1 **Postprint of Scientia Horticulturae, Volume 256, 15 October 2019, 108644**

2 **<https://doi.org/10.1016/j.scienta.2019.108644>**

3
4
5 Effect of table olive wastewaters on growth and yield of cucumber, pepper,
6 tomato and strawberry

7 Berta de los Santos^a, Manuel Brenes^b, Pedro García^b, Ana Aguado^a, Eduardo Medina^b,
8 Concepción Romero^{b,*}

9
10 ^a*Centro IFAPA Las Torres (CAPDER – JA). Apartado de Correos Oficial, 41200-*
11 *Alcalá del Río, Seville, Spain*

12 ^b*Food Biotechnology Department, Instituto de la Grasa (IG-CSIC), Ctra. de Utrera,*
13 *km. 1, Building 46, 41013, Seville (Spain)*

14
15
16 *Correspondence to: Concepción Romero, Food Biotechnology Department, Instituto
17 de la Grasa (IG-CSIC), Ctra. Utrera km 1, Building 46, 41013-Seville, Spain. E-mail
18 c.romero@csic.es

19
20
21 Declarations of interest: none

22

ABSTRACT

The table olive factory generates a large amount of wastewaters and this is a big environmental problem. The aim of this study was to look for a solution of this issue, using table olive waste as irrigation water during the growth of four Mediterranean crops: tomato (*Solanum lycopersicum* L.), strawberry (*Fragaria x ananassa* L.), cucumber (*Cucumis sativus* L.) and pepper (*Capsicum annuum* L.). These solutions were rich in sugars (17-85 mmol L⁻¹) and polyphenolic compounds (13-21 mmol L⁻¹), being hydroxytyrosol the main component (5.5-14.5 mmol L⁻¹). Also, some minerals were identified (carbon, nitrogen, sodium, potassium and phosphorus). The solutions were free of sodium chloride and no phytotoxic effect was detected, neither on the fruits or the leaves. The irrigation with the tested solutions originated an increase of the plant growth, fruit size and cumulative yield by at least 20 % compared to the dipping and spraying applications mode. Also, it was observed a decrease of the powdery mildew disease in strawberry plants. Particularly, the fruit medium weight of cucumbers treated with table olive solutions was 40g higher than the untreated fruits. Among the wastewaters generated during table olive processing, the wash water solution from Spanish-style green olives and the acidified storage liquids from black ripe olive processing could be employed as natural fertilizers and fungicide in substitution of synthetic products.

Keywords: table olive byproducts, olive (*olea europaea* L.), tomato (*Solanum lycopersicum* L.), strawberry (*Fragaria x ananassa* L.), cucumber (*Cucumis sativus* L.), pepper (*Capsicum annuum* L.)

1. Introduction

Nowadays, the food industry generates a high volume of waste. A solution to this serious problem is one of the objectives of companies which want to be environmentally sustainable and respectful to Mother Nature. The use of these wastes in agriculture is an idea which has become increasingly widespread in the last decades.

Some waste have been investigated as potential sources of biostimulants for organic tomatoes (Chehade et al., 2018) or as a mineral fertilizer to improve soil characteristics (Baldantoni et al., 2016; Zipori et al., 2018). Some researchers have proposed an agronomic use for these by-products as foliar biofertilizers or by applying them directly on the ground through irrigation or as solid fertilizer (Tejada and González, 2003; López-Piñero et al., 2008; Rodríguez-Lucena et al., 2010). In particular, the incorporation of increasing amounts of wet olive pomace has improved the nutrient content of soil (Cucci et al., 2008). However, others results have shown that these olive wastewaters could not be directly applied in agriculture. Necrosis effects on tomato leaves and phytotoxic effects during the germination of the plants have been observed (Piotrowska et al., 2005; Mekki et al., 2006; Ilay et al., 2013).

Composting is the technique most commonly used to eliminate the phytotoxicity of these olive by-products (Albuquerque et al., 2006). Compost has been obtained from olive tree prunings (Charisiou et al., 2016) and olive oil solid waste (Cayuela et al., 2010), applying it as an amendment in agriculture (García-Gómez et al., 2002), as a promising ecological alternative (Cucci et al., 2013) to conventional fertilizers in potato production (Hachicha et al., 2006), as a biofertilizer for the growth of the three rice cultivars (Seyyednejad et al., 2017) and as amendments for rye-grass (Montemurro et al., 2004). However, the dose employed is very important, and it has been verified that an application greater than 10% on the ground can reduce the growth of the plants (Killi and Kavdir, 2013). In addition, these olive by-products are evaluated as important sources of bioactive compounds (Romero et al., 2017; 2018), such as triterpenic acids and phenolic compounds, to which health benefits have been attributed.

There is a great interest to obtain a good biofertilizer and also a solution to control plant diseases (Adisa et al., 2018). Hence, researchers have applied a combination of natural products to control the powdery mildew on cucumber (Bokshi et al., 2008),

while others have administered O_3 to protect the leaves from this disease (Khan and Khan, 1999).

In the Mediterranean area, Spain is the main table olives producing country with around 500,000 t/year. Table olive processing produces a high volume of wastewaters, which can be estimated around of 5-7 liters/kg olive. These solutions have very different chemical compositions: sodium hydroxide solutions, olive wash waters, fermentation brines, storage solutions, etc. However, there are very few scientific works on their use in agriculture. Olive brines exert a high inhibitory effect on seed germination and seedling growth (Pierantozzi et al., 2012), and it has also been found that the use of the table olive wastewaters for the irrigation of olive trees is not possible because of their high salinity (Murillo et al., 2000). Nevertheless, other researchers have reported a biostimulant effect on the growth of tomato plants when they applied some table olive solutions through irrigation (Romero et al., 2011). Also, several table olive solutions free of sodium chloride displayed strong bactericidal and fungicidal activity against phytopathogenic micro-organisms (Brenes et al., 2011) when tested on a laboratory scale.

The wash water solutions from the elaboration of Spanish green table olives and the storage solutions from the elaboration of black table olives are free of sodium chloride and contain a large quantity of sugars, acetic acid, ethanol, minerals, oleosidic, polyphenolic and antimicrobial compounds (Medina et al., 2007). Consequently, we can hypothesize that these solutions could have biostimulant and biopesticity capacity. Then, the aim of this work was to evaluate the effect of those solutions free of sodium chloride on the growth and development of four Mediterranean crops: strawberry, tomato, cucumber and pepper.

2. Materials and methods

2.1. Table olive solutions

Acidified storage liquids from black ripe olive processing from olive factories located in Seville (Spain) were collected and transported to the Instituto de la Grasa laboratories. These solutions have been in contact with olives of the 'Hojiblanca' cultivar for 6 months under aerobic conditions. These liquids had 12 g L^{-1} concentration of acetic acid and a pH of around 4.0.

Fresh olives of 'Hojiblanca' as well as 'Manzanilla' cultivars were processed as Spanish-style green olives in olive factories located in Seville. Fruits were covered with a 20 g L⁻¹ NaOH solution for several hours and, subsequently, put in tap water for 7–10 h. These wash water solutions, with a pH above 12, were transported to the Instituto de la Grasa laboratories within 24 h. These wash waters were acidified with nitric acid to prevent undesirable fermentations, and stored in 30 L PVC vessels at room temperature under anaerobic conditions for 6 months.

Both types of table olive wastewater solutions were prepared before used for agronomic purposes. They were concentrated 10 fold under vacuum, then diluted with tap water to their initial volume and, finally, their pH was adjusted up to 5 units with potassium hydroxide (6 mmol L⁻¹).

2.2. Agronomic experimental designs

Three pot experiments were carried out in a greenhouse (25 °C day/15° C night ± 5 °C; 50-80% of relative humidity) located in the IFAPA Center Las Torres (Alcalá del Río, Seville, Spain, 37°30' N, 5°58' W). In all experiments, transplants were transferred to 16-cm plastic pots containing sterilized peat (Klansmann-Deilmann, Geeste, Germany). The chemical composition of the peat was: 20% organic matter, pH 5.5-6.5, salinity < 1 g L⁻¹, 130-220 mg L⁻¹ N, 160-260 mg L⁻¹ P, 170-290 mg L⁻¹ K and 80-150 mg L⁻¹ Mg.

For each crops, the experiment was designed as a randomized complete block with six replications, and control plants were treated with tap water. The solutions tested were diluted 1:4 or 1:1 with tap water. Three experiments were performed. Throughout the three experiments, irrigation was carried out in a conventional manner with tap water.

2.2.1. Experiment 1

Tomato (cv. 'Optima') and strawberry (cv. 'Camarosa') cultivars were transplanted in mid-October, 2014. Two wastewater table olive solutions were tested, a storage liquid from black olive processing (SL1) and a wash water from Spanish-style green olive processing from the 'Hojiblanca' cultivar (WWH1), both from the 2013/2014 season. The solutions were applied following three application modes: (i) transplant dipping (5 minutes); (ii) irrigation (110 mL per pot); (iii) spraying (until run-off). The

irrigation and spraying treatments were applied twice, the first one 20 days post-transplant (dpt), and the second one 35 dpt.

2.2.2. Experiment 2

Cucumber (cv. 'Beautiful') and pepper ("Green bell pepper") plants were transplanted on 25th March, 2015. Three table olive wastewaters were tested, a storage liquid from black olive processing (SL2) and two wash waters from Spanish-style green olive processing, from the 'Hojiblanca' (WWH2) and 'Manzanilla' (WWM2) cultivars, all from the 2014/2015 season. A solution of KNO_3 (7.81 g L^{-1} of potassium and 2.80 g L^{-1} of nitrogen) diluted 1:4 or 1: 1 with tap water was also used as positive control. The solutions were applied by irrigation three times on a bi-weekly basis, the first one 15 dpt.

2.2.3. Experiment 3

Tomato (cv. 'Optima') plants were transplanted on 26th April, 2015. Two wash waters from Spanish-style green olive processing were tested, from the 'Hojiblanca' (WWH3) and 'Manzanilla' (WWM3) cultivars, both from the 2014/2015 season. On this occasion, two control solutions were used, tap water and a solution of KNO_3 (7.81 g L^{-1} of potassium and 2.80 g L^{-1} of nitrogen) diluted 1:1 with tap water. The solutions were applied twice by irrigation (110 mL per pot), the first one 15 dpt, and the second one 30 dpt.

2.3. Chemical analyses of table olive solutions

The pH was measured using a Crison model 2001 pH meter (Crison Instruments, Barcelona, Spain).

Solutions were filtered through a 0.22- μm pore size nylon filter and organic acids and ethanol were analyzed by HPLC. An aliquot of 20 μL was injected into the chromatograph. The HPLC system consisted of a Waters 2695 Alliance (Waters Inc., Mildford, MA) with a pump and autosampler included, the detection was performed using a Waters 410 refractive index detector. The separation was achieved by isocratic elution using water acidified with phosphoric acid (pH 2.5) as mobile phase and a Spherisorb ODS-2 (5 μm , 250 $\times$ 4.6 mm, Waters, Inc.) column held at (30 $^{\circ}\text{C}$). The flow

rate was 1.2 mL min^{-1} . The quantification of acetic acid and ethanol was made using a commercial standard.

Sugars in the filtered solutions were analyzed by HPLC as described elsewhere (Medina et al., 2007). An aliquot ($20 \mu\text{L}$) was injected into the chromatograph. The HPLC system was described above. A Rezex RCM-Monosaccharide Ca^+ (8%) column ($300 \times 7.8 \text{ mm i.d.}$, Phenomenex) held at 85°C and deionized water as eluent at 0.6 mL min^{-1} was used. Commercial standards were used to quantify.

Phenolic and oleosidic compounds were analyzed by HPLC as described elsewhere (Medina et al., 2007). A mixture of $250 \mu\text{L}$ of table olive solution, $250 \mu\text{L}$ of internal standard (2 mM syringic acid), and $500 \mu\text{L}$ of deionized water were filtered through a $0.22\text{-}\mu\text{m}$ pore size nylon filter. The wavelengths selected for phenolic and oleosidic compounds were 280 and 240 nm, respectively. Commercial standards and isolated compounds by semi-preparative HPLC were used to quantify the phenolic and oleosidic compounds.

Carbon and nitrogen were analyzed by elemental analysis, using a LECO CHNS-932 analyzer (St Joseph, MI, USA). Previously, the samples were dried at 105°C and the moisture was calculated.

Sodium and potassium concentrations were determined by flame photometry. The solutions were diluted with deionized water in an automatic diluter (LIC Instruments Model 346, PACISA, Sweden) to obtain a concentration of less than 200 meq L^{-1} of sodium and potassium. Then, the solutions were introduced into the flame photometer (Metheor model NAK-1, PACISA, Spain). The photometer was calibrated with Na and K atomic absorption standard solutions (Aldrich Chem Comp, Milwaukee, USA).

The analysis of phosphorus was carried out using the method proposed elsewhere (Kato et al., 2010). Measurements were made in a Cary UV/Visible spectrophotometer model 60 (Agilent Technologies, Ca, USA) at 420 nm. A calibration curve was obtained with a phosphate standard solution (Aldrich Chem Comp, Milwaukee, USA).

2.4. *Morphological and production analysis of crops*

After two and three months (for Experiments 1 and 3, respectively), morphological and production parameters were weekly evaluated in tomato plants: plant height (cm),

flowers per plant, fruit size (cm), fruits per plant, and cumulative yield (g plant^{-1}). At the end of each experiment, the tomato plants were removed, washed under tap water, and root length (cm) and root weight (g) were recorded. In Experiment 1, strawberry plants were maintained in the greenhouse for four months and plant diameter (cm), flowers per plant, fruits per plant, and cumulative yield (g plant^{-1}) were weekly evaluated. In Experiment 2, cucumber and pepper plants were maintained in the greenhouse for three and four months, respectively. Plant height (cm), flowers per plant, fruit size (cm), fruits per plant, and cumulative yield (g plant^{-1}) were weekly evaluated. Growth index was estimated as the area under the curve of the plant height progress (AUCP). For all experiments, the progress in flowering and the number of open flowers per plant was observed and recorded once a week until fruiting (Sønsteby and Heide, 2007). The progress in flowering was expressed as the percentage of plants that showed at least one open flower.

2.5. *Effect of treatments on strawberry powdery mildew (Podosphaera aphanis) development*

In Experiment 1, strawberry plants were inoculated artificially by placing one severely infected plant (cv. ‘Camarosa’) in the middle of each block (Recuenco et al., 2005). The symptoms of strawberry powdery mildew on leaves were weekly evaluated on each plant. The severity of leaf symptom was assessed on a 1-6 Simpson modified scale, where: 1 = no visual symptoms and 6 = severe necrosis and some leaf death (Simpson, 1987). The 0–6 rating scale scores for each plant and for each treatment were converted into disease severity index (DSI). This measurement was based on the methodology proposed elsewhere (McKinney, 1923).

2.6. *Statistical analysis*

Chemical data were the mean of triplicate $\pm$ standard error (SE). The pot experiments were performed using a completely randomized design. In Experiment 1, the data were analyzed by three-way analysis of variance (ANOVA) and data are presented as the mean for each application mode, table olive solution and dose. In Experiment 2, the data were analyzed by two-way ANOVA and the data are presented as the mean for each table olive solution and dose. In Experiment 3, one-way ANOVA were applied to determine the significant differences among treatments. All results are expressed as the mean of six replications and means were compared according to the

least significance differences (LSD) test with a significance level of $p < 0.05$. All statistical analyses were performed with Statistix 9.0 (Analytical Software, Ltd., La Jolla, CA, USA).

3. Results and discussion

3.1. Chemical characterization of the table olive wastewaters

Table 1 contains the chemical characterization of the wastewaters employed in the three experiments. All of them had a pH value of 5.5-6.0 units. Ethanol was not detected and the concentration of acetic acid was null or residual in the SL, both compounds are volatiles and were lost during the process of vacuum evaporation.

In general, the main sugars in the WW were glucose and fructose (Papadaki et al., 2018), but a high concentration of mannitol was detected in the WWH, although its concentration was especially high in the SL (Medina et al., 2018). Total sugars varied according to olive cultivar, the kind of solution and above all, the harvest year.

Other significant constituents of these solutions were polyphenolic compounds. In all the solutions employed the major compound was hydroxytyrosol, followed by hydroxytyrosol-4-glucoside, tyrosol and others. The concentrations of phenols were in accordance with the values reported by other researchers (Ramírez et al., 2015). The only difference was that a small amount of dialdehydic form of decarboxymethyl elenolic acid either free (EDA) or linked to hydroxytyrosol (HyEDA) and oleoside-11-methyl esters were found in the SL, which are antimicrobial compounds not detected in the WW. Therefore, the preparation process for these solutions (concentration by vacuum evaporation and reconstitution) did not alter the composition of the polyphenolic and oleosidic compounds.

A high concentration of nitrogen was found in the WW compared to the SL, due to the addition of nitric acid during the storage of these solutions until further use. On the other hand, the pH of all the solutions was adjusted by adding potassium hydroxide before being used, which resulted in the detection of a significant concentration of that cation.

Sodium concentration was 3-5 times higher in the WW than in the SL, due to the removal of the excess sodium hydroxide retained in the olives during Spanish-style green processing.

3.2. Agronomic evaluation of crop performances

3.2.1. Experiment 1

Despite researchers have detected necrosis in tomato plants treated with olive mill wastewater solutions (Mekki et al., 2006), it was confirmed that both the tomato plants (Fig. 1A) and the strawberry plants (Fig. 1B), treated with WWH1 through irrigation, showed no morphological defects, neither in the leaves, nor in the fruits. In addition, a tendency toward improved growth and better appearance was seen in the plants compared to the ones treated with tap water (Fig. 1C and 1D).

The height of the tomato plants treated with SL1 (Fig. 2A) reached a significant higher value after irrigation as well as spraying compared to those treated with water, this effect was observed for both doses of the tested solutions. In addition, when the tested liquid was WWH1 (Fig. 2B), a greater effect was observed when it was applied through irrigation, with a lesser effect attributed to spraying and no significant difference between the control plants subjected to dipping. On the other hand, it was observed that the application of both liquids permitted a cumulative yield much higher in the tested plants. Statistically significant differences were found when SL1 was applied by spraying (Fig. 2C), and especially when WWH1 was applied through irrigation (Fig. 2D). It is worth noting that all the treated tomato plants presented at least one flower at 35 dpt, with an average per plant of three flowers (Table 2).

In the case of the strawberry cultivar, the effects observed were not as promising. Initially, the applications of SL1 by dipping and spraying were the most effective with regards to the cumulative yield (Fig. 3A); however, the employment of WWH1 was most beneficial when applied through irrigation (Fig. 3B). Another parameter of great importance in this cultivar was the development of symptoms on the leaves due to *Podosphaera aphanis*. In fact, researchers have found strawberry cultivar which are resistant to this disease (Gao et al., 2009). The value for the severity index (DSI) was far superior in the control plants (Fig. 3C and 3D), which showed a statistically significant difference between the results obtained in the treated plants and the control. The most effective treatment was the application of SL1 at 50% by irrigation. The high fungicide effect of SL1 solution could be explained by the presence of antimicrobial compounds in its composition (Table 1), whose effects against other plant phytopathogens have been widely demonstrated (Brenes et al., 2011; Medina et al., 2011).

Not all the strawberry plants flowered at 55 dpt. Only 30% of the plants presented at least one flower after the dipping treatment; while this percentage was greater in the case of spraying (58%) or irrigation (67%).

At the end of the test, different morphological and production parameters were measured for the two crops studied (Table 2). A three-way analysis of variance was carried out on the obtained data and the considered factors were: test solution (SL1 and WWH1), application method (dipping, spraying or irrigation), and applied dose. Results of the analysis of variance from the tomato experiment showed that the effect [solution $\times$ application method $\times$ dose] was significant for fruit medium caliber ($P = 0.0072$); medium weight of the roots ($P = 0.0048$); and cumulative yield ($P = 0.0045$). Whereas, results of the analysis of variance from the strawberry experiment showed that the effect [solution $\times$ application method $\times$ dose] was only significant for cumulative percentage of fruiting plants ($P = 0.0343$), and the effect [solution $\times$ application method] was significant for cumulative yield ($P = 0.0073$). No more significant interactions among tested factors were detected. The results indicated that the main source of variation was the application method and that for all the analyzed parameters; the irrigation method was the most effective, particularly for the tomato cultivar. Although a higher yield percentage was observed for strawberries, no statistically significant differences were observed.

On the other hand, the results for plant height, cumulative yield and mean weight of the roots in tomatoes differed according to the applied solution. The application of WWH1 was more effective than the application of SL1. However, the applied dose was not a source of variation for any evaluated parameters (Table 2).

The significant interactions among the studied factors were scarce. The interaction between the application method and the test solution is worth noting for the tomato. The plants treated by irrigation with WWH1 developed fruits with a significantly higher weight, in the order of 65 g fruit^{-1} , with lower values when dipping (27 g fruit^{-1}) or spraying (20 g fruit^{-1}) were employed. No significant differences were found in the case of SL1. Likewise, the only significant variation found for strawberries was between the application method and the test solution. The plants treated with WWH1 through irrigation developed a higher average yield (35 g plant^{-1}) with this value being lower when spraying (15 g plant^{-1}) or dipping (12 g plant^{-1}) was employed.

The results from the first experiment indicated that the application of WWH1 by means of irrigation was even very beneficial from the standpoint of the growth and yield of the plant. If we compare the chemical composition of solutions tested (Table 1), we can see that WWH1 had higher contents in sugars, phenolic compounds, nitrogen and phosphorus than the SL1 solution, which could be the reason for the biofortifying effect observed. Similar effects were found on tomato cultivars when they were treated by means of intensive irrigation with a fertilizer rich in nitrogen solutions and potassium (Al-Mohammadi and Al-Zu'bi, 2011; Vieira et al., 2016; De Andrade et al., 2017). In addition, some investigators have shown the influence of the source of nitrogen in the fertilizer (Chen et al., 2016; Trandel et al., 2018).

3.2.2. *Experiment 2*

Firstly, it must be noted that no phytotoxic effect was observed on cucumber and pepper plants which is in agreement with previous results obtained for tomato and strawberry in the first experiment.

The results from the cucumber experiment were subjected to a two-way analysis of variance and indicated that the effect of [solution x dose] was not significant. Cucumber plant growth (AUCP value) was greatest for the fertilizer-control plants (KNO_3), followed by those treated with SL2 and WWM2 (Table 3). The other parameters for which certain statistically significant differences were found were the average number of fruits per plant, with superior values for the plants treated with fertilizer-control and WWM2, and the average weight per fruit value, with remarkable values for the fruits treated with SL2 (177 g fruit^{-1}) and WWH2 (166 g fruit^{-1}), which were around 40 g higher than those obtained for the fertilizer-control fruits. Researchers have found an increase lower than 25 g in the yield of cucumbers which were treated with herbal waste as fertilizer (Haghighi, 2014).

Results of the analysis of variance from the pepper experiment showed that the effect [solution $\times$ dose] was significant for plant height ($P = 0.0194$); AUCP ($P = 0.0431$), medium number of fruits per plant ($P = 0.008$), fruit medium diameter ($P = 0.0398$), fruit medium length ($P = 0.0083$), fruit medium weight ($P = 0.0086$) and cumulative yield ($P = 0.0002$). Regarding the treatments applied to the pepper plants, the percentage of flowering was 100% after 42 dpt in the plants treated with WWH2 and only 66% in those treated with the fertilizer-control. The average number of flowers

per plant was around 3 in all the treated plants, even with the tap water control, and only 1.2 with the fertilizer control.

The parameters related to the growth of the plant (plant height and AUCP) showed the worst results for the plants treated with KNO_3 (Table 4). Some investigators have shown that the pepper is one of the few crops that do not increase the height by increasing nitrogen concentration in the irrigation water (Liu et al., 2012). Specifically, the control-fertilizer solution contained a concentration of 2.80 g L^{-1} of nitrogen and 7.81 g L^{-1} of potassium; while the table olive wastewaters (SL2, WWH2 and WWM2) contained $0.4\text{-}2.9 \text{ g L}^{-1}$ of nitrogen and $1.7\text{-}2.3 \text{ g L}^{-1}$ of potassium (Table 1). The excess of potassium could be the reason for the decrease in growth in the plants treated with the control-fertilizer.

On the other hand, in relation to the morphological characteristics of the fruits and their yield, the most favorable treatment was the control-water in most of the evaluated parameters. There was a relationship between treatments and applied doses. When the results obtained by applying only table olive wastewaters were compared, the WWH2-20 solution stood out positively for the mean value of the number of fruits per plant and the cumulative yield and the SL2-50 solution for the diameter, length and average weight of fruits (Table 4).

3.2.3. Experiment 3

The factor of crop season led us to carry out Experiment 3 with tomato plants in order to verify the data obtained in the first trial. On this occasion, the effects were greater with two wash waters from two olive cultivars, 'Hojiblanca' (WWH3) and 'Manzanilla' (WWM3). Both were applied through irrigation and at two concentrations.

In general, the results obtained for the treated plants (Table 5) were more favorable than those found for the control-water plants, which confirmed the results from Experiment 1 (Table 2), but there were not such large variations with respect to the values found after the application of the solution control- KNO_3 . An analysis of the results according to the LSD test showed that there were no statistically significant differences among treatments for the parameters flowering, mean fruit size and weight or length of the roots.

Nevertheless, remarkable results were found when WW-50 was added and higher values for plant height, mean number of fruits per plant and cumulative yield were determined. No statistically significant difference was found between the use of one WW or another, with a tendency to obtain the best results when applying WWM3. If we check the chemical composition of both (Table 1) no differentiating component was detected; although WWM3 contained a greater amount of sugars, and higher values of potassium and phosphorus. Obviously, the beneficial effect of these solutions should be attributed to the whole of its composition and not one component in particular.

4. Conclusions

It has been demonstrated for the first time that the employment of wash water from the processing of Spanish-style green olives and the storage liquids from the elaboration of black table olives, both solutions free of sodium chloride, does not produce any phytotoxic effect on the evaluated crops. The application of wash waters from the Spanish-style green olives was beneficial to plant growth, diameter and yield in the case of tomatoes, strawberries and peppers, with an elevated effect of the storage solution of black ripe olives on cucumbers. In particular, the storage liquid for black olives produced a fungicide effect against *Podosphaera aphanis*, which is responsible for the powdery mildew disease on strawberry. These results open the possibility of reusing waste solutions as they are favorable to the growth of plants and act as a substitute for synthetic fungicide, although this study should be repeated in the field conditions in the long term. This may mitigate the environmental impact of the olive processing industry.

Acknowledgements

This work was supported by grant P12-AGR-1123 from Junta de Andalucía and the European Union FEDER funds. We thank Alejandra Expósito for technical assistance.

References

- Adisa, I.O., Reddy Pullagurala, V.L., Rawat, S., Hernandez-Viezcas, J.A., Dimkpa, Ch.O., Elmer, W.H., White, J.C., Peralta-Videa, J.R., Gardea-Torresdey, J.L., 2018. Role of cerium compounds in fusarium wilt suppression and growth enhancement in tomato (*Solanum lycopersicum*). J. Agric. Food Chem. 66, 5959–5970.
- Albuquerque, J.A., González, J., García, D., Cegarra, J., 2006. Composting of a solid olive-mill by product (“alperujo”) and the potential of the resulting compost for cultivating pepper under commercial conditions. Waste Manage. 26, 620-626.
- Al-Mohammadi, F., Al-Zu'bi, Y., 2011. Soil Chemical Properties and Yield of Tomato as Influenced by Different Levels of Irrigation Water and Fertilizer. J. Agric. Sci. Tech. 13, 289-299.
- Baldantoni, D., Bellino, A., Alfani, A., 2016. Soil compost amendment enhances tomato (*Solanum lycopersicum* L.) quality. J. Sci. Food Agric. 96, 4082-4088.
- Bokshi, A.I., Jobling, J., McConchie, R., 2008. A single application of Milsana followed by Bion assists in the control of powdery mildew in cucumber and helps overcome yield losses. J. Hortic. Sci. Biotech. 83, 701-706.
- Brenes, M., García, A., De los Santos, B., Medina, E., Romero, C., De Castro, A., Romero, F., 2011. Olive glutaraldehyde-like compounds against plant pathogenic bacteria and fungi. Food Chem. 125, 1262-1266.
- Cayuela, M.L., Sánchez-Monedero, M.A., Roig, A., 2010. Two-phase olive mil waste composting: enhancement of the composting rate and compost quality by grape stalks addition. Biodegradation 21, 465-473.
- Cucci, G., Lacolla, G., Caranfa, L., 2008. Improvement of soil properties by application of olive oil waste. Agron. Sustain. Dev. 28, 521-526.
- Cucci, G., Lacolla, G., Caranfa, L., 2013. Use of composted olive waste as soil conditioner and its effects on the soil. Int. J. Agric. Res. 8, 149-157.
- Charisiou, N.D., Konstantakou, P.P., Papadakis, V.G., 2016. Exploitation of olive tree prunings as raw material for the production of high quality compost. Environ. Eng. Manag. J. 15, 2709-2717.

- 444 Chehade, L.A., Al Chami, Z., De Pascali, S.A., Cavoski, I., Fanizzi, F.P., 2018.
445 Biostimulants from food processing by-products: agronomic, quality and
446 metabolic impacts on organic tomato (*Solanum lycopersicum* L.). J. Sci. Food
447 Agric. 98, 1426-1436.
- 448 Chen, C., Xu, F., Zhu, J.R., Wang, R.F., Xu, Z.H., Shu, L.Z., Xu, W.W., 2016. Nitrogen
449 forms affect root growth, photosynthesis, and yield of tomato under alternate
450 partial root-zone irrigation. J. Plant Nutr. Soil Sci. 179, 104-112.
- 451 De Andrade, A.R.S., de Noronha, S.P., Azevedo, P.R., Silva, P.R.L.D., Santos, R.D.,
452 2017. Fertigation in cultivation of four tomato cultivars (*Lycopersicon sculentum*)
453 irrigated by drip irrigation. Appl. Res. Agrotec. 10, 7-21.
- 454 Gao, Q.H., Ye, Z.W., Zheng, H.Q., Zhang, X.Y., 2009. A New Strawberry Cultivar
455 'Shenmei 3#', Edited by Lopez-Medina J, VI International Strawberry
456 Symposium, Acta Hortic. 842, 403-406.
- 457 García-Gómez, A., Bernal, M.P., Roig, A., 2002. Growth of ornamental plants in two
458 composts prepared from agroindustrial wastes. Bioresource Technol. 83, 81-87.
- 459 Hachicha, S., Chtourou, M., Medhioub, K., Ammar, E., 2006. Compost of poultry
460 manure and olive mill wastes as an alternative fertilizer. Agron. Sustain. Dev. 26,
461 135-142.
- 462 Haghighi, M., Afsharikia, A., Mozafariyan, M., Pessarakli, M., Bolandnazar, A., 2014.
463 Usage of Herbal (Thyme and Chicory) Waste as an Organic Substrate in
464 Cucumber Production. Commun. Soil Sci. Plan. 45, 2607-2619.
- 465 Ilay, R., Kavdir, Y., Sümer, A., 2013. The effect of olive oil solid waste application on
466 soil properties and growth of sunflower (*Helianthus annuus* L.) and bean
467 (*Phaseolus vulgaris* L.). Int. Biodeter. Biodegr. 85, 254-259.
- 468 Kato, K., Yoshimoto, M., Shirai, Y., 2010. Systemization of determination methods of
469 major components in sludge fertilizer, compost and organic fertilizer. Res. Rep.
470 Fertilizer 3, 107-116.
- 471 Khan, M.R., Khan, M.W., 1999. Effects of intermittent ozone exposures on powdery
472 mildew of cucumber. Environ. Exp. Bot. 42, 163-171.

- 473 Killi, D., Kavdir, Y., 2013. Effects of olive solid waste and olive solid waste compost
474 application, on soil properties and growth of *Solanum lycopersicum*. Int. Biodeter.
475 Biodegr. 82, 157-165.
- 476 Liu, J., Leatherwood, W.R., Mattson, N.S., 2012. Irrigation Method and Fertilizer
477 Concentration Differentially Alter Growth of Vegetable Transplants. Hort.
478 Technology 22, 56-63.
- 479 López-Piñero, A., Albarrán, A., Rato-Nunes, J.M., Barreto, C., 2008. Short and
480 medium-term effects of two-phase olive mil waste application on olive grove
481 production and soil properties under semiarid Mediterranean conditions. Biores.
482 Technol. 99, 7982-7987.
- 483 McKinney, H.H., 1923. Helminthosporium disease of wheat. J. Agric. Res. 26, 195-218.
- 484 Medina, E., Brenes, M., Romero, C., García, A., De Castro, A., 2007. Main
485 antimicrobial compounds in table olives. J. Agric. Food Chem. 55, 9817-9823.
- 486 Medina, E., Romero, C., De Los Santos, B., De Castro, A., García, A., Romero, F.,
487 Brenes, M., 2011. Antimicrobial activity of olive solutions from stored Alpeorujo
488 against plant pathogenic microorganisms. J. Agric. Food Chem. 59, 6927-6932.
- 489 Medina, E., Brenes, M., García-García, P., Romero, C., De Castro, A., 2018. Microbial
490 ecology along the processing of Spanish olives darkened by oxidation. Food
491 Control 86, 35-41.
- 492 Mekki, A., Dhouib, A., Aloui, F., Sayadi, S., 2006. Olive wastewater as an ecological
493 fertiliser. Agron. Sustain. Dev. 26, 61-67.
- 494 Montemurro, F., Convertini, G., Ferri, D., 2004. Mill wastewater and olive pomace
495 compost as amendments for rye-grass. Agronomie 24, 481-486.
- 496 Murillo, J.M., López, R., Fernández, J.E., Cabrera, F., 2000. Olive tree response to
497 irrigation with wastewater from the table olive industry. Irrig. Sci. 19, 175-180.
- 498 Papadaki, E., Tsimidou, M.Z., Mantzouridou, F.Th., 2018. Changes in phenolic
499 compounds and phytotoxicity of the Spanish-style green olive processing
500 wastewaters by *Aspergillus niger* B60. J. Agric. Food Chem. 66, 4891-4901.

- 501 Pierantozzi, P., Zampini, C., Torres, M., Isla, M.I., Verdenelli, R.A.; Meriles, J.M.,
502 2012. Maestri, D. Physico-chemical and toxicological assessment of liquid wastes
503 from olive processing-related industries. *J. Sci. Food Agric.* 92, 216-223.
- 504 Piotrowska, A., Iamarino, G., Rao, M.A., Gianfreda, L., 2005. Short-term effects of
505 olive mill waste water (OMW) on chemical and biochemical properties of a
506 semiarid Mediterranean soil. *Soil Biol. Biochem.* 38, 600-610.
- 507 Ramírez, E., Gandul-Rojas, B., Romero, C., Brenes, M., Gallardo-Guerrero, L., 2015.
508 Composition of pigments and colour changes in green table olives related to
509 processing type. *Food Chem.* 166, 115-124.
- 510 Recuenco, M.E., Raposo, R., Melgarejo, P., De los Santos, B., Romero, F., López-
511 Aranda, J.M., 2005. Evaluation of the resistance of advanced selections and
512 cultivars of strawberry to powdery mildew - nursery trials. *Tests of*
513 *Agrochemicals and Cultivars* 26, 20-21.
- 514 Rodríguez-Lucena, P., Hernández, D., Hernández-Apaolaza, L., Lucena, J.J., 2010.
515 Revalorization of a two-phase olive mill waste extract into a micronutrient
516 fertilizer. *J. Agric. Food Chem.* 58, 1085-1092.
- 517 Romero, C., Medina, E., De Castro, A., Brenes, M., De los Santos, B., Romero, F.,
518 2011. Procedimiento para la obtención de una solución favorecedora del
519 crecimiento de plantas a partir de aguas de lavado de aceitunas verdes estilo
520 español y uso de dicha solución. Patent P2011322006 (CSIC, IFAPA).
- 521 Romero, C., Medina, E., Mateo, M.A., Brenes, M., 2017. Quantification of bioactive
522 compounds in Picual and Arbequina olive leaves and fruit. *J. Sci. Food Agric.* 97,
523 1725-1732.
- 524 Romero, C., Medina, E., Mateo, M.A., Brenes, M., 2018. New by-products rich in
525 bioactive substances from the olive oil mill processing. *J. Sci. Food Agric.* 98,
526 225-230.
- 527 Seyyednejad, S.M., Niroomand, A., Abrahimpour, F., Gilani, A., Khaniki, G.B., 2017.
528 Olive pomace potential appropriate alternative of chemical fertilizers on the
529 growth and yield of the three rice varieties. *Int. J. Adv. Biotechnol. Res.* 8, 2239-
530 2244.

- 531 Simpson, D.W., 1987. The inheritance of mildew resistance in everbearing and day-
532 neutral strawberry seedlings. J. Hortic. Sci. 62, 329-334.
- 533 Sønsteby, A., Heide, O.M., 2007. Long-day control of flowering in everbearing
534 strawberries. J. Hortic. Sci. Biotech. 82, 875-884.
- 535 Tejada, M., González, J. L., 2003. Effects of foliar application of a byproduct of the
536 two-step olive oil mil process on maize yield. Agronomie 23, 617-623.
- 537 Trandel, M.A., Vigardt, A., Walters, S.A., Lefticariu, M., Kinsel, M., 2018. Nitrogen
538 isotope composition, nitrogen amount, and fruit yield of tomato plants affected by
539 the soil–fertilizer types. ACS Omega 3, 6419–6426.
- 540 Vieira, I.G.S., Nobre, R.G., Dias, A.S., Pinheiro, F.W.A., 2016. Cultivation of cherry
541 tomato under irrigation with saline water and nitrogen fertilization. Rev. Bras.
542 Eng. Agríc. Ambient. 20, 55-61.
- 543 Zipori, I., Dag, A., Laor, Y., Levy, G.J., Eizenberg, H., Yermiyahu, U., Medina, S.,
544 Saadi, I., Krasnovski, A., Raviv, M., 2018. Potential nutritional value of olive-mill
545 wastewater applied to irrigated olive (*Olea europaea* L.) orchard in a semi-arid
546 environment over 5 years. Sci. Hortic. 241, 218-224.

Figure captions

Fig. 1. Image of two crops (tomato and strawberry) assayed in the greenhouse when wash water from Spanish-style green olive processing of the 'Hojiblanca' cultivar was applied to the treated plants (A and B) or tap water in the control plants (C and D) through irrigation.

Fig. 2. Plant height and cumulative yield of the tomato cultivar (cv. 'Optima') treated with two solutions from table olives, storage liquid from black olive processing (A and C) and wash water from Spanish-style green olive processing (B and D). The applied solutions were diluted 1:4 (20%) or 1:1 (50%) with tap water. The control solution was tap water. The application mode was by dipping, spraying and irrigation. The standard error for six replicates is drawn on the bars. For each application mode, vertical bars with different letters indicate significant differences according to the LSD test ($p < 0.05$).

Fig. 3. Cumulative yield and total powdery mildew on leaves detected in the strawberry cultivar (cv. 'Camarosa') treated with two solutions from table olives, storage liquid from black olive processing (A and C) and wash water from Spanish-style green olive processing (B and D). The applied solutions were diluted 1:4 (20%) or 1:1 (50%) with tap water. The control solution was tap water. The application mode was by dipping, spraying and irrigation. The standard error of six replicates is drawn on the bars. For each application mode, vertical bars with different letters indicate significant differences according to the LSD test ($p < 0.05$).

Table 1

Chemical characterization of table olive solutions employed in different experiments. Concentrations of sugars, phenols and oleosides are expressed as mmols L⁻¹; acetic acid, carbon, nitrogen, sodium and potassium concentrations are expressed as g L⁻¹; concentration of phosphorus is expressed as mg L⁻¹. Storage liquid from black olive processing from the 'Hojiblanca' cultivar (SL1, SL2); wash water from Spanish-style green olive processing from the 'Hojiblanca' cultivar (WWH1, WWH2, WWH3); wash waters from Spanish-style green olive processing, from the 'Manzanilla' cultivar (WWM2, WWM3).

	Experiment 1		Experiment 2			Experiment 3	
	SL1	WWH1	SL2	WWH2	WWM2	WWH3	WWM3
Acetic acid	3.2 ± 0.2 ^a	0.1 ± 0.0	0.2 ± 0.1	ND ^b	ND	0.1 ± 0.0	0.1 ± 0.0
Sucrose	1.3 ± 0.1	ND	ND	ND	ND	0.1 ± 0.0	ND
Glucose	10.6 ± 0.7	44.2 ± 1.8	3.9 ± 0.4	8.4 ± 0.2	46.8 ± 1.5	29.0 ± 0.7	32.3 ± 0.8
Fructose	2.5 ± 0.2	8.5 ± 0.2	2.1 ± 0.2	4.2 ± 0.4	19.9 ± 0.5	7.9 ± 0.3	18.1 ± 0.1
Mannitol	49.4 ± 2.8	31.8 ± 1.3	22.7 ± 0.8	4.7 ± 0.3	10.1 ± 0.6	14.7 ± 0.9	6.8 ± 0.1
Total sugars	63.7 ± 21.1	84.5 ± 19.0	28.7 ± 4.8	17.3 ± 2.9	76.7 ± 10.8	51.7 ± 11.5	57.2 ± 13.1
Hydroxytyrosol	8.6 ± 0.4	14.5 ± 1.2	8.6 ± 0.5	5.5 ± 0.6	13.7 ± 1.0	11.6 ± 0.9	13.4 ± 0.3
Hydroxytyrosol 4-Glucoside	1.9 ± 0.3	4.0 ± 1.1	2.3 ± 0.7	1.4 ± 0.2	1.6 ± 0.3	7.5 ± 0.2	2.3 ± 0.4
Tyrosol	0.6 ± 0.1	1.2 ± 0.4	0.8 ± 0.2	3.5 ± 0.2	2.4 ± 0.3	1.2 ± 0.3	1.4 ± 0.1
HyEDA ^c	1.0 ± 0.2	ND	0.3 ± 0.1	ND	ND	ND	ND
Others phenols ^d	0.8 ± 0.2	0.5 ± 0.1	1.8 ± 0.2	0.1 ± 0.0	0.3 ± 0.1	0.7 ± 0.2	0.3 ± 0.1
Total phenols	12.9 ± 3.6	20.2 ± 4.2	13.8 ± 2.1	10.5 ± 1.9	18.0 ± 2.7	21.0 ± 2.8	17.4 ± 3.5
EDA ^e	1.4 ± 0.3	ND	1.7 ± 0.3	ND	ND	ND	ND
Oleoside-11-methyl ester	0.7 ± 0.2	ND	0.5 ± 0.2	ND	ND	ND	ND
Others oleosides ^f	3.4 ± 0.7	1.9 ± 0.3	1.6 ± 0.3	0.8 ± 0.2	2.0 ± 0.3	2.2 ± 0.4	1.9 ± 0.2
Total oleosides	5.5 ± 1.5	1.9 ± 0.3	3.8 ± 0.9	0.8 ± 0.2	2.0 ± 0.3	2.2 ± 0.4	1.9 ± 0.2
Carbon	13.1 ± 2.5	19.6 ± 0.7	14.1 ± 1.3	7.9 ± 0.1	13.4 ± 0.4	8.2 ± 0.2	14.5 ± 0.4
Nitrogen	0.3 ± 0.1	3.6 ± 0.1	0.4 ± 0.1	2.9 ± 0.2	2.9 ± 0.1	2.3 ± 0.1	2.7 ± 0.1
Sodium	0.5 ± 0.1	2.1 ± 0.3	0.4 ± 0.1	2.3 ± 0.4	1.7 ± 0.1	2.7 ± 0.6	1.7 ± 0.1
Potassium	2.3 ± 0.2	1.4 ± 0.1	2.2 ± 0.2	1.7 ± 0.1	2.3 ± 0.2	1.6 ± 0.1	1.0 ± 0.1
Phosphorus	8.4 ± 0.7	60.5 ± 8.3	104.0 ± 5.8	53.9 ± 7.5	33.2 ± 3.6	52.0 ± 6.7	36.0 ± 4.5

^aValues are shown as mean ± SE. ^bND: not detected; ^cHyEDA: dialdehydic form of decarboxymethyl elenolic acid linked to hydroxytyrosol; ^dOther phenols: sum of hydroxytyrosol glycol, salidroside, caffeic and *p*-cumaric acids, hydroxytyrosol acetate, verbascoside and oleuropein; ^eEDA: dialdehydic form of decarboxymethyl elenolic acid; ^fother oleosides: sum of oleoside, secoxyloganin and secologanoside.

Table 2

Value of morphological and production parameters of two crops (tomato, cv. 'Optima', and strawberry, cv. 'Camarosa'). The effect of three variables (application mode, sort of table olive wastewaters, solution dose) has been tested. See Experiment 1. SL1 means Storage Liquid from black olive processing from the 'Hojiblanca' cultivar; WWH1 means Wash Water from Spanish-style green olive processing from the 'Hojiblanca' cultivar.

	Application mode			Table olive solutions		Solution : tap water	
	Dipping	Spraying	Irrigation	SL1	WWH1	1:4	1:1
<i>Tomato</i>							
Plant height (cm)*	40.7 ± 4.1 ^a b	44.0 ± 1.2 ab	50.9 ± 9.1 a	43.2 ± 0.9 b	49.1 ± 6.9 a	46.4 ± 6.0	48.8 ± 8.5
Flowering (flowers plant ⁻¹), 35 dpt ^b	3.0 ± 0.24	3.0 ± 0.33	3.0 ± 0.16	2.79 ± 0.20	3.2 ± 0.20	3.0 ± 0.21	3.0 ± 0.20
Medium number of fruits per plant*	1.2 ± 0.2 b	1.2 ± 0.2 b	1.6 ± 0.3 a	1.2 ± 0.2	1.5 ± 0.3	1.3 ± 0.3	1.4 ± 0.3
Fruit medium caliber (cm)*	3.4 ± 0.6 b	3.6 ± 0.8 ab	4.6 ± 0.7 a	3.7 ± 4.1	4.1 ± 0.9	3.9 ± 0.5	3.9 ± 1.0
Fruit medium weight (g fruit ⁻¹)*	23.1 ± 2.8 b	27.6 ± 4.2 b	49.9 ± 7.2 a	29.4 ± 3.4	38.5 ± 5.6	31.5 ± 3.4	36.9 ± 5.6
Cumulative yield (g plant ⁻¹)*	26.0 ± 3.5 b	31.1 ± 4.4 b	71.5 ± 8.7 a	32.4 ± 3.3 b	53.7 ± 7.3 a	39.0 ± 4.4	48.0 ± 7.4
Length of the roots (cm)*	36.8 ± 1.7	34.1 ± 1.4	32.8 ± 1.6	35.2 ± 1.4	33.8 ± 1.2	35.4 ± 1.3	33.6 ± 1.3
Medium weight of the roots (g)*	8.2 ± 0.4 b	7.7 ± 0.4 b	9.2 ± 0.4 a	7.7 ± 0.2 b	9.1 ± 0.4 a	8.6 ± 0.4	8.2 ± 0.4
<i>Strawberry</i>							
Plant diameter (cm)**	21.7 ± 1.3	20.1 ± 2.4	22.7 ± 1.8	21.8 ± 1.6	21.3 ± 2.5	22.1 ± 1.4	20.9 ± 2.5
Flowering (flowers plant ⁻¹) 55 dpt	0.3 ± 0.1 b	1.5 ± 0.3 a	1.0 ± 0.2 a	1.0 ± 0.2	0.9 ± 0.2	1.1 ± 0.2	0.9 ± 0.2
Medium number of fruits per plant**	1.5 ± 0.3	2.1 ± 0.4	2.5 ± 0.4	1.9 ± 0.3	2.2 ± 0.3	2.1 ± 0.3	2.0 ± 0.3
Fruit medium weight (g fruit ⁻¹)**	8.3 ± 0.6	9.3 ± 0.8	9.6 ± 0.7	16.8 ± 8.2	20.4 ± 11.9	19.3 ± 8.0	17.9 ± 12.2
Cumulative percentage of fruiting plant (%)**	60.0 ± 11.2 b	79.2 ± 8.5 ab	92.7 ± 5.8 a	73.5 ± 7.7	82.4 ± 6.6	79.4 ± 7.0	76.5 ± 7.4
Cumulative yield (g plant ⁻¹)**	12.4 ± 2.9	18.9 ± 3.4	23.9 ± 4.1	9.0 ± 0.7	9.4 ± 0.6	9.3 ± 0.6	9.2 ± 0.7

^aValues are shown as mean ± SE. ^bdpt: days post-transplant. * 2 months post-transplant. ** 4 months post-transplant. Row values per each variable followed by the different lowercase letters indicate significant differences according to the LSD test ($p < 0.05$).

Table 3

Value of morphological and production parameters in cucumber cultivar (cv. 'Beautiful'). The effect of two variables (sort of table olive wastewaters and solution dose) has been tested. See Experiment 2. WW means Wash Water from Spanish-style green olive processing from the 'Hojiblanca' (WWH2) and 'Manzanilla' (WWM2) cultivars; SL2 means Storage Liquid from black olive processing from the 'Hojiblanca' cultivar.

	Solutions tested				Solution : tap water	
	WWH2	WWM2	SL2	KNO ₃	1:4	1:1
Plant height (cm) [*]	70.4 ± 2.1 ^a	75.6 ± 2.8	75.9 ± 2.7	79.4 ± 2.3	75.4 ± 2.0	75.3 ± 1.7
AUCP ^{b,**}	393.7 ± 13.2 b	422.0 ± 13.9 ab	425.8 ± 13.6 ab	451.9 ± 13.4 a	425.9 ± 10.6	420.9 ± 9.9
Percentage of flowering (%) [*]	66.7 ± 14.2	50.0 ± 15.0	66.7 ± 14.2	50.0 ± 15.1	54.2 ± 10.4	62.5 ± 10.1
Flowering (flowers plant ⁻¹) [*]	1.2 ± 0.3	1.0 ± 0.3	1.1 ± 0.3	0.7 ± 0.2	1.1 ± 0.2	0.9 ± 0.2
Medium number of fruits per plant ^{**}	4.0 ± 0.3 b	4.3 ± 0.3 ab	3.8 ± 0.3 b	4.9 ± 0.3 a	4.2 ± 0.2	4.4 ± 0.2
Fruit medium diameter (cm) ^{**}	4.0 ± 0.1	3.8 ± 0.1	4.1 ± 0.1	3.8 ± 0.1	4.0 ± 0.1	3.9 ± 0.1
Fruit medium length (cm) ^{**}	15.9 ± 0.5	14.5 ± 0.3	15.6 ± 0.6	15.5 ± 0.4	16.1 ± 0.3	15.6 ± 0.1
Fruit medium weight (g fruit ⁻¹) ^{**}	165.8 ± 13.7 a	130.6 ± 8.6 b	176.9 ± 14.5 a	129.8 ± 8.9 b	161.9 ± 10.4	139.6 ± 7.2
Cumulative yield (g plant ⁻¹) ^{**}	656.1 ± 59.3	554.1 ± 34.7	657.3 ± 54.7	626.9 ± 41.1	651.5 ± 33.7	595.7 ± 34.6

^aValues are shown as mean ± SE. ^bAUCP means area under the curve of the plant height progress. ^{*} 20 days post-transplant. ^{**} 3 months post-transplant. Row values per each variable followed by the different lowercase letters indicate significant differences according to the LSD test ($p < 0.05$).

Table 4

Value of morphological and production parameters in pepper (“Pepper green bell”). The effect of two variables (sort of table olive wastewaters and solution dose) has been tested. See Experiment 2. WW means Wash Water from Spanish-style green olive processing from the ‘Hojiblanca’ (WWH2) and ‘Manzanilla’ (WWM2) cultivars; SL2 means Storage Liquid from black olive processing from the ‘Hojiblanca’ cultivar.

Solutions tested	Plant height (cm) [*]	AUCP ^{a,**}	Medium number of fruits per plant ^{**}	Fruit medium diameter (cm) ^{**}	Fruit medium length (cm) ^{**}	Fruit medium weight (g fruit ⁻¹) ^{**}	Cumulative yield (g plant ⁻¹) ^{**}
WWH2-20 ^b	93.6 ± 2.8 ^c a	1781.2 ± 33.4 a	10.2 ± 1.7 a	2.6 ± 0.1 bc	8.9 ± 0.4 bc	16.1 ± 1.0 bcd	164.6 ± 31.0 ab
WWH2-50	89.2 ± 1.2 abc	1699.5 ± 29.7 bc	5.3 ± 1.9 bc	2.9 ± 0.2 ab	9.0 ± 0.5 abc	17.4 ± 2.6 bc	80.3 ± 23.0 cd
WWM2-20	90.2 ± 1.7 abc	1718.2 ± 29.0 abc	7.7 ± 0.3 ab	2.5 ± 0.1 c	8.6 ± 0.4 bc	15.0 ± 1.8 cde	116.2 ± 17.5 bc
WWM2-50	87.5 ± 1.9 bc	1732.2 ± 25.9 abc	7.7 ± 1.0 ab	2.3 ± 0.2 c	7.2 ± 0.4 d	10.1 ± 1.5 e	72.3 ± 7.6 cd
SL2-20	91.7 ± 1.8 ab	1755.4 ± 16.5 ab	3.8 ± 0.9 c	2.5 ± 0.1 c	8.4 ± 0.5 cd	12.1 ± 2.1 de	53.2 ± 17.0 d
SL2-50	89.7 ± 2.5 abc	1705.9 ± 37.9 abc	6.7 ± 0.8 bc	3.1 ± 0.2 a	9.8 ± 0.5 ab	20.9 ± 1.2 ab	141.8 ± 19.0 ab
KNO ₃ -20	79.0 ± 0.9 d	1578.5 ± 27.9 d	5.7 ± 0.8 bc	2.2 ± 0.1 c	7.2 ± 0.5 d	11.4 ± 2.3 de	63.8 ± 15.6 cd
KNO ₃ -50	86.3 ± 2.4 c	1654.3 ± 31.6 cd	10.0 ± 1.4 a	2.5 ± 0.1 c	9.0 ± 0.6 abc	14.9 ± 1.5 cde	158.0 ± 29.0 ab
WATER	92.5 ± 0.9 ab	1773.9 ± 16.5 ab	8.5 ± 0.8 ab	3.2 ± 0.2 a	10.3 ± 0.2 a	23.0 ± 1.1 a	191.9 ± 10.4 a

^aAUCP means area under the curve of the plant height progress. ^bTable olive wastewaters used were diluted 1:4 (20) or 1:1 (50) with tap water. Two control solutions were used, water and KNO₃ solution diluted with tap water. ^cValues are shown as mean ± SE. ^{*}56 days post-transplant. ^{**}4 months post-transplant. Column values per each variable followed by the different lowercase letters indicate significant differences according to the LSD test ($p < 0.05$).

Table 5

Value of morphological and production parameters in tomato cultivar (cv. 'Optima') irrigated with washing waters of Spanish-style green olives (WWH3 and WWM3). See Experiment 3. WW means Wash Water from Spanish-style green olive processing from the 'Hojiblanca' (WWH3) and 'Manzanilla' (WWM3) cultivars.

	WWH3-20 ^a	WWH3-50	WWM3-20	WWM3-50	Water	KNO ₃ -50
Plant height (cm)*	58.1 ± 1.8 ^b ab	61.9 ± 1.4 a	55.5 ± 1.6 bc	60.3 ± 1.8 a	51.6 ± 1.2 c	54.8 ± 1.9 bc
Flowering (flowers plant ⁻¹), 30 dpt ^b	4.0 ± 0.4	3.8 ± 0.3	5.3 ± 0.6	4.3 ± 0.3	4.0 ± 0.4	4.7 ± 0.8
Medium number of fruits per plant*	1.7 ± 0.3 cd	2.3 ± 0.2 abc	2.0 ± 0.3 bcd	3.0 ± 0.3 a	1.3 ± 0.2 d	2.7 ± 0.5 ab
Fruit medium caliber (cm)*	5.2 ± 0.3	5.6 ± 0.2	5.3 ± 0.5	5.1 ± 0.2	5.0 ± 0.2	4.5 ± 0.3
Fruit medium weight (g fruit ⁻¹)*	87.2 ± 14.4	99.5 ± 8.1	93.7 ± 17.1	79.1 ± 2.8	72.5 ± 8.6	64.0 ± 8.0
Cumulative yield (g plant ⁻¹)*	132.2 ± 17.8 b	224.5 ± 7.0 a	168.4 ± 8.7 b	235.5 ± 16.7 a	88.6 ± 4.8 c	155.3 ± 11.7 b
Length of the roots (cm)*	27.3 ± 4.0	29.0 ± 2.4	27.2 ± 3.1	28.8 ± 2.0	26.8 ± 0.9	31.6 ± 1.4
Medium weight of the roots (g)*	2.1 ± 0.1 b	2.2 ± 0.2 b	3.2 ± 0.4 a	3.2 ± 0.6 a	1.6 ± 0.1 b	2.5 ± 0.1 ab

^aTable olive wastewaters used were diluted 1:4 (20) or 1:1 (50) with tap water. Two control solutions were used, water and KNO₃ solution diluted with tap water. ^bValues are shown as mean ± SE. ^bdpt: days post-transplant. *3 months post-transplant. Row values per each variable followed by the different lowercase letters indicate significant differences according to the LSD test ($p < 0.05$).

Figure 1

Figure 2

Figure 3