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Application of Treated Wastewater for Cultivation of Marigold Roses (*Tagetes erecta*) in a Semi-Arid Climate in Palestine

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Abstract

Local communities in many parts of the West Bank, Palestine have very limited water resources available for irrigation. In addition, since these communities are traditionally agricultural communities, water shortage and the lack of innovation in the agricultural sector led to loss of jobs in this sector. This in turn led young people to start looking for jobs in different sectors and even increased migration to urban centers. The reuse of treated wastewater can provide a viable solution to irrigation water shortage. It can help in creating jobs in the marginalized communities in the West Bank, especially in areas under full Israeli control (Area C according to the Oslo Accord). Furthermore, it is important to select crops that can resist the effects of climate change and create revenue for the farmers at the same time. In this research, we studied the impact of irrigating marigold (*Tagetes erecta*), which is a flower plant commonly used in the Palestinian market, with treated wastewater from the Nablus West Wastewater Treatment Plant (NWWTP). The quality of the treated wastewater, as indicated by parameters such as COD, BOD5, pH, EC, and TSS, shows its suitability for agricultural reuse. With low levels of organic matter, a near-neutral pH, and minimal suspended solids, the water poses minimal environmental risks and is ideal for irrigation, though monitoring for salinity buildup is necessary. Twenty-six marigold plants were planted, half of them were irrigated with the treated wastewater and the other half with tap water. Observations of length, number of roses, rose size, days to flower, and flowering days were recorded for both cases. The statistical analysis of the results shows that there is no significant difference between marigolds irrigated with treated wastewater and those treated with tap water, in terms of Plant Height, Rose Number and Rose Diameter.

Keywords: wastewater; irrigation; reuse; *Tagetes erecta*; semi-arid climate; water scarcity; Palestine

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1. Introduction

Water scarcity is a critical global challenge [1,2], currently affecting nearly one-third of the world's population [3,4]. The situation is aggravated by climate change, which increases the frequency of droughts and extreme weather events [5].

In Palestine, water scarcity is particularly acute due to restricted access to natural resources under the political situation [6–8]. Groundwater provides over 90% of available water, yet supply is insufficient to meet demand [9,10]. Although agriculture's share in the Gross Domestic Product (GDP) has declined from ~40% in 1967 to <10% today, the sector still consumes more than 45% of available freshwater. Beyond its economic role, agriculture is deeply tied to Palestinian cultural identity and resilience, making water security a national priority [11–13].

Developing countries in the Middle East are experiencing significant water resource scarcity, heavily relying on groundwater as their primary source. Over the past three decades, these nations have undergone urban development, which has included the establishment of sewer systems [14]. Many countries in the Middle East and North Africa suffer the effects of the irregularity of climate conditions on surface water and groundwater, which has affected the sustainability of water resources and caused their deterioration [15].

Urban areas in Palestine are served by sewerage collection systems; however, this progress has not been accompanied by the development of adequate treatment facilities for the large volumes of collected sewage, resulting in adverse impacts on the sustainability and quality of key water resources. Lack of financing for the construction of wastewater treatment plants has been the main reason for this environmental neglect. In Palestine, the effluents from many communities are often discharged into nearby wadis, where they continue to flow untreated, causing environmental pollution and posing a potential threat to groundwater quality. Although Palestinian standards exist to regulate wastewater reuse across different sectors, the enforcement and monitoring of these standards remain weak due to the unstable political situation. A significant improvement occurred in 2015 when Nablus West Wastewater Treatment Plant (NWWTP), funded by the German Development Bank (KfW), was put into operation, providing an alternative source of water and mitigating part of the environmental risks [16]. Treated wastewater (TWW) reuse has a great potential for solving the problems of water shortage for agriculture and the discharge of untreated wastewater into the environment, especially in arid and semi-arid regions [17–19]. This reuse of treated wastewater can not only provide the water crops need, but also it can provide nutrients [18,20,21]. The moderate to high organic matter content in treated wastewater (TWW) promotes high crop yields without affecting their quality. However, irrigation with treated wastewater could increase the salinity and/or alkalinity of the soil causing soil sealing, deterioration, and reduction in crop yield. Furthermore, it is associated with the increased risk of pathogen contamination [18,22–24]. In addition, using TWW for irrigation can increase heavy metal concentrations in soil and plants. The suitability of TWW for irrigation largely depends on the types of crops being grown [25,26].

There is a thriving market worldwide for ornamental plants such as cut flowers, especially in Western Europe, the United States and Japan, where the demand for these flowers is worth tens of billions of US dollars [27–29]. This sector could contribute to solving the job market problem in Palestine where the unemployment rate reaches 24%—36.4% among the youth [30].

A study conducted by Marinho et al. [18] found that rosebushes (Rosa hybrida "Ambiance") irrigated with treated wastewater had higher yield than those obtained with traditional cultivation. The wastewater was treated with anaerobic filters and intermittent sand filters. Regarding the salinity, it was significantly higher than the salinity when irrigated with drinking water, although it was below the critical limit. Furthermore, Nirit et al. [29] found that irrigating roses with treated wastewater for 12 months did not affect the visible appearance of the plants, their contents of macro elements, and some minerals (Fe, Cu, Mo, and Al). On the other hand, it increased the content of Cl, Mn, Cu, and B, but all within the acceptable ranges.

According to Attili [31], there has been increasing encouragement for investors to enter the flower cultivation sector due to its lucrative prospects. The local flower market in Palestine has a substantial demand, with annual consumption reaching ILS 10 million (about USD 2.7 million). Flower farming in the West Bank began in 2009, with 18 dunums (1 dunum = 1000 m^2) planted with 15 types of flowers in Jenin and Tulkarm. This sector has shown high profitability. One farmer highlighted the economic viability of flower farming, noting its high yield and strong local demand. He urged investors to seize this opportunity and stressed the need for institutional support. Another farmer emphasized that Palestinian flowers could compete with imports, offering superior quality and prices, due to faster delivery times. However, challenges like water and fertilizer supply remain. Treated wastewater has been proposed as a sustainable solution, offering both water and nutrients. A national strategy by the Ministry of Agriculture could further enhance this industry's growth potential.

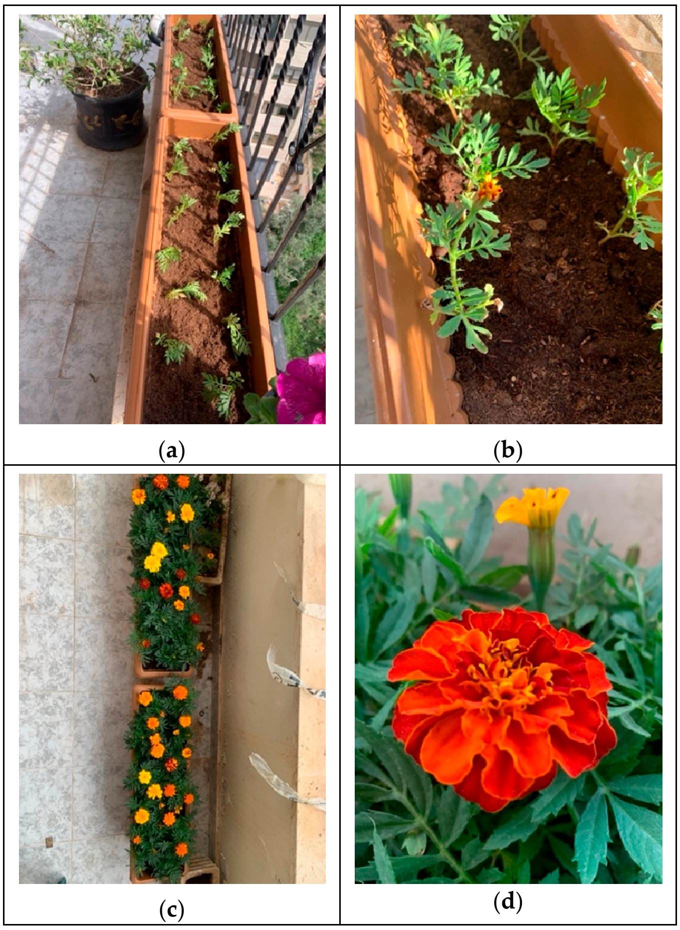
Tagetes erecta, commonly known as African marigold, is an annual flowering plant of the genus Tagetes that is rich in carotenoids such as lutein and other carotenoids. Although it is called African, it is native to Mexico, where it is found in the wild [32,33]. Notably, this type of flower is in high demand in the Palestinian market and is one of the most common flowers in the West Bank. Besides being a commercial flower, marigolds are used in traditional medicine and reported to have anti-bacterial, antimicrobial, anti-oxidant, hepatoprotective, insecticidal, and wound-healing activities mainly due to the presence of Lutein as the main pigment [32,34,35]. Furthermore, marigold fermentation wastewater has been successfully used as a fertilizer [17]. On the other hand, marigolds have been successfully irrigated with the effluent of a laboratory scale decentralized wastewater treatment system [36], and performed well when irrigated with refined wastewater [37].

In this research, we evaluate the effect of irrigating marigolds with treated wastewater from the Nablus West Wastewater Treatment Plant (NWWTP). The NWWTP is located 12 km west of the city of Nablus, Palestine. The plant was established in 2013 and currently serves a population of about 120,000. It is operated as an activated sludge process with physical, biological, and sludge treatment units. Its process units include mechanical screens, a grit/grease removal unit, primary sedimentation tanks, aeration tanks, secondary sedimentation tanks, sludge thickeners, an anaerobic digester, gas utilization unit, and sludge drying beds. The ancillary units include a laboratory, stand-by generator, administration building and workshop. The treated wastewater is currently discharged in a nearby stream (Wadi Al-Zomar), but there is an on-going major reuse project that is expected to irrigate fruit trees planted on about 3 million m^2. The plant treats about 14,000 m^3/d of wastewater, with an efficiency of about 98% for both BOD5 (Biochemical Oxygen Demand) and TSS (Total Suspended Solids) [38,39].

2. Materials and Methods

A field experiment was carried out in the city of Nablus, Palestine between 16 April and 6 June 2022. Two experimental setups, A and B, were established, where A was irrigation with secondary treated wastewater from NWWTP, and B was irrigation with tap water. Thirteen seedlings of marigold were cultivated on 16 April. The seedlings were purchased from a local nursery in Tulkarm, Palestine. At the time of transplanting, uniform and healthy seedlings were selected to minimize variation between treatments. Each experimental setup was represented by a basin with width and length of 20 cm and 75 cm, respectively. Irrigation was supplied daily to both experimental setups with same amount of 0.4 L/plant.

To compare the plant growth in response to water quality, we observed both plant height and number of flowers every 5 days. We also observed the timing of flowerings as well as diameter of flowers of each plant per treatment. The pictures in Figure 1 illustrate the experimental setting and show the growing phases of the marigolds.



(**a**) (**b**) (**c**) (**d**)

Figure 1. The experimental setup and the growing phases of the marigolds (**a**) overview of the experimental setup (**b**) early growth phase, (**c**) overview of the flowering phase, and (**d**) closeup of one flower.

Plants were irrigated manually at regular intervals to maintain adequate soil moisture. The growth medium used was a peat moss–vermiculite mixture. No fertilizers were added during the experiment in order to isolate the contribution of treated wastewater as a nutrient source. Weather conditions were logged daily using data from the Palestinian Meteorological Department. The minimum temperature recorded during the experimental period was 9 °C, while the maximum reached 38 °C. Relative humidity ranged between 41% and 68%, and no rainfall events occurred during the study period.

Tap water used for comparison in this study was supplied by the Nablus municipal network. It is considered high-quality drinking water, with turbidity <1 NTU, electrical conductivity (EC) of about 200 μS/cm, total dissolved solids (TDS) of approximately 250 mg/L, and pH of 7.9.

3. Results and Discussion

3.1. Quality of Reused Wastewater

At the time of the experiment (spring of 2022), the characteristics of the secondary treated wastewater were as shown in Table 1, which can be evaluated in terms of water quality indicators such as Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD5), pH, Electrical Conductivity (EC), and Total Suspended Solids (TSS). These parameters give insight into the water's suitability for reuse, its potential impact on the environment, and its treatment efficiency.

Table 1. Characteristics of secondary treated wastewater from NWWTP.

Parameter	Unit	Value	Palestine Standards Institute (PSI) Value
Chemical Oxygen Demand (COD)	mg/l	45	150
Biochemical Oxygen Demand (BOD_5)	mg/L	10	40
Acidity (pH)	unit	7.64	6–9
Electrical Conductivity (EC)	µS/cm	1270	1500
Total Suspended Solids (TSS)	mg/L	17	30

- Chemical Oxygen Demand (COD): The Chemical Oxygen Demand (COD) of 45 mg/L is much lower than the Palestine Standards Institute (PSI) value of 150 mg/L, indicating that the wastewater has undergone effective treatment. This lower COD value reflects a reduced concentration of both biodegradable and non-biodegradable organic matter, making the water less likely to cause pollution and suitable for reuse in irrigation with minimal environmental impact.
- Biochemical Oxygen Demand (BOD5): The BOD5 value of 10 mg/L, much lower than the PSI value of 40 mg/L, indicates a low level of organic matter in the water, which can be easily decomposed by microorganisms. This suggests good water quality, as a high BOD5 could lead to oxygen depletion, harming aquatic life. The low BOD5 makes the treated water suitable for reuse with minimal environmental impact.
- Acidity (pH): The treated wastewater has a pH of 7.64, within the acceptable range of 6 to 9 as per PSI values. This near-neutral pH is ideal for irrigation, as extreme acidity or alkalinity can harm plant growth, soil health, and irrigation systems. A slightly alkaline or neutral pH is beneficial for agricultural water use.
- Electrical Conductivity (EC): The treated wastewater has an electrical conductivity (EC) of 1270 µS/cm, below the PSI limit of 1500 µS/cm, indicating moderate salinity. While the EC is within the acceptable range for irrigation, elevated salinity can affect soil and plant health. Long-term irrigation with this water requires monitoring for potential salt buildup in the soil.
- Total Suspended Solids (TSS): The TSS level of 17 mg/L is below the PSI limit of 30 mg/L, indicating that the treated wastewater is relatively free of suspended solids. High TSS concentrations can clog irrigation systems and harm plants. Since the TSS is within acceptable limits, the treated wastewater poses minimal risk to irrigation systems and crop health.

The expected cost of treated wastewater is about USD 0.3/m^3, while the cost of tap water is approximately USD 1.4/m^3. In Palestine, the pricing of both freshwater and reclaimed water is regulated by the Palestinian Water Authority (PWA) in alignment with national water policies. The relatively lower price of treated wastewater reflects the application of the "polluter pays" principle, whereby the cost of wastewater treatment is borne primarily by the polluters, including households and industries that generate sewage. Farmers and other end-users of reclaimed water are therefore required to cover only the costs associated with transporting the water from the treatment plant to their farms. This pricing structure is intended to incentivize the reuse of treated wastewater, reduce the burden on freshwater resources, and promote more sustainable agricultural practices.

3.2. Effect of TWW on the Growth Characteristics of Marigolds

Water quality may affect the growth characteristics of marigolds; therefore, we evaluated the effect of both treated waste- and tap water on different parameters.

3.2.1. Plant Height (PH)

Plant height was observed after the transpiration date at 5-day intervals as shown in Figure 2, where (DAT refers to Days After Transplanting, PH_WW refers to plant height at wastewater experimental setup, and PH_TW refers to tap water experimental setup). There were no significant differences between the two experimental setups in both vegetative growth and reproductive phase as marigolds grown with tap water matured at an average height of 20 cm on June 6; while the one irrigated by wastewater matured at an average height of 20 cm on the same day. These results agreed with the one reported by BBC Gardeners' World Magazine [40] which reported that the height of marigolds varies between 15 and 60 cm. On the other hand, Palei et al. [41] found the average length (12.1 cm). This confirms that plant height highly differs among species and cultivars.

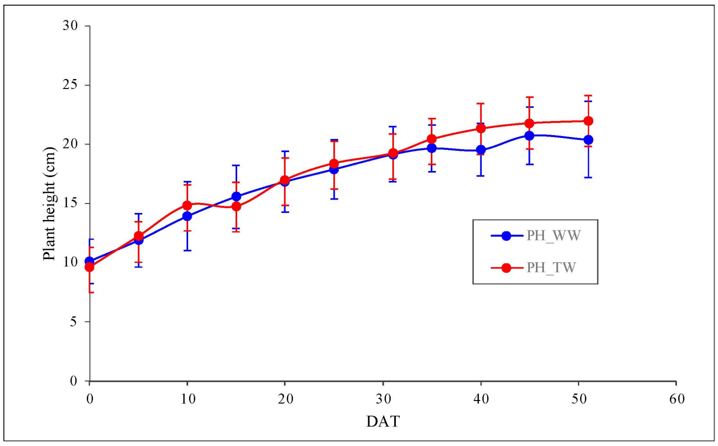


Figure 2. Observed marigold height over the growing period (error bars represent standard deviation (SD)).

3.2.2. Rose Number (RN)

The rose number was also observed at 5-day intervals for both experimental setups along the growing period as shown in Figure 3, where PH_WW refers to plant height at wastewater experimental setup, while PH_TW refers to tap water experimental setup. There were no significant differences between the two experimental setups for the total growing period. The rose numbers observed in the wastewater experimental setup were similar to the ones observed in the tap water experimental setup, except for 15 days and those after 45 days of transplanting. This may be due to more nutrients existing in the wastewater experimental setup which may have enhanced the growth number of roses. Another reason is that high winds occurred after 45 days of transplanting which caused more losses in the tap water experimental setup that has taller plants compared to the wastewater experimental setup.

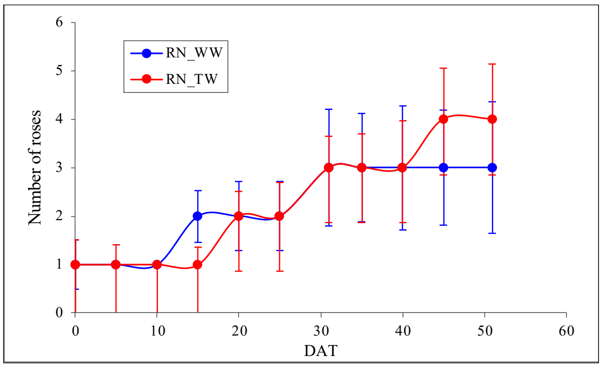


Figure 3. Observed marigold rose numbers over the growing period (error bars represent SD).

3.2.3. Rose Diameter (RD)

Rose diameter (RD) was monitored throughout the entire growing period, as illustrated in Figure 4. In this analysis, RD_WW refers to plants irrigated with treated wastewater, while RD_TW refers to those irrigated with tap water. The results indicate that there were no statistically significant differences between the two experimental setups, as the values of both groups were closely aligned along the 45° line, reflecting a consistent growth trend. Typically, the floral heads of *Tagetes erecta* range between 4 and 6 cm in diameter [42]. In our study, the mean rose diameter was 5.19 cm under both irrigation experimental setups, which falls within this expected range. This consistency suggests that treated wastewater irrigation does not adversely affect floral size, a critical parameter for marketability in ornamental plants.

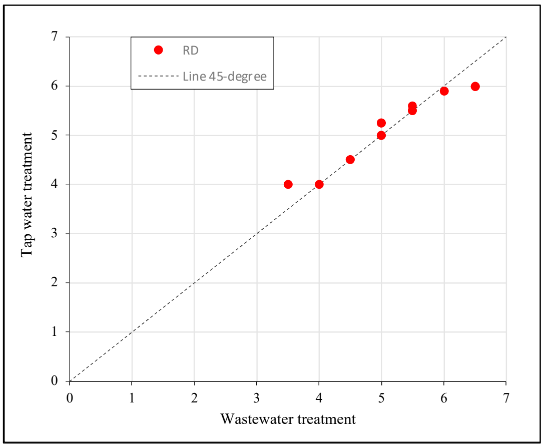


Figure 4. Observed rose diameter in marigold over the growing period.

The comparable performance under both experimental setups highlights the potential of treated wastewater as a sustainable alternative irrigation source, particularly in semi-arid regions where freshwater resources are scarce. Moreover, maintaining the flower diameter within the commercially acceptable range ensures that economic value is not compromised, thereby supporting both water conservation and livelihood resilience. These findings further reinforce the feasibility of integrating treated wastewater into floriculture practices without diminishing crop quality.

4. Conclusions

This study investigated the feasibility of using treated wastewater for the cultivation of marigold roses in a semi-arid climate in Palestine. Our findings demonstrate that the use of treated wastewater has made no significant difference in growth and yield of marigold roses compared to the control group that received only freshwater irrigation, indicating that treated wastewater can be a sustainable and viable water resource for irrigation in arid and semi-arid regions.

Moreover, our study highlights the importance of adopting wastewater reuse practices as a potential solution to the growing problem of water scarcity in many arid and semi-arid regions worldwide. The use of treated wastewater for irrigation can help reduce the pressure on freshwater resources and provide an alternative source of water for agriculture. This could have significant implications for sustainable agricultural practices and food security in regions with limited water resources.

While this study demonstrates the feasibility and potential benefits of using treated wastewater for the cultivation of *Tagetes erecta* in a semi-arid climate, it is clear that further research is required to provide a deeper understanding of its long-term implications. Such investigations should address changes in soil quality, plant growth and productivity, and the possible accumulation of heavy metals and pathogens that may pose risks to both human and environmental health. In addition, comprehensive risk assessments are needed to evaluate the broader sustainability of treated wastewater reuse, ensuring that it can be applied safely and effectively across different agricultural contexts. Extending this line of research to include other ornamental and crop species will also help to determine the wider applicability of treated wastewater irrigation in semi-arid regions.

Although the short-term results were promising, the possible long-term accumulation of salt in peat-based media and soil remains a concern when using treated wastewater for irrigation. The continuous monitoring of soil salinity and crop response is therefore essential to ensure the sustainability of this practice.

One limitation of this study is the absence of data on nutrient concentrations such as nitrogen and phosphorus in the treated wastewater. Monitoring these parameters would provide valuable information for developing a proper fertilization plan and optimizing nutrient management in floriculture. Future research should therefore include nutrient monitoring to better assess the agronomic potential and safety of treated wastewater reuse. Future studies should also include the microbiological analysis of secondary treatment effluents, as the presence of bacteria may indicate potential fecal contamination and associated health risks.

Future studies should also be designed to isolate and test the significance of key water quality parameters (COD, BOD_5, pH, EC, and TSS) by systematically varying their concentrations under controlled conditions. Such experiments would provide deeper insights into their individual and combined effects on plant growth, soil quality, and overall irrigation suitability.

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Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

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Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
DAT	Days After Transplanting
EC	Electrical Conductivity
GDP	Gross Domestic Product
pH	Acidity
PH	Plant Height
RN	Rose Number
TSS	Total Suspended Solids
TWW	Treated Wastewater

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