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ORIGINAL ARTICLE

Effects of Differently Treated Wastewater and Fertilizer on Some Quality Criteria for Strawberry (*Fragaria × ananassa* Duch, cv. 'Albion') Plants

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Abstract
The use of treated wastewater in agriculture will generate an alternative water source and alleviate some of the pressure on our waters; thus, treated wastewater has become a diminishing resource. In addition, plants can meet some of their nutritional needs from treated wastewater, which will help reduce fertilizer use. In our study, we investigated the effects of different wastewater treatment levels and fertilizer applications on the 'Albion' strawberry variety. This study was carried out in a climate chamber located at Bilecik Şeyh Edebali University's Biotechnology Application and Research Center, Turkey. The results obtained during the vegetation period under controlled conditions revealed that the application of particular amounts of treated wastewater boosted plant growth. In particular, treated wastewater applied as irrigation water at a certain rate increased characteristics such as leaf area, fruit weight, fruit width and fruit length. Research has shown that the macro and microelement contents of plants respond favorably to a particular level of treated wastewater. In addition, the chlorophyll levels measured before and after each irrigation event were the highest among the subjects that were irrigated with 30% treated wastewater. Since this increase in chlorophyll content will promote plant nutrition, treated wastewater will have positive effects on yield and quality.

Keywords Reclaimed wastewater · Strawberry · Fertigation · Alternative water source · Micro element

Introduction

Strawberry is a fruit that people enjoy eating because of its flavor, color, and appearance, as well as its antioxidant and health-promoting features. The pastry, cosmetic, and food sectors all feature this fruit prominently. In this regard, it is one of the most important fruit species, with growing demand and thus production in recent years. With increasing demand, strawberry cultivation now covers approximately 396 thousand hectares worldwide (FAOSTAT 2023). Turkey is a prominent strawberry producer country, following China and the United States.

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Irrigation strawberries is essential for fruit quality and yield, especially at flowering and fruit-ripening (Mozafari et al. 2018). Strawberry plant growth decreases greatly as a result of drought stress, which decreases plant biomass and crop production (Adak et al. 2018). In case of water constraints, yield and quality are critical environmental factors (Lozano et al. 2016). Drought is an important environmental stress that limits strawberry production worldwide and affects enzymatic and physiological activities as well as morphology. Especially in areas where water resources are scarce and threatened, the use of large amounts of water in garden planting and these areas is a concern. The potential health advantages of eating the fruits of plants with succulent fruit structures, particularly strawberries cultivated under poor conditions, will be minimal. Thus, other irrigation sources must be identified. The most pressing issue confronting society today is not a lack of water to fulfill the world's growing demands but rather fundamentally changing the way water is used, managed, and exploited. This situation can be met by wastewater, which is a water source available all year. Indeed, wastewater has the potential to be a viable source of water to meet the increasing global water demand.

Weather and temperature are also negatively impacted by quickly shifting climatic conditions. With a rising population, this condition leads to an increase in fresh water demand and consumption (Darwall et al. 2018). Furthermore, drought is expected to worsen progressively as temperatures rise and precipitation decreases. By 2050, water scarcity is expected to affect 40% of the world's population (Bakari et al. 2022). Because of the growing need for fresh water, the use of treated wastewater (TWW) in agriculture is regarded as a viable option (Uzen et al. 2016). There are numerous advantages to using treated wastewater. This will lessen both the low cost and the water constraints of irrigating plants with wastewater. This approach will also save money on energy (Dawson and Hilton 2011). Because of increased competition between the agricultural and industrial sectors and the economic value of high-quality clean water supplies for urban and industrial use, wastewater has become a low-cost and dependable alternative water source (Cakmakci et al. 2016).

The planned use of treated wastewater is particularly common in dry and semiarid regions of high-income countries such as the United States, Australia, and countries in Southern Europe. The bulk of the recovered wastewater in the United States is reused for agricultural and landscaping applications, with California (46%) and Florida (44%) accounting for the majority of wastewater reuse for agricultural irrigation. In California, treated wastewater is used to grow approximately 20 different types of crops, including raw vegetables, grains, berries, and nonfood goods (Hamilton et al. 2007).

Along with these studies, it was discovered that compared with different wastewater concentration treatments, treated wastewater applications boost plant growth (Gatta et al. 2015) and increase vegetable growth due to their enrichment in organic matter as well as macro- and micronutrients in wastewater (Khan et al. 2011). It was also shown that the wastewater concentration utilized for irrigation had a substantial impact on leaf length, leaf number, and fresh leaf weight, which ranged from fresh water to 100% wastewater treatment (Parveen et al. 2015). Another significant aspect to note is that in wastewater applications, increased fruit weight and size can increase the possibility of marketing recovered wastewater with early maturation. Furthermore, decreased hardness values in fruits treated with recycled wastewater compared to fresh water may result in fruit tree ripening earlier in the first year (Vivaldi et al. 2017).

This study will present a viable solution to challenges such as the use of treated wastewater for irrigation and the scarcity of water in desert places. In these experiments, investigations to establish the effectiveness of using treated wastewater for plant irrigation have largely focused on field crops and vegetable species, with few studies evaluating the performance of wastewater irrigation in fruits. The reuse of wastewater in agriculture is an essential problem that has yet to be thoroughly investigated. The yield, quality features, macro- and macronutrients and soil content of treated wastewater from the 'Albion' strawberry cultivar were determined in this study.

Materials and Methods

This study was carried out for 6 months under controlled conditions in a Digitech PG34-3 climate chamber located in Bilecik Şeyh Edebali University's Biotechnology Application and Research Center, Turkey. The aim of this study was to determine the effects of different rates of treated wastewater and fertilizer application on the yield and quality characteristics of the 'Albion' strawberry variety. 'Albion' strawberry seedlings were selected from a breeding program at the University of California in 1999 ('Diamante' × 'Cal 94.16-1') 'Albion' is a neutral day variety with typical long, conical and highly symmetrical fruits (Shaw and Larson 2006). The temperature of the climate cabinet used in the study was set to 24 °C for 18 h during the day and 18 °C for 6 h at night.

The study was planned according to a split-plot experimental design with three replications and 10 pots in each replication. The growing media for the study were made of a soil: peat combination at a 3:1 ratio and placed into 3-l plastic growing pots, and each pot's soil:peat mixture weighed an equivalent of 4 kg.

In this study, fertilizer was applied to the main plots, and diluted treated wastewater was applied to the subplots (Table 1). Two different fertilizer treatments were used: One group of pots received fertilizer, while the other group received no fertilizer. The treated wastewater was additionally diluted at four different rates, as shown in Table 2.

The treated wastewater used in the study was taken from Bilecik Şeyh Edebali University's wastewater treatment plant. The analysis results for the wastewater samples are given in Table 3.

Before the study started, each pot was brought to the pot capacity. To do this, the pot containing the growing medium was first completely saturated in water and left to stand for 48 h. Then, the current humidity of the pot was measured, and the pot capacity humidity was determined. After the pot capacity was determined, all other pots were brought to this ratio by adding water. Before each irrigation event, the soil moisture was measured, and the necessary water was provided to the plants to increase their pot capacity. A PCE-SMM1 portable hand-held soil moisture meter was used to determine the soil moisture in the pots. Before beginning the application, the plants were adjusted and grown for one

Table 1 Experimental plan

First plot	Second plot
Control + fertilization	Control
30% TWW + fertilization	30% TWW
60% TWW + fertilization	60% TWW
100% TWW + fertilization	100% TWW

TWW Treated wastewater

Table 2 Treated wastewater (TWW) levels forming the sub-plots

Control	100% Normal irrigation water
TWW30	30% Treated wastewater + 70% normal irrigation water
TWW60	60% Treated wastewater + 40% normal irrigation water
TWW100	100% Treated wastewater

month after planting. The pots in Block 1 were fertilized in accordance with the needs of the plants and the soil.

The water requirements of the pots for each irrigation treatment were determined using Eqs. 1 and 2.

$$dn = \frac{(P.C - M.N) \times \gamma t \times D}{100} \quad (1)$$

$$I = dn \times A \quad (2)$$

Similarly, *dn* is the amount of irrigation water to be applied for each irrigation (mm), *P.C* is the pot capacity, *M.N* is the existing moisture in the soil before irrigation, γt is the potting soil bulk weight, D is the effective root depth (mm), I is the amount of water to be applied in each irrigation (m^3), and A is the pot area (m^2).

Since the study was conducted under controlled conditions, the necessary measurements were taken within a period of vegetation, the first harvest period was completed, and the study was terminated. Morphological and physiological parameters were obtained as a result of the study. The study's observations and measurements included plant height, leaf area, fruit weight, fruit length, fruit width, fruit stem length, plant wet and dry weight, root wet and dry weight, root length (cm), chlorophyll content, macro- and micronutrients, and soil content.

These measurements of strawberries were subjected to analysis of variance (ANOVA) using Minitab 19 software (Anonymous 1995). The significance of treated wastewater and fertigation application was determined using the F test. When the F test was significant, Tukey's test ($P < 0.05$) was used to compare group means of treated wastewater and fertigation treatments and their interactions.

Results and Discussion

The analysis of the effects of the application of treated wastewater and diluted fertilizer on the 'Albion' strawberry variety revealed that the interaction effects of fertilizer, irrigation, and fertilizer irrigation were significant at the $P <$ 0.01 level for all analyzed characteristics except root dry weight. The effects of treated wastewater dosage and fertilizer application on plant height are shown in Table 4. The average plant height at which fertilizer was applied was examined, and it was found that fertilizer application (11.82 cm) produced better results. The greatest plant height was 14.47 cm in the control treatment, and the lowest plant height was 8.43 cm in the TWW100 treatment without fertilizer. When the average treated wastewater level was examined, it was discovered that the greatest change in terms of the height of the wastewater-reducing plant occurred in the control treatment (12.07 cm). Dagianta et al. (2014) reported that plants irrigated with regular irrigation water grew taller than plants irrigated with treated wastewater, whereas Ines et al. (2017) reported that plants irrigated with wastewater grew shorter than plants irrigated with recycled wastewater.

The leaf area ranged between 29.68 and 39.91 cm^2 (Table 1). The fertilization + TWW60 interaction had the greatest effect on leaf area, while the no fertilization × TWW30 interaction had the least effect. We discovered that fertilized plants had the greatest average leaf area (38.02 $cm^{2)}$ and that TWW60 plants had the greatest average leaf area (38.09 $cm^{2)}$ when we independently evaluated the applications. As a result, the issue of fertilizer application arose, and it was discovered that applying treated wastewater increased the leaf area index. Asgari et al. (2007) reported that when corn plants were irrigated with wastewater, the leaf area index increased. In this case, wastewater is thought to be useful not only as irrigation water but also as a liquid fertilizer and a substance capable of improving soil physical properties (Khan et al. 2008).

The impacts of wastewater treatment dosage and fertilizer application on fruit attributes are shown in Table 5. The fruit weights ranged from 4.95 g (no fertilization ×

Table 3 Analysis result of treated waste water

Parameters	Analysis method	Analysis result	Limit value
pH	SM 4500H$^+$B	7.28	6–9
Suspended solid matter	SM2540-D	53.350 mg/l	60
Chemical oxygen demand	SM5220 B	52.437 mg/l	160
Biochemical oxygen demand	SM 5210 D	21 mg/l	50

Table 4 Plant height and leaf area are affected by treated wastewater (TWW) and fertilizer applications

Plant height (cm)**					
Fertilization	*Levels of treated wastewater*				*Average***
	Control	*TWW30*	*TWW60*	*TWW100*	
Fertilized	14.47 a	10.68 c	11.86 b	10.29 cd	11.82 a
No fertilization	9.66 de	9.07 ef	8.67 f	8.43 f	8.96 b
Average**	12.07 a	9.88 bc	10.26 b	9.36 c	–
Leaf area (cm^2)*					
Fertilization	*Levels of treated wastewater*				*Average***
	Control	*TWW30*	*TWW60*	*TWW100*	
Fertilized	37.84 ab	35.09 b	39.91 a	39.24 a	38.02 a
No fertilization	30.06 c	29.68 c	36.28 ab	35.55 b	32.89 b
Average**	33.95 b	32.39 b	38.09 a	37.40 a	–

*Significant at the $P < 0.05$
**Significant at the $P < 0.01$

Table 5 Fruit weight, width, height, and stem length as a result of treated wastewater (TWW) and fertilizer applications

Fruit weight (g)**					
Fertilization	*Levels of treated wastewater*				*Average***
	Control	*TWW30*	*TWW60*	*TWW100*	
Fertilized	6.54 bc	7.61 a	5.99 cd	6.98 ab	6.78 a
No fertilization	6.70 bc	6.11 cd	5.76 d	4.95 e	5.88 b
Average**	6.62 a	6.86 a	5.87 b	5.96 b	–
Fruit width (mm)**					
Fertilization	*Levels of treated wastewater*				*Average***
	Control	*TWW30*	*TWW60*	*TWW100*	
Fertilized	21.68 b	24.36 a	21.47 bc	21.21 bc	22.18 a
No fertilization	20.63 cd	21.41 bc	20.63 cd	19.81 d	20.62 b
Average**	21.15 b	22.88 a	21.05 bc	20.51 c	–
Fruit height (cm)**					
Fertilization	*Levels of treated wastewater*				*Average***
	Control	*TWW30*	*TWW60*	*TWW100*	
Fertilized	26.71 b	28.56 a	24.38 c	24.73 c	26.10 a
No fertilization	25.50 c	25.39 c	21.16 d	24.50 c	24.14 b
Average**	26.10 d	26.98 a	22.77 d	24.61 c	–
Fruit stem length (cm)**					
Fertilization	*Levels of treated wastewater*				*Average***
	Control	*TWW30*	*TWW60*	*TWW100*	
Fertilized	44.93 b	43.30 c	42.60 c	39.56 d	42.62 b
No fertilization	42.75 c	43.64 c	50.16 a	45.36 b	45.48 a
Average**	43.84 b	43.47 b	46.38 a	42.46 c	–

*Significant at the $P < 0.05$
**Significant at the $P < 0.01$

TWW100) to 7.61 g (fertilized TWW30). When the treated wastewater levels were analyzed, it was discovered that the treated wastewater increased by 30%. Furthermore, when fertilizer application was examined, it was discovered that fertilizer application increased fruit weight when the fruit was grown without fertilizer. According to one study on tomato fruits, the weight of fruits obtained from wastewater-irrigated plants was greater than the weight of fruits obtained from regular irrigation water-irrigated plants (Al-Lahham et al. 2003). A similar study revealed that treated wastewater increased the weight of fruits of cauliflower and cabbage plants (Kiziloglu et al. 2008).

According to the analysis of average fruit length and fruit width, the highest values were reached at 30% purified wastewater and fertilizer application. The maximum fruit width and length values were obtained for the 30% treated wastewater level and fertilizer applications, according to average data. The fertilized × TWW30 interaction produced

Table 6 Effects of treated wastewater (TWW) and fertilizer applications on fresh, dry, and root fresh and dry weights of plants

Plant fresh weight (g)**					
Fertilization	*Levels of treated wastewater*				*Average***
	Control	*TWW30*	*TWW60*	*TWW100*	
Fertilized	103.33 b	97.00 b	115.00 a	103.00 b	104.58 a
No fertilization	39.33 e	51.66 d	58.33 d	78.00 c	56.83 b
Average**	71.33 b	74.33 b	86.67 a	90.50 a	–
Plant dry weight (g)**					
Fertilization	*Levels of treated wastewater*				*Average***
	Control	*TWW30*	*TWW60*	*TWW100*	
Fertilized	28.22 ab	25.92 bc	30.67 a	29.87	28.67 a
No fertilization	13.38 e	14.40 e	18.65 d	23.95 c	17.59 b
Average**	20.80 b	20.16 b	24.66 a	26.91 a	–
Root fresh weight (g)**					
Fertilization	*Levels of treated wastewater*				*Average***
	Control	*TWW30*	*TWW60*	*TWW100*	
Fertilized	35.66 e	43.33 d	61.67 c	83.00 a	55.91 b
No fertilization	48.33 d	60.33 c	78.33 a	70.33 b	64.33 a
Average**	42.00 d	51.83 c	70.00 b	76.66 a	–
Root dry weight (g)**					
Fertilization	*Levels of treated wastewater*				*Average^{ns}*
	Control	*TWW30*	*TWW60*	*TWW100*	
Fertilized	8.55 d	14.19 abc	13.32 c	16.59 ab	13.16 a
No fertilization	10.31 d	8.33 d	13.84 bc	16.92 a	12.35 a
Average**	9.43 d	11.26 c	13.89 b	16.76 a	–

ns Not significant
*Significant at the $P<0.05$
**Significant at the $P<0.01$

fruits with widths and lengths of 24.36 and 28.56 mm, respectively. The interactions no fertilization × TWW100 and no fertilization × TWW60 produced the smallest fruit width and length values of 19.81 and 21.16 mm, respectively. The width of the fruit stems ranged from 39.56 to 50.16 mm when measured. The fertilized × TWW60 interaction had the highest value, while the fertilized × TWW100 interaction had the lowest. This demonstrates that treated wastewater has a stimulating effect up to a certain concentration. During the independent evaluation of the applications, it was observed that the treatment of wastewater and subsequent application of fertilizer resulted in significant improvements, with a notable increase of 30%.

According to Gatta et al. (2016), irrigation treatments (secondary and tertiary wastewater) had a substantial impact on two morphological features of artichoke heads (length and diameter). Vergine et al. (2017) discovered that using treated municipal wastewater for irrigation resulted in a better marketable yield of lettuce and fennel plants compared to freshwater irrigation. According to Elfanssi et al. (2018), the use of wastewater in agricultural practices increases soil fertility, positively influencing fruit growth and development.

Table 6 shows the fresh, dry, and root fresh and dry weights of plants as a result of different wastewater treatment levels and fertilizer treatments. The table clearly shows that treated wastewater and fertilization are advantageous. The lowest plant wet weight was 39.33 g in the no fertilization × control interaction, and the highest plant wet weight was 115 g in the fertilization × TWW60 interaction. When the plant dry weights were examined, the control × no fertilization interaction had the lowest value of 13.38 g, while the fertilization × TWW60 interaction had the highest value of 30.67 g. Similarly, Dagianta et al. (2014) reported that fertilizing pepper plants with wastewater lowered the biomass dry matter content. Furthermore, Anwar et al. (2016) discovered that when mint, coriander, and fenugreek were watered with wastewater, the biomass of mint, coriander, and fenugreek was significantly affected, with mint, coriander, and fenugreek exhibiting the greatest decrease in fresh and dry biomass compared to that of the controls. In a study on barley plants, Rusan et al. (2007) reported that plants irrigated with wastewater had relatively high fresh and dry weights.

Compared with the control (60% treated wastewater and no fertilizer), the application of 100% treated wastewater and fertilizer (83 g) had the greatest effect on root fresh

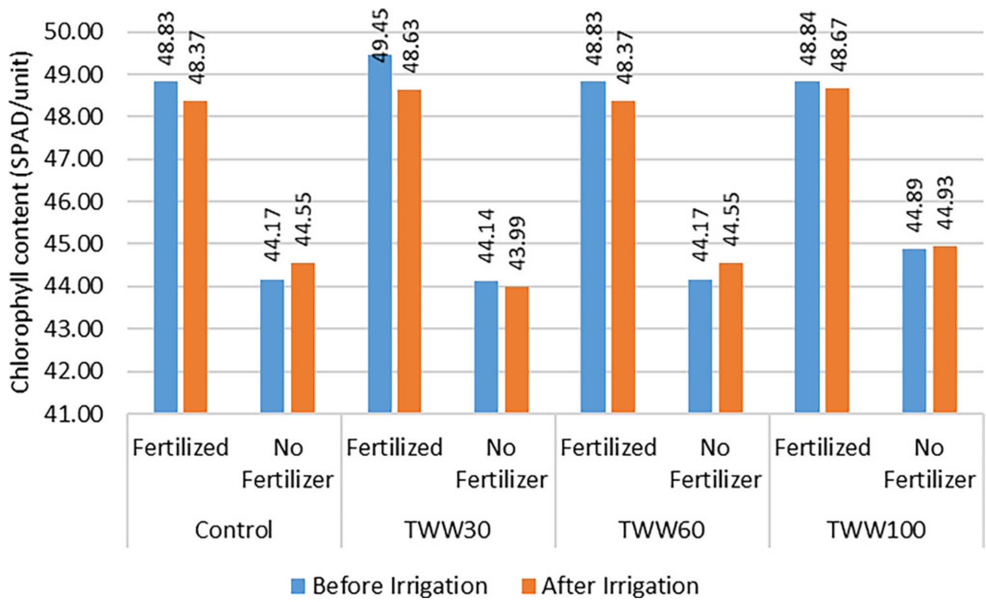

Fig. 1 Effect of treated wastewater (*TWW*) and fertilizer applications on chlorophyll contents in leaves

weight (78.33 g). The control without treated wastewater and the application of fertilizer had the lowest fresh root weight, 35.66 g. The unfertilized subject with the greatest root dry weight, 16.92%, received 100% treated wastewater, while the subject with the lowest value, 8.33 g, received 30% treated wastewater and no fertilizer. Upon conducting independent evaluations of the applications, it was observed that the subjects that received no fertilizer and were exposed to 100% treated wastewater had the highest values for medium root fresh weight. When the average values of root dry weight were examined, the best results were obtained from 100% treated wastewater, while fertilizer application did not have a statistically significant effect.

The statistical analysis revealed a substantial impact of the variables, including the timing of chlorophyll measurement, application of treated wastewater, fertilization, and the combination of treated wastewater and fertilization, on the chlorophyll content (SPAD) in the leaves (Fig. 1). The subjects that received 100% treated wastewater, both before and after irrigation, and had fertilizer added exhibited the highest chlorophyll content among the various applications of treated wastewater. This was followed by the subject that received fertilizer with 30% treated wastewater. The fertilizer-free application, comprising 60% wastewater, had the lowest chlorophyll content. In our study, we did not find a significant increase in chlorophyll, except for in the presence of 100 and 30% wastewater and fertilizer. An inadequate nitrogen content may cause a decline in leaf chlorophyll content and photosynthesis. As a result, increased chlorophyll content was detected in plants that were fertilized and irrigated with treated wastewater. Similarly, Abdallh and Sahin (2020) reported that a high N concentration in wastewater improves the soil N content, particularly in high-dose treated wastewater applications (Yang et al., 2014). According to Erdal et al. (2014), there is a close link between plant nutrition and chlorophyll levels. The findings of this study revealed that certain levels of purified water enhanced the amount of chlorophyll. The observed increase in chlorophyll content suggested a potential increase in plant nutrition, which in turn may have led to an increase in yield and improvements in some quality attributes.

The results of the fruit analyses revealed that the effects of irrigation, fertilization, and their combinations on macronutrients and heavy metals are significant. When we examined the nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur in the fruit, we found that they all had comparable results (Fig. 2). Higher values were obtained from subjects to which fertilizer was applied than from subjects to which fertilizer was not applied. When we evaluated the subjects on which fertilizer was applied, the highest results in terms of control of all macroelements were obtained, and as the treated wastewater levels increased, declines in element contents were noted. The reverse situation was found for the subjects for which no fertilizer was applied. While the lowest values were often reached in terms of the control, the application of treated wastewater caused a rise in the macroelement contents to a certain level, followed by a reduction. These findings indicate that in circumstances where fertilizer input is limited, the plant's macroelement needs can be met with a specific level of treated wastewater. This demonstrates that when the plant's fertilizer demands are met, the extra nutrients delivered to the soil by treated wastewater cannot be absorbed by the plant and even have a negative impact on nutrient uptake in the plant.

When we examined the impacts of treated wastewater, fertilization, and their interactions on microelements, we

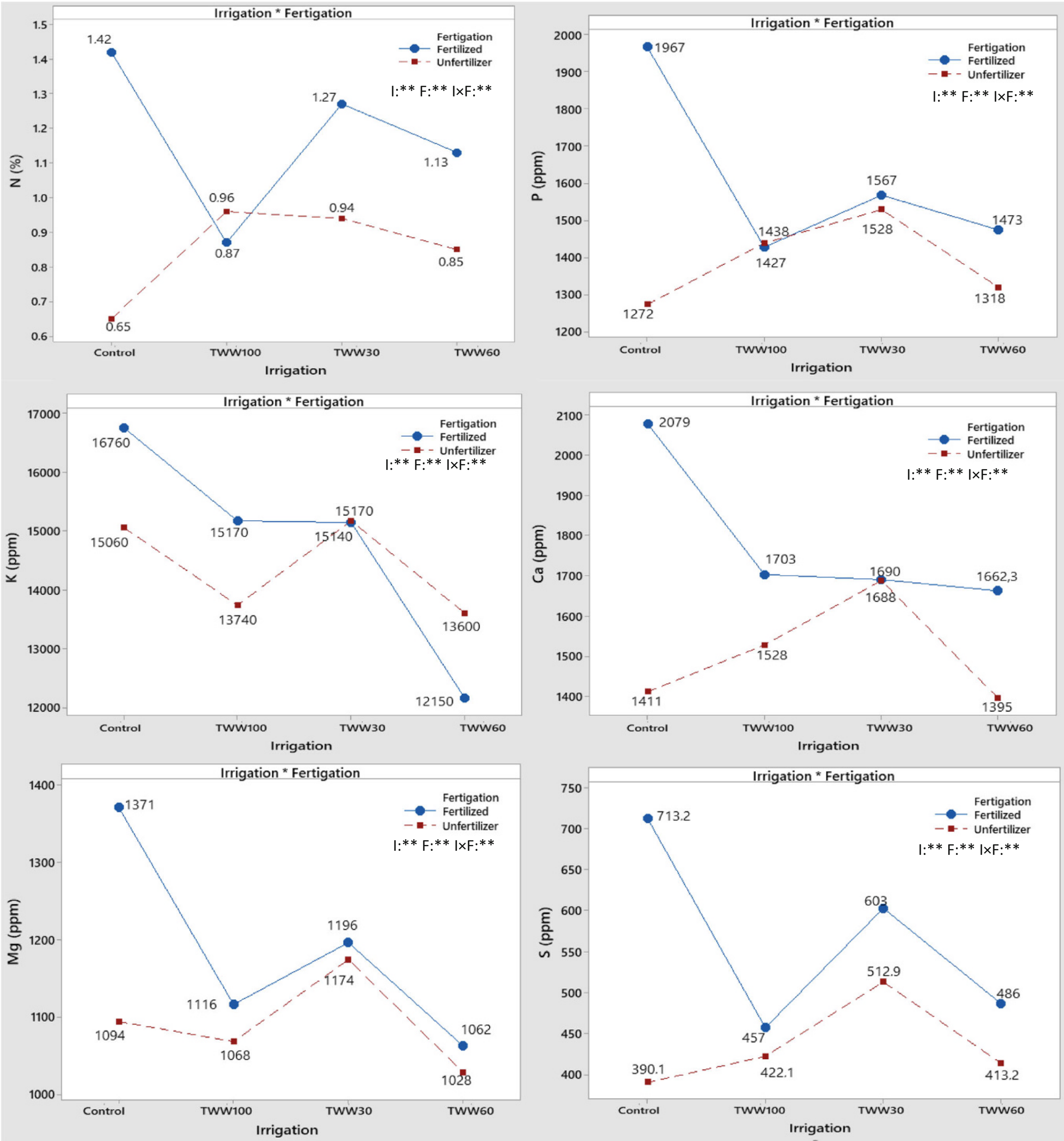

Fig. 2 Effect of treated wastewater (*TWW*) and fertilizer applications on macro nutrients contents. *Significant at the $P<0.05$, **Significant at the $P<0.01$, *ns* not significant

discovered statistically significant changes. The levels of the microelements iron, zinc, manganese, nickel, selenium, and copper found in the fruit were greater in subjects that received fertilizer than in those that did not (Fig. 3). Other microelements, such as selenium and nickel, performed better in the control irrigation group than in the control group when we evaluated which fertilizer was administered. While the 100% treated wastewater subject yielded the greatest amount of nickel, the 60% treated wastewater subject yielded the greatest amount of selenium. Compared to those in the control group, the quantities of micronutrients in the group in which no fertilizer was applied were greater in the group in which treated wastewater was applied. TWW 100 had the highest Mg content, TWW 60

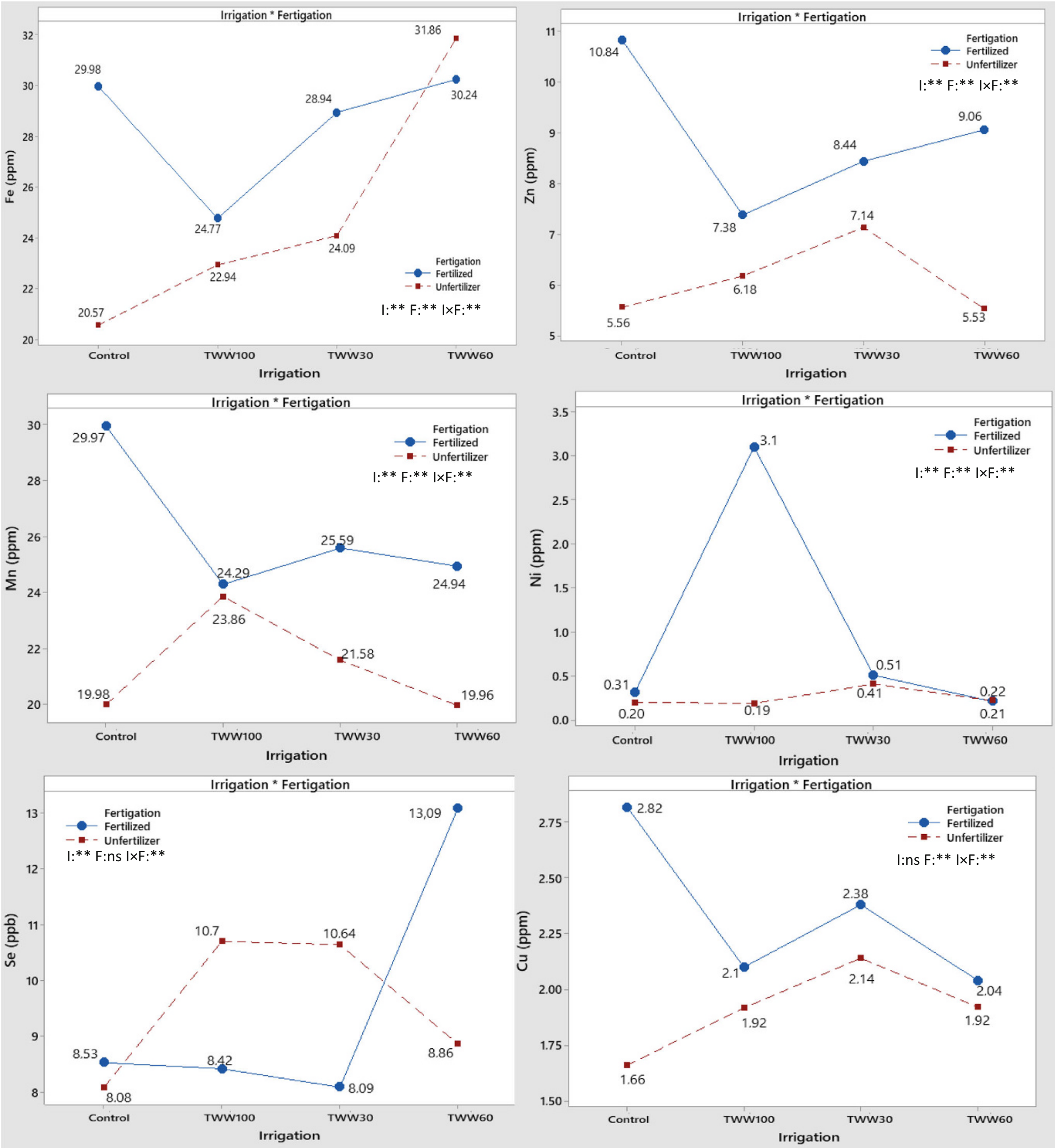

Fig. 3 Effect of treated wastewater (*TWW*) and fertilizer applications on micronutrient contents. *Significant at the $P<0.05$, **Significant at the $P<0.01$, *ns* not significant

had the highest Fe and Se contents, and TWW 30 had the highest ZN, Ni, and Cu contents. The results revealed that in the absence of fertilizer, the application of processed wastewater can meet plant nutrient requirements. In cases where fertilizer is applied, it has been shown that the entry of nutrients into the soil along with treated wastewater has a negative effect on the fruit and that the fruit cannot benefit from this excess nutritional element in the soil. Previous experiments reported similar findings, and researchers have claimed that treated wastewater increases the amount of nutrients in plants. Bakari et al. (2022) evaluated the effects of different wastewater treatment levels on strawberry

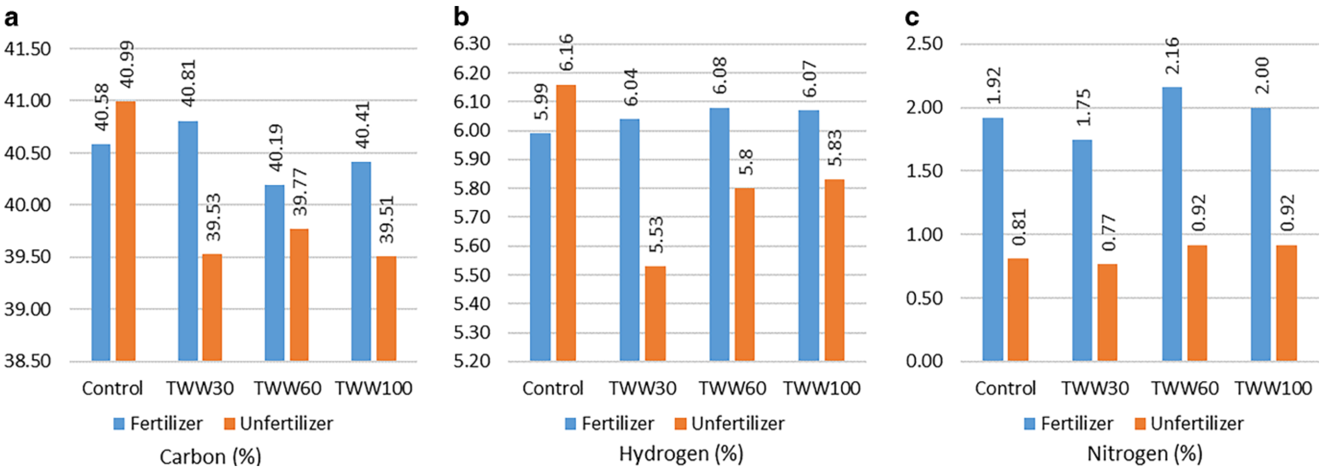

Fig. 4 Effect of treated wastewater (*TWW*) and fertilizer applications on soil carbon, hydrogen, and nitrogen contents

plants and reported that 20% of treated wastewater had the highest Fe, Mn, Zn, Cr, Cu, and Ni concentrations. Christou et al. (2016) evaluated the impact of waste and clean water on strawberry plants using various irrigation strategies. According to the findings of the study, the Cu, Zn, Mn, Co, and Ni concentrations were greater in plants irrigated with treated wastewater, regardless of the method. Cakmakci and Sahin (2021) explored the effects of limited treated wastewater on corn plants. They discovered that the N, P, K, Ca, Mg, B, and Fe levels in treated wastewater increased by 28 to 12% compared to those in clean water, as did the contents of various micro- and heavy metals. Galavi et al. (2010) reported that using treated wastewater to irrigate sorghum plants increased the plant's Fe, Cu, Zn, and Mn contents. According to Qureshi et al. (2016), heavy metal accumulation in turnip, radish, and carrot plants as a result of irrigation with treated wastewater was in the following order: Fe > Mn > Zn > Cu. In their investigation of different crops irrigated with treated wastewater, (Shamsul et al. 2021) found that treated wastewater had a positive effect on the nutrient contents of soil and vegetables.

The analysis of the soil samples taken after the trial was completed revealed that the treated wastewater affected the carbon, hydrogen, and nitrogen levels in the soil (Fig. 4). The control group with no fertilizer applied had the greatest carbon and hydrogen levels. When we evaluated the subjects where fertilizer was administered, we observed an increase in carbon and hydrogen levels in the treated effluent. The TWW30 subject had the greatest carbon rate (40.81%), whereas the TWW60 subject had the highest hydrogen level (6.08%). When we examined the nitrogen levels in the soil, we found that there was more nitrogen in the areas where fertilizer was sprayed. When the subjects to which fertilizer was administered were analyzed individually, the nitrogen content of the soil increased with the application of treated wastewater, with the TWW60 (2.16) subject having the highest nitrogen rate. As the nitrogen content of the soil increased, the nitrogen content of the fruit did not increase linearly and instead decreased. This demonstrates that when the soil nitrogen content increases, plant nitrogen uptake decreases. When the nitrogen content of the soil was examined in subjects where no fertilizer was applied, the nitrogen content rose with the treated wastewater, with the TWW60 and TWW100 (0.92) subjects having the highest values.

Conclusion

The agricultural sector is known as the area where water is used most in the world. Instead of using up precious freshwater supplies, recycled water can be used effectively. Because of the nutrients it contains, the use of treated wastewater is both an alternative water source and contributes to soil and crop productivity by reducing the need for inorganic fertilizer. To prevent soil and groundwater pollution, it is recommended that treated wastewater be diluted and that the products used be pretested. This study has been aimed at determining the effects of treated wastewater applications and fertilizer applied at different rates on the growth of 'Albion' strawberry plants. The study revealed that the greatest leaf area was obtained at 100% treated wastewater concentration with fertilizer application, and the greatest fruit weight, width, and length were obtained at 30% concentration. The plant fresh and dry weights increased up to 60%, while the root fresh and dry weights increased up to 100%. It has also been discovered that diluting treated wastewater at a certain rate increases the chlorophyll content. At the same time, the use of treated wastewater at certain levels positively affected the amount of nitrogen in the soil and the macro- and microelement contents in the plant. The increased use of treated wastewater in agriculture should be encouraged because the increased chlorophyll content benefits plant nutrition. This demonstrates that treated wastewater can stimulate strawberry plants to a certain extent, and future research should address this issue.

Conflict of interest S. Öztürk Erdem, K. Merve, K. Murat and G. Hüseyin Tevfik declare that they have no competing interests.

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