Reuse of treated wastewater and sewage sludge for fertilization and irrigation

Gonçalo Sousa, David Fangueiro, Elizabeth Duarte and Ernesto Vasconcelos

ABSTRACT

The objective of the present work was to assess the short term potential of treated wastewater and sewage sludge for ornamental lawn fertilization and irrigation. A field experiment was performed and the following treatments were considered: sewage sludge application + irrigation with public water; sewage sludge application + irrigation with treated wastewater; irrigation with public water; irrigation with treated wastewater (TW). Irrigation with treated wastewater showed a positive effect on lawn installation through higher growth of grass (1,667 cm) and higher dry matter yield (18,147 g m$^{-2}$). These results represent a significant increase in the grass yield compared with public water irrigation. The grass height (2,606 cm) and dry matter yield (23,177 g m$^{-2}$) increased even more, when sewage sludge produced in the wastewater treatment plant (WWTP) was applied to soil, which proves once more its benefits as an organic fertilizer. At the end of the experiment, an increase of some soil parameters (pH, electrical conductivity, organic matter, Ca$^{2+}$, Na$^{+}$, K$^{+}$, Mg$^{2+}$ and NH$_4^{+}$) was observed, indicating that treated wastewater irrigation can cause a soil sodization. This short term study indicated that use of treated wastewater and sewage sludge for ornamental lawn fertilization and irrigation is an environmentally sustainable option for re-use of the WWTP by-products.

Key words | fertilization, irrigation, lawn, nitrogen, sewage sludge, treated wastewater

INTRODUCTION

Treatment of wastewater is essential to avoid environmental pollution and human health hazards (Boonsong & Chansiri 2008). Wastewater treatment plants (WWTP) allow us to obtain treated wastewater with high quality standards, but considerable levels of organic matter and nutrients, namely nitrogen, still remain in such waters (Pereira et al. 2009).

Nowadays, the high volume of treated wastewater generated in a large WWTP can be reused in industry and particularly for irrigation of agricultural soils where it may be considered as fertigation depending on the nutrient concentrations (Asano 2002). In some countries in southern Europe, the high consumption of water caused by the climate can cause ecological problems (E.E.A. 2009). Thus, wastewater reuse for irrigation is important for water resource preservation and land use planning (Pereira et al. 2009). Nevertheless, in small or medium WWTPs, it may not be economically sustainable to have the required equipment for the reuse of the treated wastewater, and consequently it is generally discharged to water bodies.

Conversely, a large amount of sewage sludge is generally produced in WWTPs. Sewage sludge may be applied to soil and the main benefit of land application of sewage sludge is related to its high potential fertilizer, resulting from its wealth of organic matter and its stabilization degree (Evanylo 2009). Some nutrients from the sewage sludge, such as nitrogen (N), phosphorus (P) and potassium (K) are recycled and provide large amounts of organic matter, which will benefit the physical and chemical soil characteristics. The greatest constraint to the use of sewage sludge is related to its high content of heavy metals, which can accumulate in the soil at levels harmful to plants.

Irrigation and fertilization of ornamental areas of the WWTP may be an alternative for reuse of treated wastewater.
and sewage sludge produced in the WWTP. Indeed, in the summertime, lawns require high water volumes and a daily irrigation (Trenholm et al. 2002). Furthermore, the fertilization of the lawn may be performed using only the sewage sludge and the treated wastewater, rich in nutrients.

The main objectives of the present study were to assess the potential of treated wastewater and sewage sludge for irrigation and fertilization of ornamental lawns established at the WWTP.

### MATERIALS AND METHODS

#### Soil and sewage sludge preparation

The experimental plots were prepared through removal of the first 20 cm substituted by a 10 cm layer of sand (to improve soil drainage) covered with a 10 cm layer of sandy clay soil taken from a forest area, located in Herdade do Monte da Barca forest fertile soil. For its characterization, a representative sample was dried outdoors to reduce biological activity (Cabrera & Kissel 1988) and sieved at 2 mm. Sewage sludge applied to the soil was collected at the WWTP and kept at 4°C until used. Soil and sewage sludge were analyzed using standard methods (USEPA 1989; Carter 1993) and their main characteristics are shown in Table 1.

#### Experiment set-up

Four treatments were established: sewage sludge application at sowing and irrigation with public water (SPW); sewage sludge application at sowing and irrigation with treated wastewater (STW); irrigation with public water (PW); irrigation with treated wastewater (TW), and a randomized system of plots was used (Figure 1).

Sewage sludge was applied to soil (1 kg m⁻²) in six plots whereas the other six did not receive any fertilizer. Sowing of grass was done with a seed mixture (60% Festuca arundinacea, 30% Lolium perenne, 10% Poa pratensis) at a density of 50 g seed m⁻².

Irrigation of plots was performed daily, except when rainfall occurred. The daily amounts of water (irrigation and precipitation) added in each plot are shown in Figure 2.

Samples of treated wastewater were collected in bottles of high density polyethylene, transported in a cool box and stored at a temperature of about 4°C. Treated wastewater analysis was performed for the recommended parameters (APHA/AWWA/WEF 1998). The main characteristics of

### Table 1 | Soil and sewage sludge characteristics; mean of three replicates (dry weight basis)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Sewage sludge</th>
<th>Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH_{H_2O}</td>
<td>8.49</td>
<td>5.80</td>
</tr>
<tr>
<td>pH_{KCL}</td>
<td>/</td>
<td>4.77</td>
</tr>
<tr>
<td>Electrical conductivity (μS cm⁻¹)</td>
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<td>37.70</td>
</tr>
<tr>
<td>Dry matter (g kg⁻¹)</td>
<td>257.20</td>
<td>/</td>
</tr>
<tr>
<td>Organic C (g kg⁻¹)</td>
<td>/</td>
<td>4.27</td>
</tr>
<tr>
<td>Organic matter (g kg⁻¹)</td>
<td>487.50</td>
<td>7.60</td>
</tr>
<tr>
<td>NH₄⁺-N (mg kg⁻¹)</td>
<td>3,270.00</td>
<td>3.79</td>
</tr>
<tr>
<td>NO₃⁻-N (mg kg⁻¹)</td>
<td>4.33</td>
<td>18.47</td>
</tr>
<tr>
<td>Kjeldhal N (g kg⁻¹)</td>
<td>42.95</td>
<td>/</td>
</tr>
<tr>
<td>K (mg kg⁻¹)</td>
<td>1,200.00</td>
<td>44.64</td>
</tr>
<tr>
<td>P (mg kg⁻¹)</td>
<td>2,310</td>
<td>8.65</td>
</tr>
<tr>
<td>Cu (mg kg⁻¹)</td>
<td>127.97</td>
<td>0.70</td>
</tr>
<tr>
<td>Zn (mg kg⁻¹)</td>
<td>824.39</td>
<td>21.60</td>
</tr>
<tr>
<td>Fe (mg kg⁻¹)</td>
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<td>Mn (mg kg⁻¹)</td>
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<td>29.90</td>
</tr>
<tr>
<td>Ca (cmol(+) kg⁻¹)</td>
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<td>1.09</td>
</tr>
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<td>Na (cmol(+) kg⁻¹)</td>
<td>80.00</td>
<td>0.05</td>
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<tr>
<td>Cd (mg kg⁻¹)</td>
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<td>/</td>
</tr>
<tr>
<td>Mg (cmol(+) kg⁻¹)</td>
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<td>0.16</td>
</tr>
<tr>
<td>Ni (mg kg⁻¹)</td>
<td>19.75</td>
<td>/</td>
</tr>
<tr>
<td>Pb (mg kg⁻¹)</td>
<td>67.86</td>
<td>/</td>
</tr>
<tr>
<td>As (mg kg⁻¹)</td>
<td>12.14</td>
<td>/</td>
</tr>
<tr>
<td>Cr (mg kg⁻¹)</td>
<td>31.47</td>
<td>/</td>
</tr>
</tbody>
</table>
the treated wastewater and public water used are shown in Table 2.

The height of grass was measured (with ruler) at six random points in each plot on days 14, 21, 28, 35, 42, 49, 56, 63 and 70. Soil samples (N = 3) from the superficial layer (0–10 cm) were collected in each plot on days 0, 7, 14, 21, 28, 35, 42, 49, 56, 63 and 70. Soil samples were then analyzed in terms of dry matter, determined by drying at 105°C during 24 h and mineral N content determined by extraction with 2 mol/l KCL (1:5 w/v) (Mulvaney 1996) followed by ammonium (NH4+-N) and nitrate (NO3--N) quantification by molecular absorption spectrophotometry in a Skalar segmented flow analyzer.

At the end of the experiment (10 weeks), the grass was cut, weighed and dried in a forced ventilation oven at 65°C, to determine dry weight. Dry grass was ground in an Ultra Centrifugal Mill Retsch and the total nitrogen content determined by Kjeldahl method. Soil samples were also collected (N = 3) in each plot and fully characterized following the methods previously described.

### Statistical analysis

The results were analyzed by analysis of variance (one way) to test the effects of each treatment. The statistical significance of the mean differences was determined using the least significant difference tests based on a t-test at a 0.05 probability level. The statistical software package used was Statistix 7.0.

### RESULTS AND DISCUSSION

#### Mineral N evolution in soil

Sewage sludge application was equivalent to an addition of 3.27 g of NH4+-N and 4.33 mg of NO3--N to each plot.

### Table 2 | Public water and treated wastewater characteristics

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Public water</th>
<th>Treated wastewater</th>
</tr>
</thead>
<tbody>
<tr>
<td>NO3--N (mg L⁻¹)</td>
<td>&lt;10</td>
<td>0.08</td>
</tr>
<tr>
<td>NH4+-N (mg L⁻¹)</td>
<td>&lt;0.02</td>
<td>15.31</td>
</tr>
<tr>
<td>pH</td>
<td>7.8</td>
<td>7.66</td>
</tr>
<tr>
<td>CE (μS cm⁻¹)</td>
<td>290</td>
<td>784.67</td>
</tr>
<tr>
<td>SO4²⁻ (mg L⁻¹)</td>
<td>&lt;10</td>
<td>80.53</td>
</tr>
<tr>
<td>Cl (mg L⁻¹)</td>
<td>40</td>
<td>88.63</td>
</tr>
<tr>
<td>HCO₃⁻ (meq L⁻¹)</td>
<td>/</td>
<td>2.22</td>
</tr>
<tr>
<td>B (mg L⁻¹)</td>
<td>&lt;0.3</td>
<td>0.08</td>
</tr>
<tr>
<td>SAR</td>
<td>10.39</td>
<td>8.36</td>
</tr>
<tr>
<td>As (mg L⁻¹)</td>
<td>&lt;0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Cd (mg L⁻¹)</td>
<td>&lt;0.001</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Pb (mg L⁻¹)</td>
<td>&lt;0.005</td>
<td>0.04</td>
</tr>
<tr>
<td>Cr (mg L⁻¹)</td>
<td>&lt;0.002</td>
<td>0.15</td>
</tr>
<tr>
<td>Ni (mg L⁻¹)</td>
<td>&lt;0.01</td>
<td>0.03</td>
</tr>
<tr>
<td>Cu (mg L⁻¹)</td>
<td>&lt;0.01</td>
<td>0.10</td>
</tr>
<tr>
<td>Fe (mg L⁻¹)</td>
<td>&lt;0.05</td>
<td>1.79</td>
</tr>
<tr>
<td>Mn (mg L⁻¹)</td>
<td>&lt;0.015</td>
<td>0.47</td>
</tr>
<tr>
<td>Zn (mg L⁻¹)</td>
<td>/</td>
<td>0.26</td>
</tr>
</tbody>
</table>
A significant decrease of the NH₄⁺-N content was observed in SPW and STW treatments after the first week (p < 0.05) (Table 3). Such a decrease occurred at a lower rate in STW treatment where the NH₄⁺-N content remained significantly higher (p < 0.05) than in SPW treatment until 14 days. In treatments with no sludge application (PW and TW), NH₄⁺-N content in soils remained lower than 9 mg kg⁻¹ during all the experiments. Until the end of the experiment, the soil in SPW and STW treatment showed a low NH₄⁺-N content (<8 mg kg⁻¹). After the 14th day, higher NH₄⁺-N contents were observed in treatments irrigated with treated wastewater than in treatments irrigated with public water. This was due to the NH₄⁺ addition (about 15.30 mgN-NH₄⁺ L⁻¹) to the soil through irrigation with treated wastewater (except on 49th day, where SPW > STW, and the 70th day where SPW > TW).

An increase of NO₃⁻-N content was observed in soils from SPW and STW treatments until the 14th day, followed by a gradual decrease until the 28th day (Table 4). In PW and TW, there was an initial increase of NO₃⁻-N content into the soil, until the 7th day at a lower rate than in SPW and STW, followed by a decrease until the 21st day. The increase of NO₃⁻-N observed in STW and SPW, for the first 14 days was probably due to nitrification of N present in the sewage sludge, which is in agreement with the decrease of NH₄⁺-N content observed in these treatments during the same time period. In the PW and TW treatments, the increase in the NO₃⁻ level was due mainly to nitrification of the N present in the soil. Similarly, Boeira et al. (2002) observed a decrease of NH₄⁺-N and correspondingly an increase of NO₃⁻-N.

A strong decrease of mineral N was observed during the first 7 days in treatments where sewage sludge was applied (SPW and STW) (Figure 3). Such a decrease continued in STW until day 21 whereas in SPW, the mineral N content remained constant between the 7th and 14th days and then decreased until day 21. The decline of soil mineral N in these treatments during the first 7 days should be due to N losses by leaching or N immobilization, but not to N absorption by plants, since grass germinated only after eight days. Initially, PW and TW treatments had a lower content of mineral N than SPW and STW because the soil had a lower mineral N content, and the increase of this parameter (until 7th day) can be explained by the N mineralization in the soil. This variation resulted from N immobilization and nitrification which occurs naturally in soil, although in this experiment, NO₃⁻ content only increased in the initial phase.

An increase of mineral N content in soil amended with sewage sludge was observed during aerobic incubation by several authors (Carneiro et al. 2007; Barajas-Aceves et al. 2002), indicating that the sewage sludge is able to provide nitrogen available for plants, shortly after its application to soil. Furthermore, Boeira & Maximiliano (2009) observed a quick nitrification during aerobic incubation of soil amended with sewage sludge. This situation observed in laboratory experiments was not always observed in field experiments where a strict control of factors influencing

### Table 3 | Average values of soil ammonium-N content in treatments during experiment (mg NH₄⁺-N kg⁻¹ soil) (N – 3)

<table>
<thead>
<tr>
<th>Time (d)</th>
<th>SPW</th>
<th>STW</th>
<th>PW</th>
<th>TW</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>A 109.47&lt;sup&gt;a&lt;/sup&gt;</td>
<td>A 109.47&lt;sup&gt;a&lt;/sup&gt;</td>
<td>B 3.79&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>B 3.79&lt;sup&gt;g&lt;/sup&gt;</td>
</tr>
<tr>
<td>7</td>
<td>B 8.95&lt;sup&gt;b&lt;/sup&gt;</td>
<td>B 8.95&lt;sup&gt;b&lt;/sup&gt;</td>
<td>B 5.13&lt;sup&gt;b&lt;/sup&gt;</td>
<td>B 6.33&lt;sup&gt;def&lt;/sup&gt;</td>
</tr>
<tr>
<td>14</td>
<td>A 5.64&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>A 5.64&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>A 5.64&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>A 5.50&lt;sup&gt;ef&lt;/sup&gt;</td>
</tr>
<tr>
<td>21</td>
<td>B 5.29&lt;sup&gt;def&lt;/sup&gt;</td>
<td>B 5.29&lt;sup&gt;def&lt;/sup&gt;</td>
<td>B 5.29&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>B 7.79&lt;sup&gt;abc&lt;/sup&gt;</td>
</tr>
<tr>
<td>28</td>
<td>C 3.65&lt;sup&gt;def&lt;/sup&gt;</td>
<td>C 3.65&lt;sup&gt;def&lt;/sup&gt;</td>
<td>C 3.65&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>C 7.00&lt;sup&gt;bcd&lt;/sup&gt;</td>
</tr>
<tr>
<td>42</td>
<td>A 7.57&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>A 7.57&lt;sup&gt;bc&lt;/sup&gt;</td>
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<td>B 7.00&lt;sup&gt;bcd&lt;/sup&gt;</td>
</tr>
<tr>
<td>56</td>
<td>C 4.32&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>C 4.32&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>C 4.32&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>C 4.32&lt;sup&gt;cd&lt;/sup&gt;</td>
</tr>
<tr>
<td>70</td>
<td>AR 5.94&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>AR 5.94&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>AR 5.94&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>AR 5.94&lt;sup&gt;cd&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

In the same row, values preceded by the same capital letter are not significantly different (p < 0.05). In the same column, values followed by the same letter are not significantly different (p < 0.05). SPW – sewage sludge + public water; STW – sewage sludge + treated wastewater; PW – public water; TW – treated wastewater.

### Table 4 | Average values of soil nitrate-N content in treatments during experiment (mg NO₃⁻-N kg⁻¹ soil) (N – 3)

<table>
<thead>
<tr>
<th>Time (d)</th>
<th>SPW</th>
<th>STW</th>
<th>PW</th>
<th>TW</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>A 18.27&lt;sup&gt;c&lt;/sup&gt;</td>
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<td>A 18.47&lt;sup&gt;b&lt;/sup&gt;</td>
<td>A 18.47&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>7</td>
<td>B 21.06&lt;sup&gt;b&lt;/sup&gt;</td>
<td>B 21.06&lt;sup&gt;b&lt;/sup&gt;</td>
<td>B 19.26&lt;sup&gt;a&lt;/sup&gt;</td>
<td>B 21.19&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>14</td>
<td>A 25.09&lt;sup&gt;a&lt;/sup&gt;</td>
<td>A 25.43&lt;sup&gt;a&lt;/sup&gt;</td>
<td>B 17.53&lt;sup&gt;b&lt;/sup&gt;</td>
<td>B 18.25&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
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<td>B 2.48&lt;sup&gt;d&lt;/sup&gt;</td>
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<td>35</td>
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<td>A 1.35&lt;sup&gt;f&lt;/sup&gt;</td>
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<td>A 1.00&lt;sup&gt;def&lt;/sup&gt;</td>
<td>A 1.16&lt;sup&gt;cd&lt;/sup&gt;</td>
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<td>B 2.15&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>B 1.95&lt;sup&gt;de&lt;/sup&gt;</td>
<td>B 2.80&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

In the same row, values preceded by the same capital letter are not significantly different (p < 0.05). In the same column, values followed by the same letter are not significantly different (p < 0.05). SPW – sewage sludge + public water; STW – sewage sludge + treated wastewater; PW – public water; TW – treated wastewater.
N mineralization is not performed. Nevertheless, Shepherd (1996) also observed, in a field experiment, N leaching losses from a sandy soil amended with sewage sludge. Similarly, Dynia et al. (2006) observed NO$_3^-$-N leaching in a Typic Haplustox cropped with maize after successive applications of sewage sludge.

**Evolution of grass height**

Until the 28th day, all treatments showed a significant growth ($p < 0.05$) proven by the differences of grass average heights which follow the relationship: STW > SPW > TW > PW (Figure 4).

The differences between all treatments remained (28th and 49th days), except for SPW and TW, which showed no significant differences ($p > 0.05$), even if a decrease of grass growth was observed in all treatments. From the 49th day, TW showed greater height, than SPW. During the final stage of experiment (65rd–70th day), the differences of grass average heights were again significant between all treatments ($p < 0.05$), verifying the following relationship: STW > TW > SPW > PW.

All treatments showed more evident grass growth at the initial stage of the experiment, probably due to absorption of N present in the soil and applied through the sewage sludge (Figure 5). The decrease of grass growth verified in all treatments should result from the lower availability of N in the soil. Such an effect was less pronounced in STW and TW, probably due the daily N addition through irrigation with the treated wastewater (fertigation).
Dry matter yield, grass N content and N exportation

A higher dry matter yield was obtained in the STW (even if not statistically different from the one obtained in the TW treatment) and the lower one was obtained in the PW treatment (Table 5). The greatest amount of nitrogen available from sewage sludge and treated wastewater in STW explained the highest dry matter yield obtained. A higher yield was obtained in TW treatment relative to SPW treatment, because the amount of N provided by the treated wastewater irrigation (10.18 g N plot\(^{-1}\)) was higher than sewage sludge application in the soil (7.21 g N plot\(^{-1}\)). Hence, it may be concluded that fertigation with treated wastewater was more efficient for grass fertilization than application of sewage sludge at sowing. The lowest dry matter yield obtained in PW treatment was due to the residual amount of nutrients present in public water, which limited the growth of grass.

Irrigation with treated wastewater was beneficial for grass yield, because it showed good potential as a nutrient source, which resulted in higher yields than irrigation with public water. Azevedo et al. (2007) in previous experiments, where they used two different soil types, found significant increases (>37%) in dry matter yield of grass irrigated with treated wastewater, compared to grass irrigated with public water. Beltrão et al. (1999) found similar results in experiments using wastewater and public water with different nitrogen contents.

According to the fertilization needs of plants, if irrigation with treated wastewater is supplemented with mineral or organic fertilizer, the yield will be higher, as observed in this experiment. The highest dry matter yield obtained in STW confirmed results obtained by Monteiro (1994) who showed that an increase of grass yield can be obtained when irrigation with urban wastewater is combined with fertilizer application.

A higher grass N content was found in STW treatment (23.20 g kg\(^{-1}\)), relative to SPW (17.98 g kg\(^{-1}\)) and TW (19.44 g kg\(^{-1}\)) treatments, which showed no significant differences \((p > 0.05)\) between them, (Table 5). A significantly lower grass N content was found in PW treatment (15.34 g kg\(^{-1}\)), relative to other treatments \((p < 0.05)\). The highest grass N content in STW resulted from the largest amount of nitrogen applied in this treatment (sewage sludge and irrigation with treated wastewater). In SPW and TW treatments, nitrogen was applied at different rates and in different forms; however the differences were not significant \((p > 0.05)\). In PW, the absence of fertilization, which affected the growth of grass, also caused a lower grass N content. Similar results were obtained by Monteiro (1994).

Table 5 | Dry matter yield, grass N content and N exportation – mean of six replicates

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Dry matter (g m(^{-2}))</th>
<th>Grass N content (g kg(^{-1}))</th>
<th>N exportation (g m(^{-2}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPW</td>
<td>108.30(^{bc})</td>
<td>17.98(^{b})</td>
<td>1,947.56(^{c})</td>
</tr>
<tr>
<td>STW</td>
<td>231.77(^{a})</td>
<td>23.20(^{a})</td>
<td>5,377.76(^{a})</td>
</tr>
<tr>
<td>PW</td>
<td>16.40(^{c})</td>
<td>15.34(^{c})</td>
<td>251.63(^{d})</td>
</tr>
<tr>
<td>TW</td>
<td>181.47(^{ab})</td>
<td>19.44(^{b})</td>
<td>3,528.32(^{b})</td>
</tr>
</tbody>
</table>

In the same column, values followed by the same letter are not significantly different \((p < 0.05)\). SPW – sewage sludge + public water; STW – sewage sludge + treated wastewater; PW – public water; TW – treated wastewater.
The highest N exportation was verified in STW treatment, as a result of greater N amount provided by sewage sludge and treated wastewater (Table 5). Differences in grass N content between SPW and TW treatments were not statistically significant (P > 0.05), however N exportation in TW was higher than in SPW. PW treatment showed the smallest N exportation since a very low amount of N was provided in this treatment.

The differences in height, dry matter yield and N\textsubscript{k} content of grass, were also highlighted by the appearance of the grass (color intensity, density of plants …). Indeed, treatments irrigated with treated wastewater (STW, TW) had a better appearance comparatively to treatments irrigated with public water (SPW, PW). Beltrão et al. (1999) also reported a better appearance of the grass irrigated with wastewater, than grass irrigated with public water without nitrogen.

**Soil characteristics at the end of the experiment**

An increase of soil pH was observed in all treatments even if it was more significant in STW and SPW treatments (Table 6). This could be related to sewage sludge application to soil and to the pH of the irrigation water used in the experiment (public water and treated wastewater). Pinto (1995) reported that sewage sludge application in acid soils may caused soil alkalinization and Medeiros et al. (2005) also observed an increase of pH in soil irrigated with filtered wastewater and attributed it to the addition of exchange cations (Ca\textsuperscript{2+}, K\textsuperscript{+}, Na\textsuperscript{+}, Mg\textsuperscript{2+}) and to the alkaline pH of the irrigation water.

The largest increase of soil electrical conductivity was observed in treatments irrigated with treated wastewater (STW and TW). In SPW and PW treatments, an increase of this parameter was also noted, even if it was more evident in treatment with sewage sludge application (SPW). Thus, irrigation with treated wastewater and the application of sewage sludge into the soil induced significant increases in soil electrical conductivity (p < 0.05). However, this increase did not lead to values which may cause salinity problems in the short term. Similar results were obtained by Mohammad & Mazahreh (2003) and Gwenzi & Munondo (2008), who observed an increase in the value of the conductivity of the soil after irrigation with wastewater.

The soil organic matter and organic carbon increased significantly in STW, SPW and TW treatments, as a result of sewage sludge application and irrigation with treated wastewater. Similarly, Rattan et al. (2005) reported an increase of soil organic carbon in sandy soils irrigated with wastewater and an increase of soil organic carbon as a result of sewage sludge application to soil has been reported by Epstein (2005). Furthermore, sewage sludge application to soil also contributes significantly to increasing the organic N content of soil which in turn may be mineralized and supply mineral N for plants in the long term.

The increase of soil exchange cations (Ca\textsuperscript{2+}, Na\textsuperscript{+}, K\textsuperscript{+}, Mg\textsuperscript{2+}), namely Na\textsuperscript{+}, was significant in all treatments (p < 0.05). This accumulation was caused by the high Na\textsuperscript{+} concentration of treated wastewater (176.6 mg L\textsuperscript{−1}), however, the contribution of the sewage sludge was not negligible because an increase was also observed in SPW treatment. In their experiments, Medeiros et al. (2005), verified an increase in the Na\textsuperscript{+} concentration of the soil, after irrigation with wastewater, caused by the Na\textsuperscript{+} concentration of the wastewater (43.18 mg Na\textsuperscript{+} L\textsuperscript{−1}).

**CONCLUSIONS**

Results obtained in the present study provided useful information for implementing a WWTP sub-products (treated...
wastewater and sewage sludge) management plan. Our study showed that, in the short term, treated wastewater and sewage sludge appeared to be useful for irrigation and fertilization of a mixture of Festuca arundinacea, Lolium perene and Poa pratensis in the green spaces surrounding a WWTP. Nevertheless, more studies have to be performed to confirm the trends observed here but also to evaluate the medium and long term impact of the reuse of treated wastewater for irrigation combined with sludge application for fertilization. Furthermore, since higher quality standards of treated wastewater are required for agricultural use, the treated wastewater reuse for green spaces irrigation in the WWTP surrounding area is the most viable option from a sustainable environment perspective (environmental management approach). Such application is a good alternative to treated wastewater discharge to the water body, preserving water resources and contributing to implementation of the Portuguese program for efficient use of water in urban and agricultural components.

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