Reuse of industrial wastewater for the irrigation of ornamental plants
R. Gori, C. Lubello, F. Ferrini, F. P. Nicese and E. Coppini

ABSTRACT
This paper describes the results of experimental activities carried out for verifying the possibility of reusing reclaimed wastewater originated from textile (70%) and domestic (30%) activities for the irrigation of container-grown ornamental shrubs. Aspects that concern the refinery treatment of reclaimed wastewater and the effect of irrigation on some ornamental plant species were investigated. An experimental site consisting of a refinery treatment pilot plant (filtration and disinfection) and an agronomic experimental area was set-up. The combined treatment of PAA and UV, used for the disinfection, showed to be very effective for inactivation of E. coli with most of PAA and UV dose combinations able to assure total inactivation. The plants (Buxus, Photinia, Pistacia and Viburnum), sprinkle and drip irrigated with well water (WW), reclaimed wastewater (RW) and a water mixed (MW) between reclaimed wastewater and well water (1:1 by vol), showed interesting results. A similar growth among different treatments was achieved for Buxus and Pistacia, while Viburnum and Photinia plants showed a higher sensibility to MW and RW. Photinia, in particular, turned out to be very sensitive to sprinkle irrigation with the reclaimed water, while the drip irrigation had no such bad effects, as reported in previous works.

Key words | disinfection, irrigation, ornamental plants, phytotoxicity, textile wastewater, water reuse,

INTRODUCTION
Nursery container production of woody plants is likely to be one of the agriculture practices with the highest water demand and this explains why in most nursery areas irrigation water supply has become a major concern (Bailey et al. 1996). For many years the nursery producers have been facing increasing pressures to avoid using high-quality water supplies for irrigation (Gordon 1994). Therefore, it is important to evaluate alternative water sources for irrigation (so called not-conventional water resources) in order to maintain a high qualitative and quantitative production standards. Among the non-conventional water resources, Reclaimed Waste Water (RWW) can be considered the most important for irrigation.

In this paper is dealt with the case of Pistoia (Tuscany, Italy) which represents one of the main nursery areas in Europe with a devoted surface of 5,000 ha for both field-grown and container-grown plants. Local groundwater represents the main water resource both for irrigation and civil consumption causing serious shortage problems during summer period.

In this scenario the use of RWW for nursery irrigation can represent an interesting alternative source of water and nutrients. Research previously carried out in Pistoia, provided good results using civil RWW to irrigate several ornamental plant species (Gori et al. 2000, 2004; Lubello et al. 2004). However the amounts of RWW available in the nursery area can only partially cover the water demand for the irrigation of container grown plants which is around 12 Mm³/y. As a consequence it was considered also the possibility of reusing effluents coming from WWTPs located...
in Prato (Tuscany, Italy) which is few kilometres far from the nursery area and represents one of the biggest Italian textile district.

Among the many aspects that must be considered in a RWW reuse project, the two following ones were considered in this research:

- identifying a suitable refinery treatment facility in order to make the effluent in compliance with the national regulations (D.M. 185/2003) for RWW to be reused for irrigation;
- the effect of RWW on some ornamental plant species representative of the local nursery production.

Reuse of industrial wastewater for irrigation

With the exception of a few specific cases (see for example Mohsen & Jaber 2003; Aharoni & Cikurel 2006) industrial wastewater are rarely considered a possible source for irrigation because of their possible negative impacts on soil and plants.

In particular textile effluents are usually considered not suitable for irrigation; as a matter of fact wastewater originated from wet textile processes are characterized by the presence of colour, surfactants and high salinity whose removal by biological processes (especially for salinity) is negligible. In addition high salinity is usually due to high concentration of sodium and chloride ions which are well known to be responsible of phytotoxic phenomena for plants and detrimental effects on soil structure.

As a consequence in the scientific literature only a small number of applications in the nursery–ornamental plants sector are reported (Singh et al. 2001; Bhati & Singh 2003) with different responses.

Concerning the agronomic aspects, this work was aimed at evaluating the suitability of textile RWW in comparison with traditional well water source, for the irrigation of four container-grown ornamental species characterized by different salt tolerance.

Refinery treatment of industrial wastewater for irrigation

In spite of treatments able to reduce salt content has been considered for the treatment of municipal and industrial wastewater to be reused for irrigation (Jolis et al. 1995; Aharoni & Cikurel 2006) these are usually considered too expensive. Refinery treatment of industrial RWW to be reused for irrigation are usually aimed at reducing the suspended solids (SS) and microbial content. For this latter sand filtration and physical or chemical disinfection are usually used (Gómeza et al. 2006) even if membrane-filtration have been proposed showing excellent results but higher costs (Gómeza et al. 2007).

In this case, for the refinement of reclaimed textile wastewater, sand filtration and disinfection with a combined treatment of Peracetic Acid (PAA) and UV was experimented as it already demonstrated to be very effective for the disinfection of municipal RWW to be reused for irrigation purposes (Caretti & Lubello 2003).

MATERIALS AND METHODS

The trial was carried out within the Calice Wastewater Treatment Plant (WWTP), located in Prato, which treats on average 25,000 m$^3$/d of sewage wastewater originated from textile (70%) and domestic (30%) activities.

The WWTP is based on preliminary and primary treatment (screening, grit and oil removal, chemically enhanced primary sedimentation) and a conventional nitrification-denitrification activated-sludge process. Due to the poor-settling capacity of the activated sludge, secondary effluent is further treated with coagulation-flocculation and chemical decolourization before to be discharged in the receiving water body. The experimental site set up within the Calice WWTP consisted of a refinery treatment pilot plant, and an agronomic experimental area (see Figure 1 for layout).

Refinery treatment pilot plant

The pilot plant was aimed at achieving the limit of 10 Escherichia coli (E. coli) in 100 mL set by national regulations (D.M. 185/2003) for RWW to be reused for irrigation. The pilot plant consisted of sand filtration, and disinfection with Peracetic Acid (PAA) and UV irradiation system.

For filtration of Calice WWTP effluent a sand filter already used for the refinement of effluent reused for internal purposes. During this experimentation, we evaluated the
effect of the addition of PAA upstream the UV device (see Figure 1) which bring about the formation of hydroxyl radicals $\cdot OH$ due to the photolysis of the PAA when in presence of the UV rays (Caretti & Lubello 2003).

PAA was added through a commercial solution containing, by weight, hydrogen peroxide (28%), acetic acid (8%), water and stabilizers (59%) and PAA (5%). UV irradiation was provided by a cylindrical closed system (diameter 163 mm, length 792 mm, 13.6 litres volume, contact time of 7 s at a flow rate of 8 m$^3$/h) equipped with 8 low pressure lamps (electric power 0.8 kW) (mod. M8S, Montagna s.r.l.). Different doses of UV (between 129 and 170 mJ/cm$^2$) and PAA (between 0 and 16 mg PAA/l) were tested. The solution of sand filtered RWW with the desired PAA concentration was prepared in batch condition and pumped to the UV device. According to the information provided by the manufacturer, different UV doses were provided changing the flow rate (from 2 to 8 m$^3$/h) and the dose was calculated taking into account the absorbance of water at 254 nm.

The analytical method used for determination of *E. coli* content was the Membrane Filter Technique according to the ISO 9308-1 method (Cultural media: T.B.X medium; Incubation: 24 h at 44°C).

**Agronomic experiment**

The agronomic effects of the Calice WWTP effluent were evaluated with an experiment carried out using one-year-old uniform cutting propagated plants of Laurustinus (*Viburnum tinus*) and Buxus (*Buxus sempervirens*), two evergreen bushy habit shrub, Fraser Photinia (*Photinia x “Fraseri”* var. “Red Robin”), a medium sized shrub and Evergreen Pistache (*Pistacia Lentiscus*), a small to medium-sized shrub. On 4 May 2004, a total of 800 plants (200 per each species) were planted in 3 litre (18 cm dia) black plastic containers using a peatmoss-pumice medium (1:1 by vol) supplemented with a 5 kg/m$^3$ of a slow-release fertilizer (Osmocote Exact 5-6, 15N-9P-9K and microelements, Scotts Co.).
Plants were placed outdoors in an area within the Calice WWTP; irrigation water was provided from three different sources: reclaimed wastewater refined by the tertiary treatment pilot plant (RW), well-water after ponding (WW) and a water mixed (MW) between reclaimed wastewater and well water (1:1 by vol). Plants were irrigated twice a day both as drip irrigation (DI) (with 0.75 l) and sprinkle irrigation (SI) (with 10 mm as water heights) through a series of valves regulated by a PLC. Six treatments (DI-SI and RW-WW-MW) were arranged in a randomized complete block design with 5 replicates (10 plants each) per treatment. Standard commercial nursery production for irrigation and pest control were followed.

At the beginning, in mid August and at the end of the growing season, six plants for each specie, water treatment and irrigation method were planted out. Fresh weights were recorded immediately, and dry weights after the vegetative material was oven-dried at 80°C until constant weight was achieved. All the data were subjected to analysis of variance.

### Wastewater characterization

During the experimental period the quality of RWW (RW), well-water (WW) and mixed water (MW) was monitored as summarized in Table 1. All samples for physical-chemical analysis were taken during irrigation (at least once a month for WW and twice a week for RW) and immediately analyzed (except for sodium) according to the methods indicated in Table 1. MW was analyzed for the main parameters; parameters not analyzed can be indicatively obtained through a mass balance considering the mixing ratio between WW and RW.

#### RESULTS AND DISCUSSION

### Wastewater characterization

The main chemical–physical characteristics of the water sources used in the agronomic experiment are summarized in Table 1.

Results of water quality monitoring show that while the WW quality characteristics were such to make it suitable for the irrigation of any type of plant, the RW and MW (in spite of the blending of RW with WW) have a sub-optimal physical-chemical quality especially with respect to conductivity, sodium and chloride ions concentration. As a matter of fact sodium and chloride ions are considered to be potentially phytotoxic because they can antagonize the uptake of other elements (such as calcium, potassium) or

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Method</th>
<th>Well water</th>
<th>RWW (WW)</th>
<th>Mixed water (RW)</th>
<th>Optimal range (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>pH unit</td>
<td>Specific probe</td>
<td>7.69 ± 0.21</td>
<td>8.09 ± 0.35</td>
<td>7.94 ± 0.21</td>
<td>5.8–6.5</td>
</tr>
<tr>
<td>Conductivity</td>
<td>µS/cm</td>
<td>Specific probe</td>
<td>799 ± 78</td>
<td>1972 ± 177</td>
<td>1401 ± 137</td>
<td>≥ 1200</td>
</tr>
<tr>
<td>TSS</td>
<td>mg/l</td>
<td>IRSA-CNR 2090 method</td>
<td>n.d.</td>
<td>3.4 ± 1.1</td>
<td>n.a.</td>
<td>–</td>
</tr>
<tr>
<td>COD</td>
<td>mg/l</td>
<td>Rapid kit (Merck Spectroquant)</td>
<td>27.4 ± 16.1</td>
<td>68.2 ± 14.9</td>
<td>n.a.</td>
<td>–</td>
</tr>
<tr>
<td>Ammonium</td>
<td>mg N/l</td>
<td>Rapid kit (Merck Spectroquant)</td>
<td>0.52 ± 0.32</td>
<td>0.74 ± 1.12</td>
<td>n.a.</td>
<td>–</td>
</tr>
<tr>
<td>Nitrate</td>
<td>mg N/l</td>
<td>Rapid kit (Merck Spectroquant)</td>
<td>5.0 ± 0.26</td>
<td>15.3 ± 14.9</td>
<td>n.a.</td>
<td>–</td>
</tr>
<tr>
<td>Orthophosphate</td>
<td>mg P/l</td>
<td>Rapid kit (Merck Spectroquant)</td>
<td>n.d.</td>
<td>0.1 ± 0.01</td>
<td>n.a.</td>
<td>–</td>
</tr>
<tr>
<td>Potassium</td>
<td>mg/l</td>
<td>IRSA-CNR 3240 method</td>
<td>3 ± 0.5</td>
<td>22.2 ± 9.1</td>
<td>n.a.</td>
<td>–</td>
</tr>
<tr>
<td>Surfactants</td>
<td>mg/l</td>
<td>IRSA-CNR 5170 + 5180 methods</td>
<td>n.a.</td>
<td>0.79 ± 0.3</td>
<td>n.a.</td>
<td>–</td>
</tr>
<tr>
<td>Absorbance –</td>
<td></td>
<td>Absorbance at 420 nm</td>
<td>n.d.</td>
<td>0.05 ± 0.01</td>
<td>n.a.</td>
<td>–</td>
</tr>
<tr>
<td>Chloride</td>
<td>mg/l</td>
<td>IRSA-CNR 4090 method</td>
<td>41.6 ± 4.9</td>
<td>390 ± 127</td>
<td>220 ± 69.5</td>
<td>≤ 50</td>
</tr>
<tr>
<td>Sodium</td>
<td>mg/l</td>
<td>IRSA-CNR 3270 method</td>
<td>36.8 ± 0.8</td>
<td>318 ± 120</td>
<td>185 ± 40.2</td>
<td>≤ 50</td>
</tr>
<tr>
<td>Calcium</td>
<td>mg/l</td>
<td>IRSA-CNR 3130 method</td>
<td>104.4 ± 0.4</td>
<td>70.8 ± 14</td>
<td>n.a.</td>
<td>50–120</td>
</tr>
<tr>
<td>Magnesium</td>
<td>mg/l</td>
<td>IRSA-CNR 3180 method</td>
<td>40.4 ± 0.35</td>
<td>22.9 ± 4.2</td>
<td>n.a.</td>
<td>25–50</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>mgCaCO₃/l</td>
<td>IRSA-CNR 2010 method</td>
<td>345.7 ± 4.7</td>
<td>316.5 ± 105.2</td>
<td>n.a.</td>
<td>≤ 130</td>
</tr>
</tbody>
</table>

Adapted from Whipker (1999), n.d.: not detectable, n.a: not analyzed.
accumulate in leaf tissues causing burning or scorch (Whipker 1999). Nevertheless, it is important to highlight that concentration of sodium and chloride as well as conductivity value responsible for the arising of adverse effects vary between plant species and with plant age.

Table 1 shows also that conductivity, sodium and chloride are characterized by high standard deviation values. It is due to the significantly lower values registered in August due to shutdown of most of the textile factories in the surrounding area and the consequent reduction of the industrial component in the Calice WWTP influent.

Concerning mineral content, the major differences between RW and WW were detected for potassium and nitrate content while ammonium contents appeared to be very similar.

Reclaimed wastewater disinfection

The sand filter effluent showed a SS content comprised between 2 and 6 mg/L which makes the effluent suitable for UV disinfection. Nevertheless the sand filter efficiency in SS removal was not very satisfactory and its improvement could be associated with a great benefit for microbial inactivation with UV. As a matter of fact, this latter is very sensitive to increase of TSS concentration when TSS content is low (indicatively < 5 mg TSS/l) (Janex et al. 1998).

The transmittance at 254 nm (radiation wavelength of low pressure UV lamps) of filtered effluent was comprised in the range 0.13–0.51 with a mean value of 0.31, indicating a really high UV absorbance capacity due to the residual organics, such as dyes and surfactants, not removed in the WWTP.

The E. coli content in the filtered samples before the disinfection treatment varied between 980 and 2,800 CFU/100 ml with a mean value of about 1,900 CFU/100 ml.

The Table 2 shows the average results of disinfection with PAA and UV, expressed both as Log E. coli inactivation and E. coli content, obtained during the experiments for different combination of PAA and UV doses. For the calculation of mean log inactivation, we associated all total inactivation to 3.45 which corresponds to the Log of the maximum E. coli content measured in our experiments.

The addition of PAA upstream UV showed to be very effective for inactivation of E. coli in the filtered effluent of Calice WWTP.

For most of the PAA and UV combinations the mean content of E. coli was lower than 10 CFU/100 ml. In the case of combinations with low UV dose results showed that:

- most of samples complied with law limit but some of them exceeded the law limit;
- the E. Coli inactivation was highly variable clearly showing a more sensitivity of these combinations to changes of effluent characteristics.

In Table 3, among all experimented combinations of PAA and UV doses, are shown those that assured total

### Table 2 | Ranges and average values of Log inactivation and E. coli content for different combinations of PAA and UV doses (values are average of 6 samples)

<table>
<thead>
<tr>
<th>PAA (mg/l)</th>
<th>UV (mJ/cm²)</th>
<th>Mean and range of Log Inactivation</th>
<th>Mean and range of E. coli content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>129</td>
<td>155</td>
<td>170</td>
</tr>
<tr>
<td>2</td>
<td>n.a.</td>
<td>n.a.</td>
<td>T.I.</td>
</tr>
<tr>
<td>4</td>
<td>1.92 (0.4–2.68)</td>
<td>2.84 (1.91–3.45)</td>
<td>T.I.</td>
</tr>
<tr>
<td>8</td>
<td>2.55 (1.81–2.98)</td>
<td>3.17 (2.39–3.45)</td>
<td>T.I.</td>
</tr>
<tr>
<td>16</td>
<td>3.24 (2.78–3.43)</td>
<td>T.I.</td>
<td></td>
</tr>
</tbody>
</table>

*Introduced before the UV device. T.I.: total inactivation of E. coli; n.a.: not analyzed.

### Table 3 | Combinations of PAA and UV able (+) or not (–) to assure total inactivation or compliance with the law value for all samples

<table>
<thead>
<tr>
<th>UV (mJ/cm²)</th>
<th>Total inactivation in all samples</th>
<th>Compliance with the law limit in all samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
<tr>
<td>4</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>8</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>16</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

n.a.: not analyzed.
inactivation or compliance with the value set by law in all samples analyzed.

Results confirmed the synergy between PAA and UV; as a matter of fact for both PAA and UV, within the experimented dose ranges, the higher was the dose the higher was the \textit{E. coli} inactivation. Figure 2 shows the trends of mean log inactivation as a function of UV and PAA doses.

In order to determine the best combination of PAA and UV doses between the different solutions which guarantee compliance to Italian legislation an economic analysis was performed for operating costs considering a continuous (24 h a day) running of the plant, including costs for chemicals (0.46 €/l of a 15% PAA solution) and energy (0.1 €/kWh). Results of the analysis are shown in Table 4.

Results of Table 4 show that the operating costs of UV and PAA combinations that are able to assure the compliance with the law value for all samples, are in the range of 0.046–0.088 €/m³. The combination of 2 mg PAA/l and 170 mJ/cm² of UV was the cheapest solution.

Agronomic results

After 25 weeks of irrigation, results of plant growth monitoring show a different response of the species tested to irrigation water, as reported in other research carried out on ornamentals (\textit{Fitzpatrick et al.} 1986; \textit{Wu et al.} 1995). As a matter of fact, \textit{Buxus} and \textit{Pistacia} plants didn’t show any remarkable effect, regardless of water source and irrigation method used (Figure 3). On the other hand \textit{Viburnum} and \textit{Photinia} had a significant decrease in plant growth from WW to MW and RW, and \textit{Photinia}, in particular, showed an interaction between water source and irrigation method (drip irrigation being more effective than sprinkle). As reported in previous works (\textit{Wu et al.} 2001) this could be due to a phytotoxic phenomena caused by leaf direct contact with salts and the accumulation of Na⁺ and Cl⁻ in leaf tissues when sprinkle irrigation is used.

CONCLUSIONS

In this paper the results of experimental activities carried out for verifying the possibility of reusing RWW originated from textile (70%) and domestic (30%) activities for the irrigation of container-grown ornamental shrubs were described. Aspects that concern the refinery treatment of reclaimed wastewater and the effect of irrigation on some ornamental plant species were investigated.

The addition of PAA upstream UV irradiation confirmed to be very effective for inactivation of \textit{E. coli} in the case of textile wastewater with most of PAA and UV dose combinations able to assure total inactivation or to comply with the value set by law in all samples analyzed.

Reclaimed wastewater showed sub-optimal characteristics for the irrigation especially with respect to conductivity,
sodium and chloride ions concentration even if blended with well water. Nevertheless, the suitability of this kind of water for the irrigation of ornamental plants was partly confirmed, but the use of drip irrigation rather than sprinkle irrigation should be suggested in order to avoid a decrease in the quality of the plants produced due to tip and edge burn of leaves. Actually, because of the salt-sensibility of numerous plants, the use of a tertiary effluent with such water quality can always be recommended for short periods, as an emergency water supply.

ACKNOWLEDGEMENTS

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