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Effect of fertigation using fish production wastewater on Pelargonium x zonale growth and nutrient content

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ABSTRACT

Aquaculture effluent can supply certain plant nutrients in adequate amounts. However, the nutrients present in the fish waste solution are not balanced. Mixing this effluent in an independent unit with a hydroponic nutrient solution can help to optimize conditions for the plants and minimize such drawbacks. The objective of this work was to assess the crop production and the nutritional responses of *Pelargonium zonale* fertigated with different percentages of fish wastewater. Five treatments were performed: 100NS, 75NS + 25AS, 50NS + 50AS, 25NS + 75AS and 100AS, where AS is the fish wastewater and NS a hydroponic nutrient solution. The species used to provide the fish waste solution was tilapia nilotica (*Oreochromis niloticus*). The results of this assay show that: i) fish wastewater can be utilized for the fertigation of *Pelargonium zonale* (a short-cycle crop) as there are no differences in the leaf, stem-petiole and flower dry matter, leaf water content, leaf area, plant height and leaf color compared to *Pelargonium zonale* fertigated with a chemical fertilizer; ii) the application of 75NS + 25AS accelerated flowers, shoots and leaves production. A higher percentage of fish waste solution mixed with the applied nutrient solution significantly reduces the K concentration in the nutrient solution and in the leaf; however, tilapia waste solution supplies adequate N, P and Ca nutrients to the pelargonium plants. Therefore, the reuse of fish waste solution can reduce the application rate of some inorganic fertilizers, which in turn can reduce the cost of fertilizers while preventing environmental pollution.

1. Introduction

Traditional agricultural systems are being confronted with globally declining resources resulting from climate change and a growing population (Saha et al., 2016). The European Water Framework Directive demands the good chemical and ecological status of water, and ground water resources, in the EU member states. Nowadays, treated wastewater is discharged into the sea, soil or river, which induces negative environmental effects. The reuse of reclaimed wastewater by farmers has several advantages, such as utilizing low-cost water resources and a reduced need for nutrient supplementation, which minimizes the application rate of commercial fertilizers (Prazeres et al., 2016).

Aquaponics consist of the integration of aquaculture and hydroponics, a soilless system for crop production (Love et al., 2015). Aquaponic systems have many advantages and are targeted at solving some of the problems the world is facing, including a population surge, soil degradation, water scarcity and food safety (Addy et al., 2017). Additionally, chemical and bacterial analyses have indicated that there is no evidence of any public health hazard associated with treated wastewater reuse in aquaculture (Khalil and Hussein, 1997). The aquaponic recirculation system has proven itself not only a successful method for biomass production, such as food crops, but also a useful system for recycling aquaculture wastewater (Endut et al., 2016), However, since aquaponics needs to balance the growth condition for both the fish and the vegetable produce, the overlap of the two sets of conditions often leaves only a thin margin for the system to succeed (Addy et al., 2017). One of the most critical points for this system is the different optimum pH levels for fish, plants and nitrates in the aquaponic system (Suhl et al., 2016). The efficiency of nitrification (a crucial process in aquaculture as it reduces the ammonium level, which is a major cause of toxicity for farmed fish) is higher in alkaline solutions, at a pH of 7.5–8.0; this is the reason for the relatively high pH in most aquaculture facilities. Plant growth can be affected by a high pH (> 7), while a pH of 5.8 is considered optimal for nutrient availability in hydroponics (Roosta and Mohsenian, 2012). Another critical issue is the nutrient supply. It has been reported that aquaponic systems that rely solely on fish waste to supply nutrients for plants have low levels of P, K, Fe, Mn and S (Roosta and Hamidpour, 2011). Therefore, to be effective at nutrient removal, aquaponic systems should be sized correctly to balance fish output and nutrient uptake by plants (Endut et al.,

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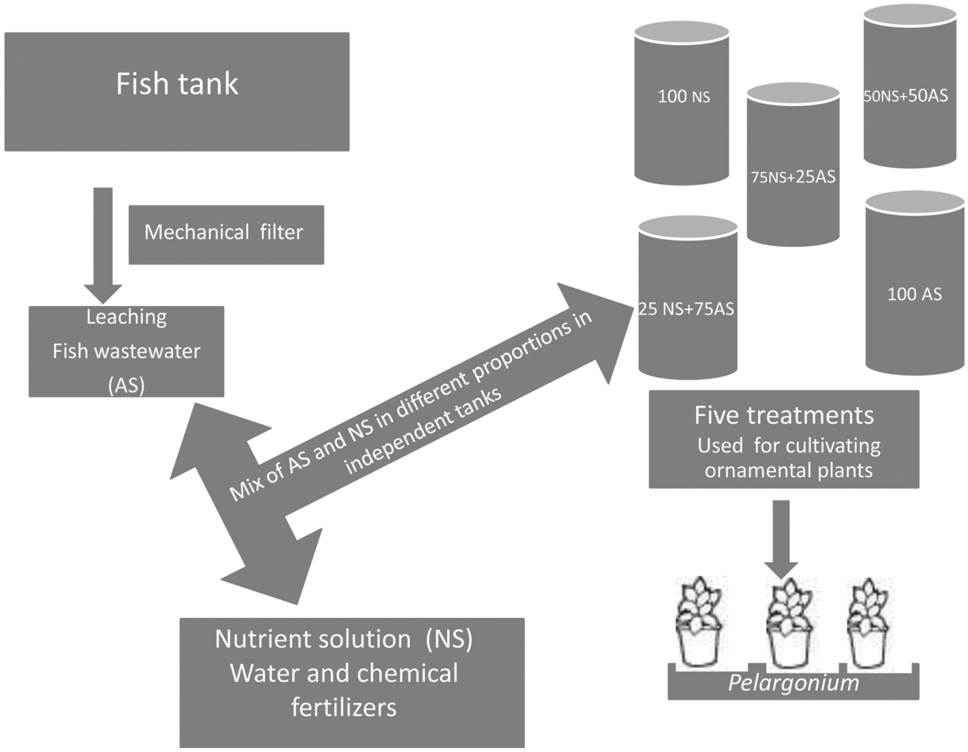

Fig. 1. Illustration of the general assay procedure. Fish wastewater was collected and cleaned using a mechanical filter. After collecting, the aquaculture wastewater was mixed with the nutrient solution in different proportions and used to grow hydroponics. Five treatments were set up: 100NS, 75NS + 25AS, 50NS + 50AS, 25NS + 75AS and 100AS; AS being the fish wastewater and NS the nutrient solution.

2016). In order to overcome the disadvantages mentioned above, Kloas et al. (2015) developed a new concept for aquaponic systems to improve sustainability, increase productivity and reduce environmental emissions. The aquaponic system for (nearly) emission-free tomato and fish production in greenhouses consists of 2 independent recirculating units: an aquaculture system for the fish, and a hydroponic unit for plants (Kloas et al., 2015). Both systems are connected by a 1-way valve to deliver fish water containing nutrients into the hydroponic reservoir, where the fish water can be optimized as fertilizer in order to meet the specific demands of the plant species (Kloas et al., 2015). The water and nutrients can be used twice, firstly for fish rearing and secondly for plant irrigation, enabling sustainable crop production (Suhl et al., 2018). The separation of the units allows the adjustment of optimal conditions such as pH and nutrient composition for both the production systems independently (Suhl et al., 2018), in order to increase productivity and prevent adverse interactions between the plant and fish units (Kloas et al., 2015). However, using fish wastewater in double recirculating aquaponic systems (DRAPS) increases the risk that the oxygen concentration drops to zero during the daytime in summer; a factor that can affect plant growth (Suhl et al., 2019). This is probably due to greater microorganism activity and a higher content of solids within the fish wastewater compared to fresh water (Suhl et al., 2019). Using fish wastewater on its own or mixed with a standard nutrient solution for the fertigation of pot plants, while controlling pH and EC, is standard practice for growers and is a good solution for avoiding this problem.

In this context, we hypothesized that different proportions of fish wastewater used in the fertigation would influence the nutritional responses of Pelargonium x zonale.

The objective of this work was to study crop production and the nutritional responses of *Pelargonium zonale* fertigated with four different percentages of fish wastewater (25, 50, 75 and 100%) compared to conventional fertigation.

2. Material and methods

2.1. Plant material and growing conditions

The trial was conducted in a tunnel greenhouse at the University of Almería. *Pelargonium zonale* plants were cultivated with peat moss and perlite (80:20 v/v) in 3.5 L black plastic square containers. This substrate provides an ideal medium for ornamental production because of its suitable physical properties, such as its high air and water-holding capacity. This substrate also has a low nutrient content, low level of decomposition and high cation exchange capacity which helps to reduce the leaching of nutrients. Temperature and relative humidity were recorded every 15 min with a HOBO U12-013 data logger (Onset Computer Corporation, Bourne, MA, USA) placed at canopy height in the central part of the cultivation table where the plants were grown. The vapour pressure deficit was estimated using the equation proposed by Rosenberg et al. (1983). External radiation was measured every 15 min with a Q20-B sensor. To estimate internal radiation, the cover transmission coefficient was estimated as a ratio between internal and external radiation, with a manual quantum photoradiometer (Detal OHM, model RAD/ PAR). The average temperature, vapour pressure deficit and photosynthetically active radiation were 20.2 °C, 1.14 kPa and 18.5 E m^{-2} day^{-1}, respectively. Maximum and minimum averages of the temperature and vapour pressure deficit were 30.7 and 11.8 °C and 1.97 and 0.63 kPa, respectively.

2.2. Treatments and fertigation

Fish wastewater was supplied from a tilapia production farm located in Cordoba "*Granjas piscícolas del Sur*". The fish species cultivated were tilapia nilotica (*Oreochromis niloticus*). The farm uses an intensive closed recirculating system with a density of 20 adults/m^{-3}. The renewal rate was 0.5% daily. After collecting, the fish wastewater was cleaned by a mechanical filter, mixed with the nutrient solution in different proportions in a tank and then used to fertigate the plants (Fig. 1). The standard nutrient solutions (Dickson and Fisher, 2017) were prepared with water and mineral fertilizer.

Table 1
Concentration of the nutrient solution used, expressed in mmol L^{-1}.

	100NS	75NS + 25AS	50NS + 50AS	25NS + 75AS	100AS
$H_2PO_4^-$	0.52 ± 0.02	0.48 ± 0.04	0.49 ± 0.05	0.47 ± 0.04	0.46 ± 0.02
Ca^{2+}	2.49 ± 0.20	2.18 ± 0.23	2.18 ± 0.27	2.01 ± 0.10	2.08 ± 0.11
Mg^{2+}	1.00 ± 0.12	0.90 ± 0.10	0.82 ± 0.12	0.82 ± 0.10	0.34 ± 0.11
K^+	2.99 ± 0.15	2.82 ± 0.14	2.23 ± 0.16	0.91 ± 0.64	0.80 ± 0.57
SO_4^{2-}	0.71 ± 0.05	0.63 ± 0.04	0.67 ± 0.09	0.86 ± 0.07	0.90 ± 0.13
$NO_3^- + NH_4^+$	7.24 ± 0.32	6.84 ± 0.30	6.83 ± 0.30	6.67 ± 0.30	6.57 ± 0.31
NO_3^-	7.04 ± 0.30	6.69 ± 0.23	6.72 ± 0.22	6.60 ± 0.25	6.56 ± 0.26
NH_4^+	0.20 ± 0.01	0.15 ± 0.02	0.11 ± 0.01	0.07 ± 0.02	0.01 ± 0.02
pH	6.5 ± 0.3	6.6 ± 0.2	6.6 ± 0.2	6.5 ± 0.1	6.6 ± 0.2
EC (dS m^{-1})	1.6 ± 0.2	1.4 ± 0.3	1.2 ± 0.2	1.0 ± 0.2	0.8 ± 0.3

There were 5 stock treatments, in which the percentage of fish wastewater varied: 100NS, 75NS + 25AS, 50NS + 50AS, 25NS + 75AS and 100AS. NS is the nutrient solution and AS the fish waste solution. An independent 50 L tank was used for each treatment. The solution was refreshed weekly. The pH in all the treatments was maintained at around 6.5. Nitric acid was added in order to balance the pH of the nutrient solutions. The composition of the nutrient solution was analyzed weekly during the trial. The nutrient solutions used are listed in Table 1. Fertigation was applied manually until the leachate fraction reached 20%. The average dose was 100 ml per plant per day. The water use efficiency was estimated as the ratio between the dry matter production of a plant (kg) divided by the total water use (L).

2.3. Plant parameters

The number of leaves, shoots and flowers per plant was counted each week during the crop cycle. Also, each week, the flowers were separated from the plants and weighed on a scale. Plant height was measured from the top edge of the pot to the tip of the last open leaf of the plant using a graduated rule. At the end of the assay, the plant material was washed and separated into different organs. Absorption organs (roots), conductive organs (stems and petioles), photosynthetic organs (leaves) and reproductive organs (flowers) were weighed on a Mettler Toledo PB-303-S to obtain the fresh weight. Afterwards, they were dried in a forced air oven at 60 °C for 48 h and weighed to obtain the dry weight (DW). The leaf water content was calculated as the ratio between leaf FW-DW and the leaf DW. The root:shoot DW ratio is the relationship between the root DW and the sum of the conductive organs, flowers and leaf DW. The leaf area was estimated by a non-destructive method, using the formula $S = a + b\text{LW}$, proposed by Giuffrida et al. (2011), where S is the foliar surface area, L is the leaf length (cm), A is the leaf width, and the coefficients a and b are specific to each species. The leaf length and width were measured using a ruler. Leaf color was identified according to the Munsell chart for leaves using three parameters (chroma, shine and intensity).

2.4. Nutrient solution analysis

The parameters determined in the nutrient solutions tested were pH, EC, NO_3^-, SO_4^{2-}, $H_2PO_4^-$, NH_4^+, Ca^{2+}, $Mg^{2+}$and K^+. pH was measured with a Crison MicropH 2001 pH-meter and EC with a Crison Micro CM 2200 conductivity meter. Anions and cations were determined by HPLC (High Performance Liquid Chromatography; Metrohm 883 Basic IC Plus). NO_3^-, SO_4^{2-} and $H_2PO_4^-$ were quantified using a Metrosep A SUPP 4 column (IC conductivity detector range 0–15 dS m^{-1}). The mobile phase was prepared by mixing 190.6 mg of CO_3^{2-} and 142.8 mg of HCO_3^- and then diluting this in 1 L of deionized water, acidified with H_2SO_4 (50 mM). The NH_4^+, Ca^{2+}, Mg^{2+} and K^+ were quantified using a Metrosep C4 column (IC conductivity detector range 0–15 dS m^{-1}) and the mobile phase was prepared by mixing 117 mg of 2 6-pyridinedicarboxylic acid and 1.7 mL of nitric acid (1 M) diluted in 1 L of deionized water. The pH was analyzed using a pH-meter following the methodology described by the Spanish Ministry of Agriculture and Fisheries (Ministry of Agriculture and Fishing, 1994).

2.5. Plant analysis

Leaves were dried in a forced air oven at 60 °C for 48 h and weighed on a Mettler Toledo PB-303-S scale to obtain the dry weight (DW). Afterwards, a subsample was ground in a Wiley mill. Total K^+ was directly measured by flame spectrophotometry (Lachica et al., 1973), using an Evans Electroselenium LTB Flame Photometer (Halstead, Essex, England). Total Ca^{2+} and Mg^{2+} were analyzed by atomic-absorption spectrophotometry (Hocking and Pate, 1977), using a Perkin Elmer Atomic Absorption Spectrometer 3300. P was analyzed using the method proposed by Hogue et al. (1970) and N using the method proposed by Krom (1980).

2.6. Experimental design and statistical analysis

The experimental design was a completely randomized block with 5 treatments, 4 replicates per treatment and 3 plants (pots) per replicate. The treatments' effect significance was examined using the standard analysis of variance (one-way ANOVA) and Fisher's Least Significant Difference (LSD) test, performed using Statgraphics Centurion XVI.II (Statpoint Technologies, Inc. Warrenton, Virginia, USA). Differences were considered significant at $P < 0.05$.

3. Results

3.1. Nutrient solution and water-use efficiency

Table 1 shows the means of the pH, EC and nutrient concentration for the nutrient solution. The pH for all the treatments was 6.5–6.6. The EC decreased with the increase in fish wastewater percentage due to the reduced nutrient inputs in this water. N, P and Ca, which had means of 6.57, 0.46 and 2.08 mmol L^{-1}, respectively, in the treatment with 100% fish waste solution, had e optimal values for bedding plant growth. The phosphorous concentration in the nutrient solution was similar in all the treatments. However, increasing the fish wastewater percentage led to an increase in the amount of sulphate, while decreasing K and Mg concentrations. The values for K and Mg in the nutrient solution for 100% AS were 0.80 and 0.34 mmol L^{-1}, respectively, which were above optimum levels (Rouphael et al., 2008). The water use efficiency improved as the AS proportion increased, the values being 4.0, 4.2, 4.1, 4.3 and 4.5 Kg m^3 for treatments 100NS, 75NS + 25AS, 50NS + 50AS, 25NS + 75AS and 100AS respectively.

3.2. Biometric parameters

No differences between treatments with respect to the leaf and stem-

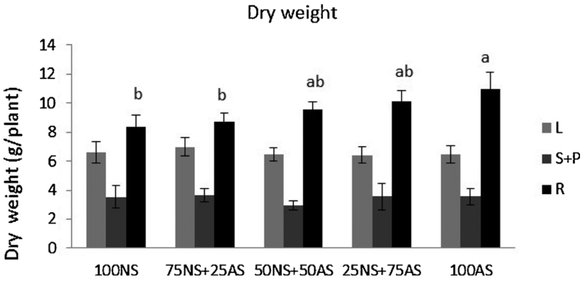

Fig. 2. Dry weight (g/plant) of L (leaves), S + P (stems and petioles) and R (roots) at the end of the trial for the 100 NS, 75NS + 25 AS, 50NS + 50AS, 25NS + 75AS and 100 AS treatments, where NS is the nutrient solution and AS the fish waste solution. Different letters indicate significant differences between treatments at the $P < 0.05$ level using the LSD test. Values represent the average (n = 12); bars represent the standard error.

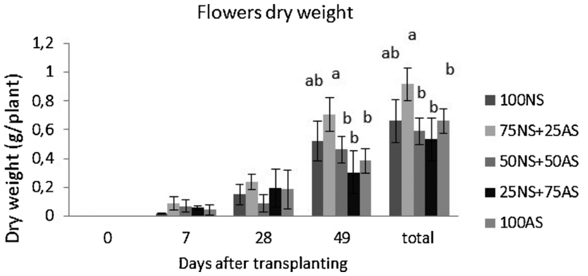

Fig. 3. Dry weight (g/plant) of the flower during the crop cycle for the 100 NS, 75NS + 25AS, 50NS + 50AS, 25NS + 75AS and 100 AS treatments, where NS is the nutrient solution and AS the fish waste solution. Different letters indicate significant differences between treatments at the $P < 0.05$ level using the LSD test. Values represent the average (n = 12); bars represent the standard error.

petiole dry matter were found (Fig. 2). Nevertheless, applying the fish wastewater solution increased root dry weight by up to 24%. Treatment with 25% AS improved plant development in terms of greater flower dry weight, and the number of flowers, shoot and leaves (Figs. 2 and 3, and Tables 2–4). However, we observed no differences between the 100 NS, 50NS + 50AS,25NS + 75AS and 100 AS treatments in flower dry weight and leaf and shoot numbers. Treatment with 25% AS increased the number of flowers by 28% compared to the control. No differences were found between treatments in terms of water content, leaf area and plant height (Fig. 4, Table 5 and 6). In the domain of efficient agriculture, the root:shoot of plants has become an important issue (Delaide et al., 2016). Regarding the plant root:shoot dry ratio, we observed an increase in this parameter when the fish wastewater percentage increased (Fig. 5a); this being higher (26%) when 100% AS was applied, compared to the control treatment. Related to this, the root:shoot dry weight ratio and the fish wastewater percentage showed a good correlation ($R^2 = 0.88$) (Fig. 5b). In foliage plants, one of the fundamental quality parameters is leaf color. The Munsell chart was used to define color. For all the treatments at the end of the assay, the leaves were identified as 5GY 4/4 for color, value and chroma, respectively (Table 7).

3.3. Nutritional status

The N and Ca concentrations in the leaves were within the range described by Marschner (2012). However, the K, Mg and P concentrations in the leaves were slightly lower than the levels described by Marschner (2012). No visual nutrient deficiency symptom was seen since we observed no differences in leaf color between treatments. Nonetheless, the macronutrients in the leaves differed between treatments. The N concentration in the leaves showed no significant differences in the treatments with 0, 25, 50 and 75% AS. However, the 100% AS treatment decreased the nitrogen concentration in the leaves by 14%. The K concentration in the leaves decreased significantly when plants were irrigated with the wastewater solution. With 100% AS, the potassium concentration in leaf reduced by 36% compared to the control. This decrease in K in the leaves is associated with a reduction of these elements in the nutrient solution. Nevertheless, despite there being a decrease in Ca in the nutrient solution, no differences in the calcium concentration were found between treatments. The P concentration differed between treatments but no clear effect on the treatments from this parameter was found; this was higher in the 100NS, 25NS + 75AS and 100AS treatments. In the leaves, the Mg concentration was significantly higher in the 25% AS treatment; after this, we observed a decrease in this parameter. No differences between the control and the 50NS + 50AS, 25NS + 75AS and 100AS were observed (Fig. 6).

4. Discussion

Previous works have reported on the productivity of aquaponics systems (Rakocy et al., 2006). However, scant research has been carried out on double recirculating aquaponic systems; one that has, a study on tomato in double recirculating aquaponic systems stands out, in which similar yields to those from conventional hydroponics were obtained (Suhl et al., 2016; Kloas et al., 2015).In this study, the result confirmed that fish wastewater can be employed for fertigation because there was no effect on the leaves, stems + petiole dry matter, water content, plant height or leaf area. The application of 25% fish wastewater improved plant development in terms of a greater number of flowers, shoots and leaves. Additionally, root growth was positively influenced by fish wastewater despite the relatively low Mg and K supply in these treatments. Low Mg and K supply can significantly reduce root growth (Marschner, 2012). This positive effect in both aquaponic and complemented aquaponic treatments, compared to hydroponic treatment, indicates that this water must contain factors that stimulate plant growth. We can assume that two factors having a plant growth-promoting effect are present in recirculating aquaculture system water: (1) dissolved organic matter, and (2) plant growth-promoting rhizobacteria and/or fungi (Delaide et al., 2016). Humic acid, like fulvic acid, and certain phenolics that tend to accumulate in recirculating aquaculture system water can increase shoot and root growth, as well as root ATPase activity (Delaide et al., 2016). Directly absorbed and assimilated by plants, these compounds stimulate growth, enhance yields, as well as increase vitamin and mineral content (Rakocy et al., 2006). Additionally, aquaponic solutions include algae, of which *Chlorella sp* is

Table 2

Flower number per plant during the growth period for the 100NS, 75NS + 25AS, 50NS + 50AS, 25NS + 75AS and 100AS treatments, where NS is the nutrient solution, AS the fish waste solution and dat are the days after transplanting. Values represent the average (n = 12).

	0 dat	7 dat	14 dat	21 dat	28 dat	35 dat	42 dat	49 dat
100NS	0	0.33 ± 0.30	0.60 ± 0.25	0.60 ± 0.25 b	1.33 ± 0.29b	2.00 ± 0.50c	4.00 ± 0.48c	6.66 ± 0.57b
75NS + 25AS	0	0.75 ± 0.25	1.5 ± 0.28	3.00 ± 0.40 a	5.25 ± 0.48a	6.25 ± 0.48a	8.25 ± 0.48a	11.15 ± 0.41a
50NS + 50AS	0	0.50 ± 0.28	0.75 ± 0.25	1.50 ± 0.48 b	2.75 ± 0.75b	3.00 ± 0.70c	4.25 ± 0.75c	7.15 ± 0.81b
25NS + 75AS	0	0.50 ± 0.28	1.25 ± 0.25	2.75 ± 0.48 ab	4.75 ± 0.48a	5.00 ± 0.41b	6.00 ± 0.81b	7.5 ± 0.86b
100AS	0	0.25 ± 0.25	0.75 ± 0.48	2.00 ± 0.57 ab	3.50 ± 0.64ab	3.75 ± 0.48bc	4.75 ± 0.47c	6.75 ± 0.82b

Different letters indicate significant differences between treatments at the $P < 0.05$ level using the LSD test.

Table 3
Shoot number per plant during the growth period for the 100NS, 75NS + 25AS, 50NS + 50AS, 25NS + 75AS and 100AS treatments, where NS is the nutrient solution, AS fish waste solution and dat are the days after transplant. Values represent the average (n = 12).

	0 dat	7 dat	14 dat	21 dat	28 dat	35 dat	42 dat	49 dat
100NS	1.0 ± 0	1.0 ± 0	1.8 ± 0.3	2.3 ± 0.3	3.3 ± 0.3	3.8 ± 0.3	5.0 ± 0.7	5.0 ± 0.4b
75NS + 25AS	1.0 ± 0	1.0 ± 0	2.3 ± 0.3	3.3 ± 0.3	3.5 ± 0.3	4.2 ± 0.3	5.5 ± 0.3	6.5 ± 0.4a
50NS + 50AS	1.0 ± 0	0.8 ± 0.3	1.3 ± 0.3	2.5 ± 0.3	3.3 ± 0.6	3.5 ± 0.6	4.0 ± 0.6	5.9 ± 0.5ab
25NS + 75AS	1.0 ± 0	1.0 ± 0	1.5 ± 0.3	2.3 ± 0.3	2.5 ± 0.3	3.3 ± 0.3	4.5 ± 0.3	5.4 ± 0.7ab
100AS	1.0 ± 0	1.25 ± 0.3	1.0 ± 0.3	2.5 ± 0.3	2.8 ± 0.2	3.5 ± 0.5	5.0 ± 0.7	6.3 ± 0.6ab

Different letters indicate significant differences between the treatments at the $P < 0.05$ level using the LSD test.

Table 4
Leaf number per plant during the growth period for the 100NS, 75NS + 25NS, 50NS + 50AS, 25NS + 75AS and 100AS treatments, where NS is the nutrient solution, AS the fish waste solution and dat are the days after transplant. Values represent the average (n = 12).

	0 dat	7 dat	14 dat	21 dat	28 dat	35 dat	42 dat	49 dat
100NS	5.50 ± 0.29	6.25 ± 0.25	8.25 ± 0.63	10.25 ± 0.25	13.00 ± 0.41	16.50 ± 0.65b	21.25 ± 1.11b	24.80 ± 1.10b
75NS + 25AS	6.00 ± 0.41	7.00 ± 0.41	9.00 ± 0.82	12.25 ± 0.75	16.25 ± 1.11	21.50 ± 0.96a	27.25 ± 0.85a	30.80 ± 0.84a
50NS + 50AS	5.75 ± 0.48	6.50 ± 0.50	7.25 ± 0.48	10.25 ± 0.48	13.00 ± 0.71	17.00 ± 0.91b	21.25 ± 1.11b	24.80 ± 1.10b
25NS + 75AS	5.50 ± 0.65	6.00 ± 0.58	8.00 ± 1.08	10.75 ± 0.85	13.25 ± 1.03	17.50 ± 1.26ab	21.75 ± 1.93b	25.03 ± 1.90b
100AS	5.75 ± 0.75	6.25 ± 0.48	8.50 ± 0.29	11.50 ± 0.65	15.00 ± 0.71	19.50 ± 1.75ab	23.75 ± 1.75b	27.25 ± 1.80b

Letters indicate significant differences between the treatments at the $P < 0.05$ level using the LSD test.

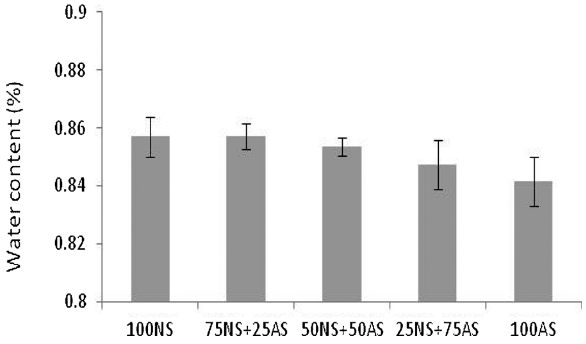

Fig. 4. Water content (%) for the 100 NS, 75NS + 25 NS, 50NS + 50AS, 25NS + 75AS and 100 AS treatments, where NS is the nutrient solution and AS the fish waste solution. Different letters indicate significant differences at the $p < 0.05$. Values represent the average (n = 12); bars represent the standard error.

the most abundant species (Addy et al., 2017), but also other species such as *Navicula* sp., *Scenedesmus* sp. and *Aphanizomenon* sp. The growth promoting effects of seaweed are related to the direct or indirect effect of the phytohormones present in the algae (Battacharyya et al., 2015). In addition, plant growth-promoting rhizobacteria have also been identified as being able to promote plant growth and improve root development. Plant growth-promoting rhizobacteria can release phytohormones or induce hormonal changes within plants, which stimulate plant cell elongation and division. Schmautz et al. (2017) examined the microbial communities within an experimental aquaponic system. The majority in the plant roots were assigned to the predominate phyla (Actinobacteria, Bacteroidetes, Proteobacteria, Verrucomicrobia and Cyanobacteria (Schmautz et al., 2017). The rhizosphere microbiome affects plant growth by excreting plant hormones (Qiao et al., 2017); in particular, cyanobacteria produce a wide array of compounds such as amino acids, auxins, gibberellins and cytokines (Singh et al., 2014), which are known to play crucial roles in plant development.

pH is a key factor for plant growth because it can limit nutrient availability. In aquaponic solution, pH is maintained at an average value of 7.4, and this is considered to be high for a hydroponic system (Rakocy et al., 2004). The optimal pH for geraniums is 6.0-6.6. In this case, the irrigation solution was prepared in an independent tank. By adding nitrate acid, we could control this parameter and avoid any possible pH effects on plant growth.

Fish effluent can complement, or even substitute the use of fertilizers for vegetable production (Endut et al., 2016). In closed recirculating systems with very little daily water exchange (less than 2%), dissolved nutrients accumulate in concentrations similar to those in hydroponic nutrient solutions (Rakocy et al., 2006). Aquacultural effluent typically supplies 10 of the 13 required plant nutrients in adequate amounts, with only Ca, K and Fe needing supplementation (Rakocy et al., 2004). In the present study, high concentrations of P, N and Ca in the nutrient solution were observed in all the treatments. Fish wastewater contains these essential nutrients through fish excretion, the feed supplied (N, P) and the Ca content in the fresh water used for fish production. Aquatic species such as fish consume only 20–50% of the N and 15–65% of the P from the feed supplied, and about 50–80% of the N and 35–85% of the P are released into the wastewater (Schneider et al., 2005). As with previous studies, the ammonium concentration in the fish wastewater solution in this study was very low. The total ammonia/ammonium level should be controlled at less than 3 ppm (Addy et al., 2017). Nitrification is a biological process that maintains water quality in recirculating aquaculture systems and has been shown to transform 93% to 96% of nitrogenous fish waste

Table 5
Average leaf area (cm^2 /plant) during the growth period for the 100NS, 75NS + 25NS, 50NS + 50AS, 25NS + 75AS and 100AS treatments, where NS is the nutrient solution, AS the fish waste solution and dat are the days after transplant. Values represent the average (n = 12).

	0 dat	7 dat	14 dat	21 dat	28 dat	35 dat	42 dat	49 dat
100NS	13.71 ± 3.00	18.40 ± 4.62	32.58 ± 3.39	43.45 ± 4.75	62.38 ± 6.16	73.60 ± 3.00	91.06 ± 1.27	109.96 ± 4.38
75NS + 25AS	15.97 ± 2.51	25.18 ± 5.22	34.37 ± 1.97	48.84 ± 1.00	69.81 ± 4.60	79.50 ± 4.14	93.70 ± 4.34	106.60 ± 4.55
50NS + 50AS	12.23 ± 1.44	22.21 ± 4.24	31.23 ± 5.07	44.13 ± 2.75	67.35 ± 5.63	73.81 ± 3.29	88.68 ± 5.50	112.48 ± 6.68
25NS + 75AS	15.09 ± 2.42	25.28 ± 3.55	40.10 ± 7.09	47.40 ± 1.82	73.34 ± 4.54	83.88 ± 2.37	98.46 ± 2.55	115.80 ± 5.27
100AS	13.38 ± 0.81	25.28 ± 3.37	31.49 ± 5.59	43.50 ± 4.92	65.96 ± 3.72	79.89 ± 7.51	101.94 ± 12.24	127.10 ± 8.24

Table 6
Plant height (cm) for the 100NS, 75NS + 25 NS, 50NS + 50AS, 25NS + 75AS and 100AS treatments, where NS is the nutrient solution, AS the fish waste solution and dat are the days after transplant. Values represent the average ($n = 12$).

	0 dat	7 dat	14 dat	21 dat	28 dat	35 dat	42 dat	49 dat
100NS	4.5 ± 0.3	6.5 ± 1.4	8.8 ± 0.9	10.1 ± 0.9	11.8 ± 1.1	14.6 ± 1.5	18.3 ± 2.0	24.2 ± 1.8
75NS + 25AS	4.5 ± 0.3	7.9 ± 0.7	8.3 ± 0.3	10.1 ± 0.2	12.3 ± 0.3	15.3 ± 0.8	18.9 ± 1.3	26.0 ± 2.2
50NS + 50AS	4.5 ± 0.3	6.7 ± 1.0	7.6 ± 0.4	8.8 ± 0.1	10.4 ± 0.2	14.0 ± 0.6	17.9 ± 1.0	24.7 ± 1.9
25NS + 75AS	4.5 ± 0.3	8.2 ± 1.3	8.6 ± 1.0	10.0 ± 0.7	11.8 ± 0.4	15.8 ± 0.7	19.8 ± 1.0	23.1 ± 1.3
100AS	4.5 ± 0.3	6.9 ± 1.0	8.1 ± 0.5	9.3 ± 0.6	10.6 ± 0.7	14.8 ± 1.1	19.3 ± 1.6	24.5 ± 1.7

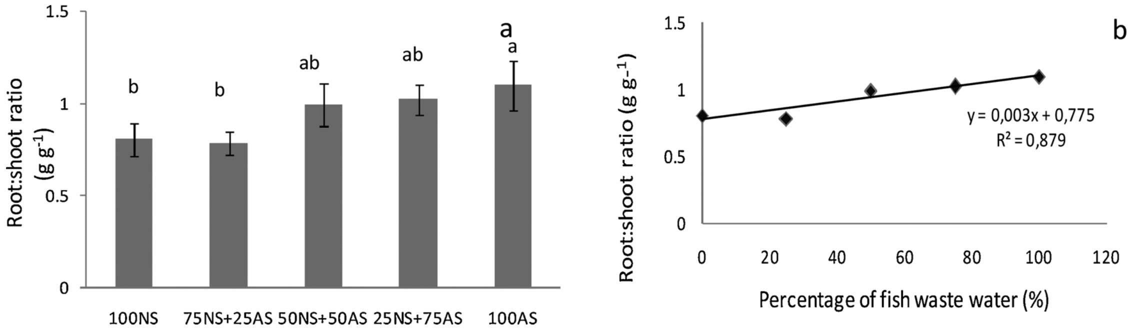

Fig. 5. Effect of the fish waste solution on root:shoot dry weight ratio at the end of the experiment (a) and the simple regression between the root/shoot dry weight ratio average and the percentage of fish waste solution (b). Different letters indicate significant differences at the $p < 0.05$. Values represent the average ($n = 12$); bars represent the standard error.

Table 7
Chroma, shine and intensity of leaves for the 100NS, 75NS + 25NS, 50NS + 50AS, 25NS + 75AS and 100AS treatments, where NS is the nutrient solution, AS the fish waste solution and dat are the days after transplant. Values represent the average ($n = 12$).

	0 dat	7 dat	14 dat	21 dat	28 dat	35 dat	42 dat	49 dat
100NS	5GY 5/4	5GY 5/4	5GY 5/4	5GY 4/4	5GY 4/4	5GY 4/4	5GY 4/4	5GY 4/4
75NS + 25AS	5GY 5/4	5GY 5/4	5GY 5/4	5GY 4/4	5GY 4/4	5GY 4/4	5GY 4/4	5GY 4/4
50NS + 50AS	5GY 5/4	5GY 5/4	5GY 5/4	5GY 4/4	5GY 4/4	5GY 4/4	5GY 4/4	5GY 4/4
25NS + 75AS	5GY 5/4	5GY 5/4	5GY 5/4	5GY 4/4	5GY 4/4	5GY 4/4	5GY 4/4	5GY 4/4
100AS	5GY 5/4	5GY 5/4	5GY 5/4	5GY 4/4	5GY 4/4	5GY 4/4	5GY 4/4	5GY 4/4

(ammonia-nitrogen (NH_3-N) into nitrate (NO_3^--N) (Tyson et al., 2017). However, despite the fish waste solution being mixed with a hydroponic nutrient solution, the mean K concentration in the nutrient solution (0.80, 0.91 and 2.23 mmol L^{-1} for 100AS, 25NS + 75AS and 50NS + 50AS, respectively) was above the optimum level required by this crop and was reflected in a low K leaf concentration. Nevertheless, no detrimental effects on plant growth or development were observed compared to the standard nutrient solution treatment. Aquaponic systems that rely solely on fish waste to supply nutrients for plants have reported low potassium levels (Tyson et al., 2017). This is because potassium is not added to fish feed as it is not needed by the fish; hence it doesn't enter the system, (Graber and Junge, 2009). Even though the Mg concentration in the nutrient solution decreased from 1.00 to 0.34 mmol L^{-1}due to the low concentration of this ion in the AS, we observed no differences in Mg concentration in the leaves between 100% SN and 100% AS. The reasons for this high nutrient uptake are the significant increases in root volume (Shaaban, 2001) and because aquaculture system water must contain factors that stimulate this uptake (Delaide et al., 2016). The initial K and Mg content in the irrigation solution of the 100%AS treatment was sufficient for plant growth. *Pelargonium* has a short growing cycle. To provide complete plant nutrition in long growing cycles plants, external nutrients probably need to be supplied.

The 25% fish wastewater provided the best results in terms of plant development given that most of the growth parameters improved when compared to the control (inorganic fertilizers). The positive effect of

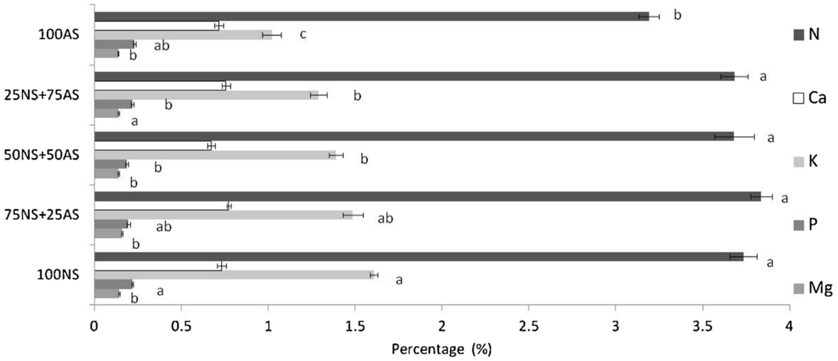

Fig. 6. Concentration in leaves (%) for the 100 NS, 75NS + 25 NS, 50NS + 50AS, 25NS + 75AS and 100 AS treatments, where NS is the nutrient solution and AS the fish waste solution. Different letters indicate significant differences between treatments at the $P < 0.05$ level using the LSD test. Values represent the average ($n = 12$); bars represent the standard error.

fish wastewater in promoting plant growth, and the similar concentration of nutrients in the nutrient solution compared to the control, explains the good results from this treatment. Therefore, using 25% fish wastewater is the best proportion for promoting *Pelargonium* growth. However, as no detrimental effects on plant growth or development were observed in the other treatments compared to the SN treatment, other proportion can also be used. From the point of view of reducing the potable water and fertilizer consumption, 100% of AS is the best proportion for plant growth. The data from this assay will allow growers to choose the best proportion to apply during crop development based on the price and availability of the sources (fish waste solution and inorganic fertilizer).

5. Conclusions

The results obtained confirm that fish wastewater can be utilized for the fertigation of *Pelargonium zonale* (in a short-cycle crop), as it has no detrimental effect on plant growth or development. Root growth was positively influenced by the fish waste solution. Using 25% fish wastewater enhanced yields and improved most of the ornamental quality parameters of *Pelargonium zonale* compared to inorganic fertilizers. The fish waste solution can supply adequate levels of N, P and Ca nutrients to *Pelargonium* plants, thus reducing the cost of fertilizers. Even though no visual deficiencies appeared, when a high concentration of fish waste solution was used, there was a depletion in the K leaf concentration. Future research should be conducted to study the influence of the presence of hormones and micronutrients in this wastewater on plant growth.

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