially treated, diluted, or untreated wastewater is diverted and used deliberately by urban and peri-urban farmers as a source of plant nutrients and alternative water (Minhas *et al.*, 2015). Nevertheless, untreated wastewater contains pathogens and toxic pollutants that pose risks to human health and the environment. Proper irrigation scheduling is vital to achieving maximum water use efficiency and crop productivity (Nzediegwu *et al.*, 2019) [12]. Practical tools such as soil water content and matric potential sensors can monitor soil water status and guide irrigation decisions on farms (Paltineanu, 2014; Provenzano *et al.*, 2016) [13]. Therefore, this study aims to estimate the crop water requirement, water use efficiency, and economics of marigold (*Tagetes patula* L.) under groundwater-wastewater irrigation regimes using a frequency domain reflectometer (FDR) to measure soil moisture.

Materials and Methods

General Details on experimental site and treatments

A field experiment was conducted at the research farm of the Water Technology Centre (WTC Field No. 1) of ICAR Indian Agricultural Research Institute (IARI), New Delhi, India during 2020-21. The WTC experimental farm is located between 28° 37’ 22” to 28° 39′ 00″ N latitude and 77° 8′ 45″ to 77°10′ 24″ E longitudes with an average elevation of 230 m above mean sea level. The average annual rainfall was 710 mm. The initial soil properties of the experimental field at a depth of 0-30 cm are given in Table 1. Quality characteristics of groundwater and wastewater used for experimental crop are given in Table 2. Eight treatments T-1: Groundwater irrigation scheduled at 25% MAD (θv =27%); T-2: Groundwater irrigation scheduled at 50% MAD (θv =22.5%) T-3: Groundwater irrigation scheduled at 75% MAD (θv= 18%);T4: Groundwater irrigation scheduled as per farmers practice/recommended POP; T-5: Wastewater irrigation scheduled at 25% MAD (θv= 27%); T-6: Wastewater irrigation scheduled at 50% MAD (θv= 22.5%); T-7: Wastewater irrigation scheduled at 50% MAD (θv= 18%); T-8: Wastewater irrigation scheduled as per farmers practice/recommended POP were laid out in a randomized block design (RBD) with three replications. Proper package and practices for cultivation of marigold were followed during crop growth period. FDR moisture sensor was to determine the soil moisture.

Estimation of crop water requirement using soil water balance method

Soil-water balance/water budgeting method was used to estimate the actual crop Evapo-transpiration (ET_c) which was equal to crop water requirement of marigold. Hence, ET_C of marigold was measured by below given soil-water balance equation;

$$ET_{cf} = I + R + Cp – R_{off} + Dp – S \pm dW \quad (1)$$

$$ET_{cf} = WR_{cf} \quad (2)$$

Where:

- WR_{cf} is water requirement of marigold (mm).
- ET_{cf} is the actual evapo-transpiration of marigold (mm).
- I, irrigation (mm), is the controlled variable in field experiment or decision variable in irrigation scheduling.
- R is the rainfall (mm).
- Cp is the capillary contribution from the ground water table to the crop root zone (mm).
- R_{off} the runoff (mm).
- Dp is the deep percolation below the root zone (mm).
- S is the seepage (mm).
- dW is the change in soil water storage in the root zone (mm).

Measurement of components of soil-water balance equation

The total irrigation depth in each treatment plot was calculated in selected loose flower and I, irrigation and R, rainfall was directly measured. The experimental plots were closed by bunds (30 cm height) and the depth of the water table of the WTC tube well is less than 10 m from the surface of the earth. The surface runoff and the vertical upward inflow or capillary flow to the root zone would therefore be considered nil in the calculation of ET_{cf} using Eq. (1). In addition, FDR measured readings are observed for deep percolation or drainage below the root zone (root zone depth of selected crop is 30 cm) to observe/measure the soil-water content. The total change in stored water, dW, was determined from the difference in the content of measured soil water just before the planting of the marigold (but after land preparation) and immediately after the harvest of the loose flowers from each replication. As mentioned above, soil-water equilibrium/soil water budgeting is widely used to calculate total actual water usage or crop evapo-transpiration (ETc)When there are no Lysimeter installations available (Farahani *et al.,* 2009). Therefore, now the equation is;

$WRc=ET_{cf}= I + R + Cp – R_{off} + Dp–S \pm dW$, $WRc=ET_{cf}= I + R + 0 – 0 + 0 –0 \pm dW$

$$WRc=ET_{cf}= \text{Irrigation (I)} + \text{Rainfall (R)} \pm \text{Change in soil moisture Storage (dW)} \quad (3)$$

Estimation of water use efficiency of marigold flower production

Water use efficiency (WUE) is defined as the amount of carbon assimilated as biomass or grain produced per unit of water used by the crop. It was determined by considering the marketable yield of selected loose flower from each treatment plot on a weight basis and also by considering the actual loose flower evapotranspiration (ET) values calculated for each treatment plant using the soil-water balance method as mentioned above. The efficiency of water usage was therefore be measured as shown in the formula below.

$$WUE = Y/ET$$

Where:

- WUE is the water use efficiency (kg/ha-mm).
- Y is the marketable yield of selected loose flower (kg/ha)

ET is the actual evapotranspiration of selected loose flower (mm).

Estimation of economics of loose flowers

Economics of marigold flower production using wastewater irrigation as a benefit cost ratio (BCR) that is calculated based on Total Revenue divided by Total Variable Cost. Total revenues were calculated as the total number of loose flower production of marigold per hectare multiplied by the average price of the marigold flowers (in terms of kg). Total Variable Cost includes land preparation costs, planting of seedlings, weeding, other cultural activities, pest and disease management, irrigation and harvesting costs. Wastewater irrigation costs were considered to be zero. Data on variable cost components were collected from interactions between farmers and also from published literature. Gross Margin was calculated as total revenue minus total variable cost.

Results and Discussion

Impact on crop water requirement and water use efficiency of marigold

Table 3 shows that the number of irrigations with groundwater and wastewater at 25, 50, and 75 percent MAD were 14, 11, and 8, respectively. As a result, the irrigation depths in treatments T1, T2, T3, T5, T6, T7 and T8 were 13.51, 27.51, 40.04, 13.51, 27.51, and 40.04 mm, respectively. The total rainfall during the crop growth period was 285.40 mm. The changes in soil moisture storage in treatments T1, T2, T3, T4, T5, and T6 were -40.12, -38.15, -39.56, -40.12, -38.15, -39.56, mm. The crop water requirement of marigold varied from 434.42 to 566.16 mm depending on the treatment. Water use efficiency of marigold was varied from 4.27 to 5.61 kg/ha-mm. Maximum water use efficiency of marigold (7.05 kg/ha-mm) was found in the treatment T6 where wastewater irrigation was scheduled at 50% MAD and minimum water use efficiency (4.27 kg/ha-mm.) was observed at in the treatment T3 where groundwater irrigations were scheduled at 75%. From Table 3, it is evident that Crop water requirement of marigold under different treatments was varied from 434.42 to 566.16 mm. Hence the highest crop water requirement of marigold (566.16 mm) was found in the treatments where groundwater and wastewater irrigations scheduled at 75% MAD and lower (434.42 mm) at 25% MAD. This is may be due to less and more water applied at 75% MAD and 25% MAD, respectively. Water use efficiency of marigold was found more in the treatment T6 where wastewater irrigations were scheduled at 50% MAD. This is may be due to more yield of marigold was observed under this treatment.

Impact on economics of marigold production

Table 4 reveals that Total Variable Cost was calculated using the costs of land preparation, seedling planting, weeding, other cultural operations, pest and disease management, irrigation, and picking. Except for the cost of irrigation water, all costs for all treatments were the same. Irrigation costs for groundwater varied due to the number of irrigations applied. As a result, total variable cost (TVC) was highest (Rs. 80,502) in treatment T1, where groundwater irrigations were scheduled at 25% MAD, and lowest (Rs. 66,552) in treatment T6, where wastewater irrigations were scheduled at 50% MAD. The highest total revenue (TR: Rs. 2,26,825) was observed in treatment T6, where wastewater irrigations were scheduled at 50% MAD, and the lowest TR (Rs.1,45,250) was observed in treatment T1, where groundwater irrigations were scheduled at 25% MAD. Economics as benefit cost ratio (BCR) was calculated by dividing Total Revenue (TR) by Total Variable Cost (TVC). The benefit cost ratio (BCR) was varied between 1.80 and 3.41. The treatment T6 had the highest BCR (3.41), while the treatment T1 had the lowest BCR (1.80). It is also revealed by Table 4 that Economics as benefit cost ratio (BCR) was varied from 1.80 to 3.45. Highest BCR (3.45) was found with the treatment T6 where wastewater irrigations scheduled at 50% MAD and minimum BCR (1.80) was found in the treatment T4 where groundwater irrigations were scheduled according to POP. This is may be due to higher yield of marigold was observed under wastewater irrigation as compared to groundwater. At 50% MAD, the number and quantity of irrigation was optimum for marigold which promoted the higher physiological and biological activities of the plant and enhanced the yield of marigold. At 75% MAD, less frequent and a lesser number of irrigations were applied which resulted water stress condition in plant and reduced the yield of marigold.

Table 1: Initial soil properties of the experimental field at 0-30cm

S. N.	Parameters and Unit	Values	Method Followed	Reference
(A)	**Soil Physical Properties**			
1.	**Particle size distribution**			
	a. Sand (%)	71	Bouyoucos Hydrometer Method	Bouyoucos, 1962
	b. Silt (%)	14		
	c. Clay (%)	15		
	d. Textural Class	SL		
2.	Bulk density (g/cc)	1.52	Core Sampler Method	Jackson, 1967
3.	Water Retention at Field Capacity (%)	21.96	Pressure Plate Apparatus Method	Hillel, 1982
4.	Water Retention at Permanent Wilting Point (%)	8.21	Pressure Plate Apparatus Method	Hillel, 1982
5.	Mean Weight Diameter (MWD) of Soil Aggregates (mm)	0.98	Wet Sieving Yoder Apparatus Method	Yoder, 1936
6.	Geometric Weight Diameter (GMD) of Soil Aggregates (mm)	0.54	Wet Sieving Yoder Apparatus Method	Yoder, 1936
7.	Basic Infiltration Rate (cm/hr.)	1.7	DR Infiltrometer	Hillel, 1982
8.	Hydraulic Conductivity (cm/hr.)	0.65	CH Permeameter	Hillel, 1982
(B)	**Soil Chemical Properties**			
9.	pH (1:2.5)	7.65	Digital pH Meter	Richards (1954)
10.	EC (1:2.5) (dS m^{-1})	0.29	Conductivity Bridge	Richards (1954)
11.	Organic Carbon (OC) (%)	0.32	Walkley and Black Method	Walkley and Black, 1934
12.	Available N (kg ha^{-1})	128.71	Nitrogen Analyzer	Subbiah and Asija, 1956
13.	Available P (kg ha^{-1})	26.55	Olsen method	Olsen *et al.*, 1954
14.	Available K (kg ha^{-1})	283.61	Ammonium Acetate Method	Hanway and Heidel, 1952
15.	**Soil Micronutrients Metals (mg kg^{-1})**			
	DTPA Copper (Cu)	1.03	Atomic Absorption Spectrophotometer (AAS) Method	Singh *et al.*, 2005
	DTPA Iron (Fe)	1.12		
	DTPA Manganese (Mn)	7.13		
	DTPA Zinc (Zn)	1.13		
16.	**Soil Toxic Heavy Metals (mg kg^{-1})**			
	DTPA Cadmium (Cd)	0.01	Atomic Absorption Spectrophotometer (AAS) Method	Jackson, 1993
	DTPA Lead (Pb)	1.12		
	DTPA Nickel (Ni)	0.32		
	DTPA Chromium (Cr)	0.24		
(C)	**Soil Biological Properties**			
17.	Fecal Coliforms (MPN/100ml)	$4.3x10^3$	Multiple-Tube Fermentation Technique	APHA (2005)
18.	Total Coliform (MPN/100ml)	$7.5x10^3$		

Table 2: Quality characteristics of irrigation waters used for experiment crop (2020-21)

S. N.	Characteristics	Unit	GW	WW	MPLiw
Irrigation Quality Parameters					
1.	pH	0-14	7.35	7.36	6.5-8.0
2.	EC	dS/m	1.25	1.35	0-3
3.	Sodium (Na^+)	meq/L	7.63	8.23	40
4.	Calcium (Ca^{2+}) + Magnesium (Mg^{2+})	meq/L	5.13	4.77	25
5.	Carbonate (CO_3^{2-})	meq/L	0.00	0.00	0.1
6.	Bicarbonate (HCO_3^-)	meq/L	4.63	4.80	10
7.	Sodium Adsorption Ratio (SAR)	$(mmol/L)^{0.5}$	4.97	5.48	0-15
8.	Residual Sodium Carbonate (RSC)	meq/L	-0.50	0.03	2.5
Water Pollution Parameters					
9.	Biochemical Oxygen Demand (BOD)	mg/L	ND	189.14	100*
10.	Chemical Oxygen Demand (COD)	mg/L	ND	398.36	-
Macro Nutrients Potential Parameters					
11.	Nitrate-Nitrogen as NO_3^-N	mg/L	2.62	26.13	0-10
12.	Phosphate- Phosphorous as PO_4-P	mg/L	0.28	1.35	0-2
13.	Potassium as K^+	mg/L	1.24	16.38	0-2
Heavy metals Contents					
14.	Copper as Cu	mg/L	ND	0.07	0.20
15.	Iron as Fe	mg/L	ND	4.07	5.00
16.	Manganese as Mn	mg/L	ND	0.75	0.20
17.	Zinc as Zn	mg/L	ND	0.54	2.00
18.	Lead as Pb	mg/L	ND	1.21	5.00
19.	Cadmium as Cd	mg/L	ND	0.002	0.01
20.	Nickel as Ni	mg/L	ND	0.07	0.20
21.	Chromium as Cr	mg/L	ND	0.09	0.10
22.	Faecal Coliform	MPN/100ml	ND	$450x10^3$	$10x10^3$*
23.	Total Coliform	MPN/100ml	ND		-

Note: GW-Groundwater, WW-Wastewater, MP Liw-Maximum Permissible Limits for Irrigation Waters (FAO, 1985), *Standards for effluent discharge for irrigation/agriculture.

Table 3: Impact of FDR sensor-based application of wastewater irrigations on water requirement and water use efficiency of marigold (2020-21)

Treatment	(No)	Di (mm)	TID (mm)	TR (mm)	Dw (mm)	ETc/CWR (mm)	WUE (kg/mm)
T-1	14	13.51	189.14	285.40	-40.12	434.42	4.81
T-2	11	27.51	302.61	285.40	-38.15	549.86	4.58
T-3	8	40.04	320.32	285.40	-39.56	566.16	4.27
T-4	10	49.50	495.00	285.40	-39.89	740.51	4.83
T-5	14	13.51	189.14	285.40	-40.15	434.42	6.51
T-6	11	27.51	302.61	285.40	-38.15	549.86	7.05
T-7	8	40.04	320.32	285.40	-39.56	566.16	6.22
T-8	10	49.50	495.00	285.40	-39.89	740.51	5.61

In: Number of irrigation given in each treatment, Di: Depth of irrigation for each treatment, TID: Total Irrigation Depth, TR: Total Rainfall, dW: Change in soil moisture storage, ETc/CWR: Actual Crop Water Requirement of Marigold, WUE: Water use efficiency of marigold

Table 4: Impact of FDR sensor-based application of wastewater irrigations on production economics of marigold (2020-21)

Particular	T1	T2	T3	T4	T5	T6	T7	T8
Land preparation cost	3000	3000	3000	3000	3000	3000	3000	3000
Planting material cost	20,602	20,602	20,602	20,602	20,602	20,602	20,602	20,602
Fertilizer /manure cost	14600	14600	14600	14600	8500	8500	8500	8500
Weeding cost	17500	16000	15000	13500	18000	16500	15000	14500
Other cultural operation cost	9500	9500	9500	9500	9500	9500	9500	9500
Plant protection cost	2800	2950	3500	4000	2800	2950	3500	4000
Irrigation cost	7000	5500	4000	4500	0	0	0	0
Picking cost	5500	5500	5500	5500	5500	5500	5500	5500
Total variable cost	80, 502	77, 652	75, 702	75,202	67, 902	66, 552	67, 102	65, 602
Flower production in kg/ha	5810	6240	6579	6639	8663	9593	8466	7634
Avg Price/Kg (Rs)	25	25	25	25	25	25	25	25
Total Revenue (Rs. Lakhs)	1.453	1.560	1.645	1.660	1.487	2.268	2.117	1.909
Gross margin (Rs. Lakhs)	0.647	0.788	0.888	0.858	1.601	1.733	1.496	1.406
B:C ratio (BCR)	1.80	2.00	2.17	2.20	3.10	3.41	3.15	2.91

Conclusion

Crop water requirement of marigold under different treatments was varied from 434.42 to 566.16 mm. Hence the highest crop water requirement of marigold (647.04 mm) was found in the treatments where groundwater and wastewater irrigations scheduled at 75% MAD and lower (434.42 mm) at 25% MAD.

Water use efficiency of marigold was varied from 4.27 to 6.51 kg/ha-mm. Maximum water use efficiency of marigold (7.05 kg/ha-mm) was found in the treatment T6 where wastewater irrigations were scheduled at 50% MAD and minimum water use efficiency (4.27 kg/ha-mm) was observed at in the treatment T3 where groundwater irrigations were scheduled at 75% MAD. Benefit cost ratio (BCR) was varied from 1.80 to 3.41. Highest BCR (3.41) was found with the treatment T6 and minimum BCR (1.80) was found in the treatment T1.

Acknowledgement

I, (first author) am very much thankful to the Indian Council of Agricultural Research (ICAR), New Delhi for giving me financial support in the form of Junior Research Fellow (JRF) for conducting this research work under my M.Sc. degree programme in the discipline of Water Science and Technology (WST) at Water Technology Centre (WTC), ICAR-Indian Agricultural Research Institute (IARI), New Delhi. Authors are also grateful to Director, ICAR-IARI, New Delhi for providing necessary labs and others infrastructure facilities to conduct this study.

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