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Effect of treated wastewater on strawberry

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ABSTRACT

Algeria is facing a problem of water scarcity which has been increasing for decades and which is likely to worsen as a result of the global warming phenomenon. As well as, the precipitation is insufficient and irregular in time and space. Therefore, the recycling and the use of treated wastewater (TW) in irrigation is a necessity in order to protect and preserve our surface and underground water resources. However, the assessment of the effects of the reuse of TW in irrigation on the different components of crops and the agricultural environment, as well as an optimization of this reuse of TW, are only at their beginning in Algeria. In this perspective, we conducted a comparative study on a strawberry crop (Camarosa variety) irrigated with TW and conventional water (CW), at the experimental station of the Superior National Agronomic School of Algiers (ENSA-El-Harrach Alger). The results show that the effect of the waters on the crown diameter, the plants' heights, the number of fully developed leaves and the chlorophyll content were not significant, but there are statistically, very highly significant differences between fruit production of the plants depending on the irrigation water quality. In order to avoid eventual risks, the use of TW requires regular monitoring and the reuse standards must be respected.

Keywords: Algeria; Treated wastewater; Irrigation; Strawberry crop; Conventional water; Fruit production

1. Introduction

In Algeria, surface and groundwater resources are irregular and unequally distributed. They are distributed in fossil waters (the Continental Intercalaire and Terminal Complex aquifers) of the Sahara, and in renewable natural water resources (superficial and underground) located mainly in the country north [1]. Algeria is among the poorest countries in terms of water potential. The theoretical threshold of scarcity set by the World Bank is 1,000 m^3/hab/year, it will be only 430 m^3/hab/year in 2020 [2]. The global demand for water increase quickly and greatly. Strong competition develops between the great consumers (fresh water

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distribution, industry, agriculture), in addition to the imbalances in the availability of resources between regions, and making it increasingly difficult to arbitrate distribution [1]. Predictions, following the phenomenon of global warming, indicate a water shortage and an increasing degradation of conventional water resources.

In these chronic deficit conditions, water management becomes one of the main challenges of sustainable development in agriculture and exploitation of unconventional water resources (brackish water, desalinated seawater, treated wastewater [TW]), a priority axis to develop. For that reason, the reuse of TW appears to be a necessary alternative resource for preserving the conventional water resources, of the environment and promotion of the agricultural sector [3]. As well as, the wastewater treatment and its use in irrigation is an attractive option because it represents a source of water and additional renewable fertilizers [4].

Algeria has currently 800 million m^3 of wastewater where only part of it is treated before being discharged into the sea and will have 1.5 billion m^3 by 2020 [5]. This deposit is inexhaustible and renewable. In this regard, Algeria can no longer afford to turn its back to the possibility of reusing the huge amounts of wastewater discharged into nature or the sea [6].Over 1 million ha of irrigated land barely, about 10,000 ha (1% of irrigated land), they are irrigated by TW (3.4 Hm^3/year) since only 2–3 years [7]. This shows the lack of interest previously given to this resource (TW).

The effects and impacts of the use of TW are not well controlled in our context. We led for the purpose the tests on strawberry (Camarosa variety) irrigated in a tunnel greenhouse by the conventional waters (CW) and the treated wastewater (TW), from the WWTP of Corso, (Boumerdes). These tests were carried out at the experimental station of the Superior National Agronomic School of Algiers (ENSA-El-Harrach Alger) during the academic year 2016/2017.

The study aims at assessing the effects of the reuse of TW on the strawberry growth and its yield.

2. Materials and methods

2.1. Material

The experimentation has been accomplished at the experimental site of the National Superior Agronomic School during the academic year 2016/2017. This station is characterized by a Mediterranean climate with dry warm summers and humid soft winters and an average annual precipitation amount of 640 mm.

The device that we have been put in place contains pots in a greenhouse, placed on a plastic film without contact with the floor of the greenhouse, containing the strawberry plants (Camarosa variety) in rework soil, calcimagnesic type.

The greenhouse is a tunnel type (240 m^2), the irrigation localized through perforated flexible sheaths (40 cm spacing between holes), debiting 1 L/h, using two different water sources (treated wastewater from the WWTP of Corso and the school drilling water).

The experimental device set up is of type total randomization to a single factor of variation (water quality) and one repetition in time (one vegetative cycle; Fig. 1).

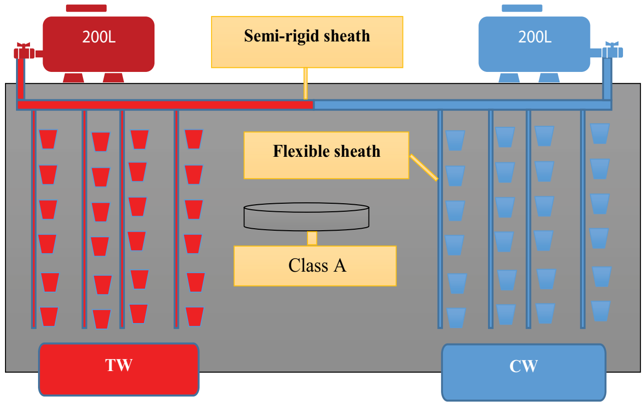

Fig. 1. Adopted experimental protocol.

2.2. Methods

2.2.1. Procedures for strawberry (plant and fruit evaluation)

The objective is to compare the development of strawberry plants that are irrigated with TW and the ones that are irrigated with CW through the regular measurement and the monitoring of the morphological and agronomic parameters throughout the plant cycle.

Data collection (nondestructive analysis) on all the plants, every 20 d starting from planting time (included) or as differently indicate in each parameter, such as: crown diameter (which is measured using calipers on the living plant without removing it from the soil in mm), the plant height (which represents the tallest part and is measured using a ruler in cm), the number of the leaves that are fully developed and the chlorophyll content (which is measured using a SPAD meter on two selected leaves from each plant).

Morphological and physical parameters of fruits: data collection on 30 fruits or more for each treatment during the production period.

We select primary or secondary fruits in order to determine: The fruit fresh weight (g), the fruit dry weight (g), the dry matter rate and dry matter of the fruit (%) as well as, one determines, total fruit production per plant and the fruits dimensions (length and width cm, using calipers).

2.2.2. Statistical analysis

The obtained results were the subject of a statistical analysis (JMP-8 software), with a significance threshold of $\alpha = 0.05$, based on one variation factor (irrigation water quality) according to a device by total randomization.

3. Results and discussion

3.1. Soil analysis evaluation

The silt percentage is superior to 65%, the soil is silty, with a slaking index that is superior to 2. Its electrical conductivity is that of class 1, which results in unsaline soil [8]. The pH is neutral. Cationic exchange capacity (CEC) is relatively high. The soil is averagely rich in organic matter (OM) [9] (Table 1).

Table 1
Soil physico-chemical analysis

Physico-chemical analysis		Values
pH		7.18
Electrical conductivity (ds/m)		0.38
Total limestone ($CaCO_3$) (%)		2.15
Adsorbent complex	Na^+	2.6
(meq/100 g)	K^+	0.49
	Ca^{++}	14.55
	Mg^{++}	Not measured
CEC (meq/100 g)		17.5
OM (%)		1.9
Grain size	Clay	17.75
distribution (%)	Fine silt	46.15
	Coarse silt	20.13
	Fine sand	9.4
	Coarse sand	6.57

3.2. Irrigation water assessment

The quality of irrigation water (TW or CW) has been evaluated for irrigation as regards their physicochemical and toxicological properties such as heavy metals.

Irrigation waters used were fully compliant with the standards for reuse of treated wastewater [10] and quality standards destined for drinking water [11], respectively, for TW and CW. This gives an aptitude to be used for agricultural purposes (Table 2).

Effluent from treated wastewater and conventional waters applied to irrigation had a slightly alkaline reaction, the pH values lying between 7.29 and 7.62 for TW and CW, respectively. These irrigation waters (TW and CW) are, therefore, in a favorable pH range for irrigation, it is between 6.5 and 8.4 [12].

Physicochemical analysis of irrigation waters showed that the values of electrical conductivity range from 1.1 to 1.27 for TW and CW, respectively. This showed that the waters used for irrigation has an average salinity, which is below the limit allowed for irrigation.

The concentration of almost all the elements nutrients tended to be higher in the TW compared with CW. The nitrate

Table 2
Physico-chemical parameters of the irrigation waters

Parameters	CW	Standard [11]	TW	Standard [10]
pH	7.62	6.5–9	7.29	$6.5 \leq pH \leq 8.5$
Electrical conductivity (25°C), µs/cm	1,278	2,800	1.11	3
Temperature, °C	24.7	25	18.02	–
BOD5, mg/L	–	–	13.53	30
COD, mg/L	–	–	26.21	90
Ammonium, mg/L	<0.02	0.5	3.55	–
Nitrite, mg/L	<0.02	0.2	0.08	–
Nitrate, mg/L	2.615	50	5.41	–
Total nitrogen Kjeldahl, mg/L	–	–	6.27	–
Phosphate, mg/L	<0.02	0.5	1.58	–
Total phosphorus, mg/L	–	–	48.17	–
Calcium, mg/L	74	200	–	–
Magnesium, mg/L	51.6	50	–	–
Chloride, mg/L	139.7	500	3.18	10
Cadmium, mg/L	0.001	0.005	0.01	0.05
Copper, mg/L	0.009	0.05	<0.01	5
Nickel, mg/L	–	-	0.007	2
Zinc, mg/L	0.012	5	<0.04	10
Iron, mg/L	–	–	0.1	20
Cobalt, mg/L	–	–	0.004	5
Lead, mg/L	0.008	0.01	0.101	10
Aluminum, mg/L	–	–	0.039	20
Manganese, mg/L	–	–	0.041	10
Mercury, mg/L	–	–	<0.004	0.01
Chrome, mg/L	–	–	<0.01	1

BOD_5 = biochemical oxygen demand; COD = chemical oxygen demand.

content (NO_3–N = 5.41 mg/L), ammonium (NH_4 = 3.55 mg/L) and nitrite (NO_2–N = 0.08 mg/L) are higher than the contents (NO_3–N = 2.6 mg/L, NH_4 and NO_2–N ≤ 0.02 mg/L) present in the CW. For that, the content average total nitrogen (TN) in the TW was 15.31 mg/L, which is higher compared with the average concentration that was measured in CW (TN = 2.62 mg/L). So concentration does not exceed the FAO recommended limit of 30 mg/L. Total phosphorus (TP) was 48.17 mg/L in TW higher at the concentration measured in the CW or TP ≤ 0.02 mg/L. the concentration of TW exceeds the limit recommended by Müller and Cornel [13] of 13 mg/L, knowing that this limit is based on the requirements of most crops.

Heavy metals including Cd, Cu, Zn and Pb have been detected in irrigation waters (TW and CW), and their concentrations was lower than the allowable limit set by Algerian regulations for the reuse of TW for agricultural purposes.

3.3. Measured parameters during the plant development cycle

3.3.1. Non-destructive analysis on the plants

3.3.1.1. Crown diameter

Fig. 2 represents the diameter evolution during the plant vegetative cycle.

We observe an evolution in the plants diameters according to rhythms going from 0.11 to 0.12 mm/d for CW and TW, respectively (Fig. 2). The differences between plants diameters go from 0.19 to 7.74 mm, indicating that the water effect was not important. This conclusion is confirmed by the variance analysis on the average diameter of plants. The obtained Fisher test probability value (p = 0.06), superior to threshold 5%, indicates that there is no statistically significant difference between the average plant diameters according to the water quality used for irrigation. Domestic effluents may contain important nutrients for agricultural crop development [14]. Gatta et al. [15] showed that the TW were always characterised by higher contents of NH_4–N, NO_3–N, total N, PO_4–P, Ca^{2+}, Mg^{2+} and K^+ than those measures for the CW. In addition, irrigation with TW improved the contents of nitrogen, potassium, phosphorus, OM and other trace elements; thus providing a good source of nutrient for the growth, yield and quality of crops [16,17]. Ben Said et al. [18] showed that the diameter of plants irrigated with TW was larger than the diameter of those irrigated with CW in both growth cycles, the largest diameter was observed in wastewater irrigated plants. Dagianta et al. [19] have demonstrated that pepper irrigated with TW increased the stalk thickness, which turned out to be similar to plants that had been irrigated with the CW with the fertilizer; also the use of TW with the fertilizer produced thicker stalks than those produced using the CW. It is important to emphasize that the nutrient contents presented in the treated wastewater does not replace the use of nitrogen fertilizers, it only provides part of the amount necessary, as emphasized by Fonseca et al. [20] and Damasceno et al. [21]. The TW supplied part of the fertilizers needed, and when it was applied with no fertilizer, the production did not present desirable levels when compared with the cultivation using fertilizers.

3.3.1.2. Plants height

Fig. 3 represents the evolution of the plant height during the plant vegetative cycle

We observe an increasing evolution of plants height according to rhythms going from 0.079 to 0.082 cm/d, for CW and TW, respectively, but the heights decreased towards the end of the crop vegetative cycle (Fig. 3). The effect of water quality was not significant. This conclusion is confirmed by the variance analysis on the plants average height. The obtained Fisher test probability value p = 0.14, widely superior to threshold 5%, indicates that there is no statistically significant difference between the average plant heights. Elfanssi et al. [22] found that the best growth on the average leaf area of alfalfa was noted with the raw wastewater irrigation followed by the treated wastewater irrigation during the three alfalfa crop seasons, whereas low growth has been noted with well water irrigation treatments. Elfanssi et al. [22] reported that at the end of each growing season of crop there was a decrease of the average leaf area of alfalfa irrigated by CW, while average leaf area of alfalfa (*Medicago sativa* L.) irrigated with raw and treated wastewater was still growing, which shows that wastewater irrigation positively affected alfalfa length. Ben Said et al. [18] crops irrigated with TW showed a better growth during

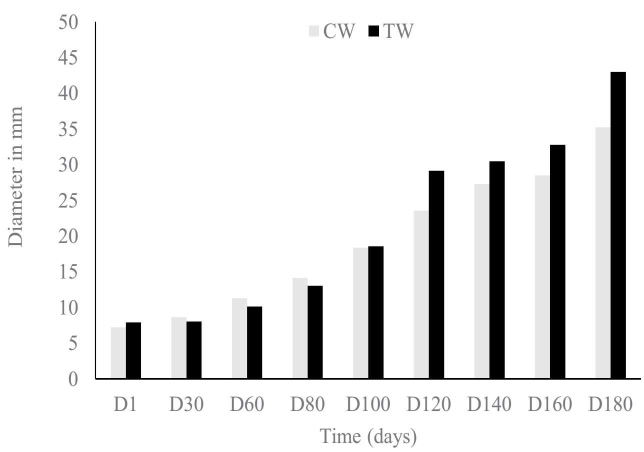

Fig. 2. Plant diameter evolution during the plant vegetative cycle.

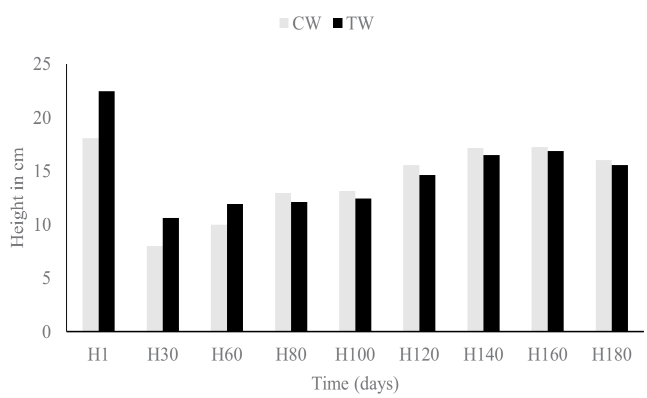

Fig. 3. Plant height evolution during the plant vegetative cycle.

the two growth cycles than those irrigated with CW, in both cycles of growth the quality of irrigation water significantly affected plant (*Cenchrus ciliaris*) heights. However, a significant increase in terms of height was observed in the two growth cycles of plant (*Cenchrus ciliaris*), the greatest height was observed in wastewater irrigated plants (end of the first cycle of growth), as well as the highest leaf length was observed under TW irrigation; on the other hand, the plants irrigated with CW were shorter than plants irrigated with reclaimed wastewater [18]. Similar results on turf, tomato, pepper and forage species were reported by Dagianta et al. [19], Castro et al. [23], Cirelli et al. [24], and Kim et al. [25], who observed that crops irrigated with treated wastewater produced taller plants compared with those grown with fresh water alone.

3.3.1.3. Entirely developed leaves number

Fig. 4 represents the number of leaves that are entirely developed during the plant vegetative cycle.

We observed a rising evolution of the number of leaves of plants irrigated with treated wastewater and conventional waters; this evolution was identical at the beginning of the plants growth cycle, then we observed a slight difference towards the end of the growing cycle depending on the quality of irrigation waters (i.e., the number of leaves of plants irrigated with treated wastewater was slightly higher than that of plants irrigated with conventional waters; Fig. 4). This shows that the effect of the water quality was not important. This conclusion is confirmed by the variance analysis on the number average leaves of plants. The Fisher test probability of $p = 0.0664$, above the 5% threshold, indicates no statistically significant difference between the average number of plants fully developed leaves according to the quality of irrigation waters. The water supply provides an important amount of OM, in major fertilizing elements (N, P and K), secondary fertilizing elements (Ca, Na, Mg) and trace elements (Fe, Cu, Ni, Zn), allowing to enhance the agronomic parameters of the cultivated plants [26–28]. As a result, the improvement of the physico-chemical characteristics of the soil through the use of wastewater for irrigation has often had a positive influence on crop yields and, in some cases; these improvements may be beneficial for the quality parameters of crop yields [29]. Uzma et al. [30] have demonstrated that the stimulating effects of treated wastewater could be attributed to the presence of many essential nutrients such as N, P, K, Ca and Mg. These nitrogenous effects improve the synthesis of plant proteins, resulting in an increase in plant growth characteristics [31]. Ben Said et al. [18] showed that plants leaf length, in the first cycle, was increased more by TW than CW, while no significant differences in leaf length were observed in the second cycle between the plants irrigated with TW and CW, the greatest leaf number was detected in plants irrigated with TW in both growing cycles. These results are in agreement with those of Oliveira-Marinho et al. [32], indicating an increase in the leaf number of Rosa hybrida irrigated with TW. An increase in leaf number was also reported for *Gossypium hirsutum* when irrigated with biologically TW [33].

3.3.1.4. Chlorophyll content

Fig. 5 illustrates the evolution of chlorophyll content during the plants vegetative cycle.

The observed differences between plants chlorophyll content go from 0.15 to 2.06 (SPAD), which seems to indicate that the influence of water quality was not significant between the average contents chlorophyll of plants (Fig. 5). This conclusion is confirmed by the variance analysis on the plants chlorophyll contents. The obtained Fisher test probability of $p = 0.85$, which is widely superior to threshold 5%, indicates that there is no statistically significant difference between the average contents of chlorophyll of the plants according to the quality of irrigation waters. These higher levels of fertilizer nutrients in the treated waters indicated that the treated waters are important sources of plant nutrients; thus, they contribute to crop growth and yield [34,35]. The intake of TW in fertilizer nutrients (Fe, Mn, Cu and Zn), in low quantity, is indispensable for the crops growth. Singh et al. [36] have shown that irrigation with an effluent with the lowest concentration of fertilizer nutrients enhances the growth in the chrysanthemum. On the other hand, the effluent at higher amounts of fertilizer elements present a risk of toxicity and inhibition of the plant development [26,37]. Cuba et al. [38] showed that by using only TW the plants presented visual signs of nutrient deficiency, such as a yellow colour on

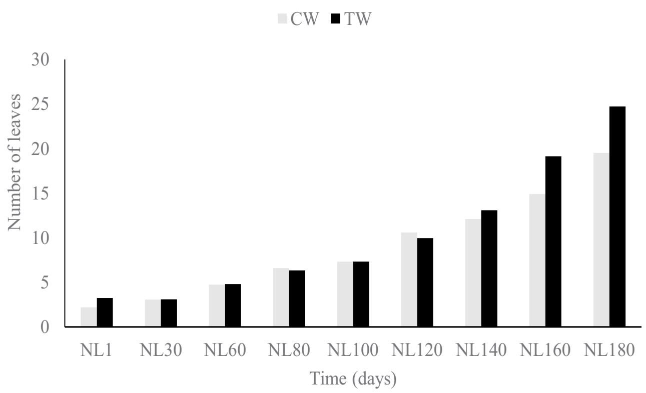

Fig. 4. Evolution of entirely developed leaves according to water quality.

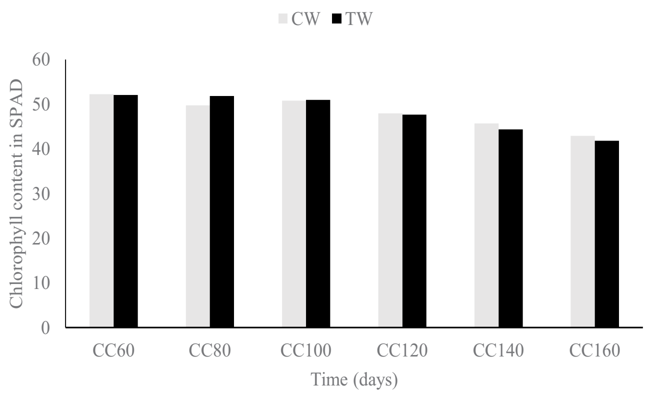

Fig. 5. Chlorophyll content of plants according to irrigation waters quality.

the leaves (nitrogen deficiency), the leaves tip burn (calcium deficiency). These deficiency symptoms were observed in our case; strawberry irrigated with TW without fertilization. The TW supplied part of the fertilizers needed, and when it was applied with no fertilizer, the production did not present desirable levels when compared with the cultivation using fertilizers. Elfanssi et al. [22] showed that raw wastewater led to a significant reduction in the total chlorophyll of plants of the alfalfa; on the other hand, the alfalfa irrigated by treated wastewater showed an almost similar content of total chlorophyll as did alfalfa irrigated by CW.

3.3.2. Morphological parameters of the fruit

3.3.2.1. Fresh weight of the fruit and their sizes (length, width)

The flowering began 3 months after the plants planting (December 2016) and lasted until the end of July 2017. We have realized on the experimental campaign 2016/2017 (from December to July), 22 fruit picking.

The 22 harvesting has resulted in a total weight of 5,238 g (CW) and 4,043 g (TW). The average production per plant was 137.85 and 106.4 g, respectively, for CW and TW (Fig. 6). The production was higher for plants irrigated by CW compared with those irrigated by TW, a difference of 31.45 g/plants. This shows that water quality has an important effect on plant production. This conclusion is confirmed by the variance analysis on the fruit productivity. The Fisher test probability of $p = 0.0057$, which is widely inferior to threshold 5%, shows that there are statistically highly significant differences between fruit production per plants according to irrigation water quality. This shows that treated wastewater used for irrigation of strawberry plants negatively affects strawberry production compared with strawberry production obtained by conventional waters. In this sense, Elfanssi et al. [22] showed improved soil fertility and crop productivity after irrigation with treated wastewater. Vergine et al. [35] showed that the marketable yield of lettuce and fennel crops irrigated with treated municipal wastewater was higher than that obtained with fresh water irrigation. Similarly, another study showed that treated wastewater irrigation positively affects cauliflower and cabbage yields, with the highest marketable yields for these two vegetable species obtained using treated wastewater [39].

A noticeable difference is observed in the number of fruits according to the quality of irrigation water. The number of fruits obtained on plants irrigated with conventional waters was higher compared with the number obtained on plants irrigated with treated wastewater, with a difference of 123 fruits and an average difference of three fruits/plants. The Fisher test probability of $p = 0.0137$, which is widely inferior to threshold 5%, shows that there is a statistically significant difference between the fruit number according to the quality of the irrigation waters.

Fig. 6 illustrates fruit parameters obtained during experimentation according to water quality.

It is noted that the quality of irrigation water has no effect on fruit size (Fig. 6), this is confirmed by the variance analysis. The Fisher test probability $p = 0.97$ and 0.6 obtained, respectively, for fruit length and width, well above the 5% threshold, shows that there is no statistically significant difference between average size of fruits according to the quality of irrigation waters. Gatta et al. [15] showed that the irrigation treatments (the secondary wastewater and tertiary wastewater) significantly affected the two morphometric parameters of the artichoke heads (i.e., length, diameter). The artichoke heads obtained with the secondary wastewater and tertiary wastewater were longer than those obtained with the CW as well as, the artichoke head diameters were on average greater for the secondary wastewater and tertiary wastewater than for the CW, as observed for the production parameters; these differences in the morphometric parameters are likely due to the increased intake of mineral nitrogen in the wastewater treatments [15]. Christou et al. [40] reported that TW irrigation did not significantly affect on mean fruit weight and maximum fruit diameter, as compared with control irrigation with CW. Cirelli et al. [24] and Aiello et al. [41] reported that tomato mean fruit weight was not affected by TW irrigation, as compared with irrigation with CW. Al-Lahham et al. [42] found that the tomato fruit diameter and weight were significantly higher in tomato plants irrigated with TW, as compared with those in plants irrigated with CW.

3.3.2.2. Rates in dry matter (%) and dry matter (%) of the fruits

In order to determine the dry matter rate (DMR) and dry matter (DM) of the fruits, we have chosen 84 fruits for each treatment. The fruits weigh 717.61 g (CW) and 694.24 g (TW). After drying the fruit at 70°C/72 h, we have obtained 59.24 g (CW) and 59.86 g (TW). The results allow us to estimate the value of the DMR and the dry matter (Fig. 7).

The graph shows that the DMR and the dry matter of the fruits obtained are identical according to the quality of irrigation water, with the difference not exceeding 0.37%, indicating that water quality did not have a significant effect (Fig. 7), which is confirmed by the variance analysis on those parameters. The Fisher test probability $p = 0.855$ and $p = 0.229$ obtained, respectively, for the DMR and dry matter of the fruits, the values are widely superior to threshold 5%, shows that there is no statistically significant difference between the DMR and dry matter of fruits collected according to the quality of irrigation water. Ganjegunte et al. [17] have shown that no significant differences in switch grass biomass production between wastewater and freshwater

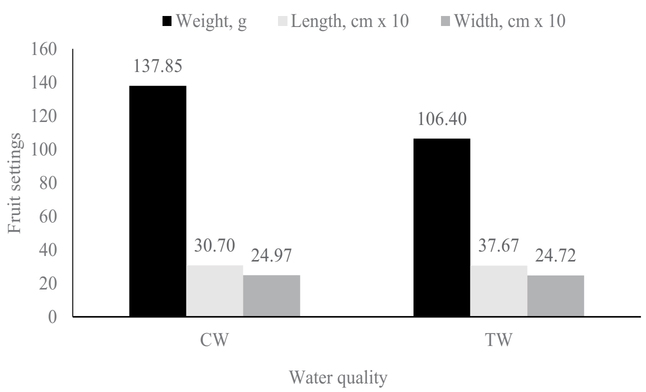

Fig. 6. Fruit parameters obtained during experimentation according to water quality.

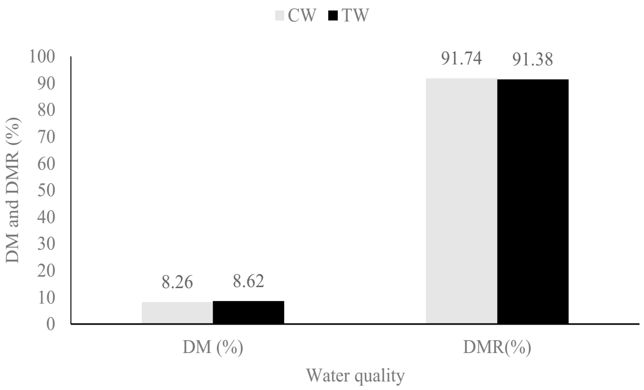

Fig. 7. Dry matter rate and dry matter of the fruits.

irrigated columns were noticed within a given year. Dagianta et al. [19] showed that pepper irrigation with TW combined with fertilization reduced the dry matter content of the biomass. As well as, Anwar et al. [43] showed that the biomass of mint, coriander and fenugreek was negatively affected when irrigated with wastewater, mint showed a maximum reduction of fresh and dry biomass compared with controls followed by coriander and fenugreek. Marwari and Khan [44] reported decreasing fresh and dry biomass when plants were irrigated with polluted water at 20%–30%. On the other hand, Rusan et al. [45] who reported that barley irrigated with wastewater generated a larger biomass than barley grown with CW. Farhadkashani et al. [46] suggested that the type of crop and the employed method for irrigation are two important factors that should be considered in the reuse of wastewater in agriculture.

4. Conclusion

In this contribution, we have assessed the influence of irrigation with treated wastewater, in comparison with conventional waters, on the evolution of the agronomic parameters of a strawberry crop.

The results showed that, with the exception of the yield obtained (which is lower in the case of treated wastewater), the development of other parameters did not show significant differences. This is reassuring because we have the same development of strawberry plant for both treatments (TW and CW). This makes it possible to consider the possibility of using treated wastewater in agriculture without leading to a negative impact on the main agronomic parameters of the crop.

Water treatment and its use in irrigation are attractive options, because it represents a source of renewable additional water and fertilizer. However, in order to avoid the eventual risks, the reuse of the treated wastewaters has to be regularly monitored and the reuse standards should be respected.

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