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Research Article

Physiological, nutritional and tolerance effects in *Chrysanthemum morifolium* irrigated with grey and treated water

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Abstract

This research provides basic information on the recovery or reuse of grey and treated water in a sustainable approach. For the research development, treated water was collected and synthetic greywater was prepared to use for irrigation of potted plants and their adaptability was measured according to the different irrigation water and physicochemical parameters in plant and soil. The results show that plants with the highest flowering and the highest accumulation of NO_3 in the stem were the plants irrigated with treated water in response to the total nitrogen of 41.53 mg/L. The plant's adaptability was more complicated with the irrigation of greywater but with greater growth and more resistance to pests and diseases than with the irrigation of treated water. The response to the accumulation of As, Ag, Cr, P, Pb, S, and Ti was significant differences according to the irrigation water in the different organs of the plants. During the crop development under the different types of irrigation, the pot soils are within the Mexican regulation, which presented neutral pH, slightly saline, with high organic matter, and without problems of dangerous accumulations of heavy metals.

Keywords: adaptability; floriculture; ornamental plants; potted plants; soil analysis

Introduction

The scarcity of fresh water and the increasing demand for it have emerged as one of the most pressing challenges of our times (UNESCO, 2015). Wastewater discharges in Mexico are classified as municipal or domestic when they come from community sewers (CONAGUA, 2017). In the north of Mexico, characterized as an arid zone, water scarcity becomes a more serious problem (CONABIO, 2014). Currently in arid zones, efforts are being made to mitigate the demand for water with the reuse of wastewater in agricultural and

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domestic areas (Palacios *et al.*, 2017). Currently in large cities, gray water reaches up to 50% of total wastewater, which makes it an important factor of study (Wu *et al.*, 2016), evaluating its quality in organic content and pH in agricultural soils or orchards and gardens to be used for irrigation (Al-Hamaiedeh and Bino, 2010), in order to support an economic activity with a sustainable approach without affecting the quality of the plant for its commercialization (Zurita *et al.*, 2008).

Constructed wetlands have been a viable solution in the treatment of domestic wastewater, due to their low operating cost, environmental friendliness, and a safe technique for cleaning both domestic and industrial greywater (Xiao Z *et al.*, 2007). In this sense, data has been studied in relation to the use of ornamental plants with commercial value with good results in the bioremediation of greywater, also increasing the environmental benefits of the process of building wetlands and beautifying the landscape (Morales *et al.*, 2013). The selection of ornamentals for each region is made mainly considering temperatures and water demand (Tollenaar and Hunter, 1983). In Chihuahua, Mexico, where a dry-arid climate prevails, an ornamental species that has commercial and cultural value and is easily accessible to farmers in the region is the *Chrysanthemum morifolium*, which demands large volumes of water when produced under cuttings, and reaching flowering between the months of October and November, dates when the "Day of the Dead" is celebrated in the Mexican Republic (Barrera *et al.*, 2007). Under the conditions of Chihuahua, Mexico, there are no studies related to *Chrysanthemum* and the use of gray or treated water, which is why the objective of this research was to evaluate the adaptability of *Chrysanthemum morifolium* irrigated with gray and treated water determining physicochemical parameters in plant and soil and providing basic information on the recovery or reuse of gray water and treatment in a sustainable approach, to develop phytoremediation techniques.

Materials and Methods

Ornamental plants

Chrysanthemum morifolium was used due to its adaptability to the environmental conditions of the region, and its commercial impact on the Mexican culture, especially during the festivities of the traditional Day of the Dead; it is the second most sold flower in the country (SIAP, 2018). For the purposes of this investigation, the cuttings rooted were provided by producers from the Tabalaopa, Ejido region in the municipality of Chihuahua (latitude 28°40'3"N and longitude 106°0'57"W). The cuttings rooted (small plants) from crop field were transplanted directly into the pot with same experiment conditions of soil and temperature of greenhouse of the experiment, without using rooting or stimulant products were used. For their adaptation irrigated with tap water for a week before starting the experiment.

Collection of treated water, preparation of greywater and analysis

The collection of treated wastewaters was realized directly from the reservoir of Campus I of the Autonomous University of Chihuahua (UACH), which supplies water to all the irrigation lines of said campus and is supplied by the municipal wastewater treated line, whose coordinates are Lat: 28.6557, Lon: 106.0895. For the experimental development, at intervals of three weeks, 20 L of this type of water were collected.

The used greywater was synthetic, prepared in the laboratory according to the procedures of the National Science Foundation/American National Standards Institute (NSF/ANSI, 2013), standard 350. Which proposes to use local tap water with initial pH of 8.8 ± 2, alkalinity of 6.5 - 10, and monochloramine present at 1 - 2 mg/L as Cl_2. The water preparation simulated a mixture of 67% shower water (20 g of body wash, 2 g of toothpaste, 1.3 g of deodorant, 26.7 g shampoo/conditioner, 2 g of lactic acid, 15.3 g of liquid soap for hands per 100 L) and 33% laundry water (13.2 mL laundry detergent, 7 mL liquid fabric softener, 1.3 g Na_2SO_4, 0.67 g $NaHCO_3$, 1.3 g Na_2HPO_4, 10 g powder test per 100 L).

To these synthetic, treated and tap waters, some physicochemical parameters were determined such as Hydrogen Potential (pH), Oxide Reduction Potential (ORP), Electrical Conductivity (ECCE), Total Suspended Solids (TSS), Volatile Suspended Solids (VSS), Total Dissolved Solids (TDS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Phosphorus (TP), Total Nitrogen (TN), Nitrites (NO_2), Nitrates (NO_3) and Ammonia (NH_3). Some of these were compared with normativity NOM-001-SEMARNAT-1996 and NOM-003-SEMARNAT-1997 (Table 1). Metals determination in water of Lead (Pb), Cadmium (Cd), Copper (Cu), Zinc (Zn), Nickel (Ni), Chromium (Cr), and others like Silver (Ag), Titanium (Ti), Sulphur (S), was performed by atomic absorption spectrophotometry (AAS), in a GBC Avanta Sigma equipment. Arsenic (As) was determinate using AAS coupled to the Hydride Generator GBC Model HG3000. By Inductively coupled plasma optical emission spectroscopy (ICP-OES) in a Thermo Scientific model Icap 6500 equipment was determined Silver (Ag), Titanium (Ti), Total Phosphorus (TPPT) and Sulphur (S).

Table 1. Parameters with the Mexican Norms for their determination in water and maximum permissible levels in Official Mexican Norms (Own Elaboration, 2022)

Parameters	Regulation standard	*MPL	Measurement Standard
Hydrogen Potential (pH)	NOM- 001- SEMARNAT-1996	10 units	NMX-AA-008-SCFI-2011
Oxide Reduction Potential (ORP)	-	-	-
Electrical conductivity (CE)	-	-	NMX-AA-093-SCFI-2000
Total Suspended Solids (TSS)	NOM- 003- SEMARNAT-1997	30 mg/L	NMX-AA-034-SCFI-2015
Volatile suspended Solids (VSS)	-	-	NMX-AA-034-SCFI-2015
Total dissolved Solids (TDS)	-	-	NMX-AA-034-SCFI-2015
Biochemical Oxygen Demand (BOD)	NOM- 003- SEMARNAT-1997	30 mg/L	NMX-AA-028-SCFI-2001
Chemical Oxygen Demand (COD)	-	-	NMX-AA-030/1-SCFI-2012
Total Phosphorus (TP)	NOM- 001- SEMARNAT-1996	10 mg/L	NMX-AA-029-SCFI-2001
Total Nitrogen (TN)	NOM- 001- SEMARNAT-1996	25 mg/L	NMX-AA-026-SCFI-2010
Nitrites (NO_2)	-	-	NMX-AA-026-SCFI-2010
Nitrates (NO_3)	-	-	NMX-AA-026-SCFI-2010
Ammonia (NH_3)	-	-	NMX-AA-026-SCFI-2010
Lead (Pb)	NOM- 001- SEMARNAT-1996	1 mg/L	NMX-AA-051-SCFI-2001
Cadmium (Cd)	NOM- 001- SEMARNAT-1996	0.1 mg/L	NMX-AA-051-SCFI-2001
Copper (Cu)	NOM- 001- SEMARNAT-1996	6 mg/L	-
Zinc (Zn)	NOM- 001- SEMARNAT-1996	20 mg/L	NMX-AA-051-SCFI-2001
Nickel (Ni)	NOM- 001- SEMARNAT-1996	4 mg/L	NMX-AA-051-SCFI-2001
Chromium (Cr)	NOM- 001- SEMARNAT-1996	1.5 mg/L	-
Arsenic (As)	NOM- 001- SEMARNAT-1996	0.4 mg/L	-
Silver (Ag)	-	-	NMX-AA-051-SCFI-2001
Titanium (Ti)	-	-	-
Sulphur (S)	-	-	NMX-AA- 84-1982

**MPL= Maximum Permissible Levels*

Adaptability of potted plants with irrigation of grey and treated water

The experiment was realized with three repetitions of plant by type of water, with irrigation of greywater, treated water and 1 control with tap water irrigation (tap water), in a heated greenhouse (coordinates are Lat: 28.6572, Lon: -106.0880) with a humid wall that allowed not to pass the temperature of 35 °C. The observations were registered according to the mortality detection; according the pest's presence aphid (Aphididae), as well as flowering (in number of flowers and aesthetics of these). Each plant growth was measured weekly on seven months, with an estimated time to one cut, considering that it is an annual variety.

Determination of physicochemical parameters in plant and soil

At the end of the growth measurements, the plants were removed, subsequently washed, and disinfected to be cut by organs and put to dry to be finely crushed. On the other hand, the soils, after being dried at room temperature in the laboratory for one day, were ground into smaller particles and sieved at 2 mm. The soil samples and each plant organ were placed in Sn capsules OD: 3.5 mm; H: 5 mm, Thermo scientific (PN 240 05300, Germany) to be analysed in a Flash Smart Elemental Analyzer device by type of irrigation where Carbon (C), Hydrogen (H) and Nitrogen (N) were determined. For the determination of nitrates, the Brucine method and UV-visible spectrophotometry were used in both soil and plant tissues.

In soil, the maximum permissible levels of some parameters established in Mexican regulations were considered in Table 2. The pH and EC for soil were determined, according to the specifications of Mexican regulations (Table 2). The metals determination in plant and soil was realized by ICP-OES, the total metal concentration was analysed for Pb, Cu, Zn, Cr, As, Ag, Ti, TP and S.

Table 2. Parameters with the Mexican Norms for their determination in soil and maximum permissible levels in Official Mexican Norms (Own Elaboration, 2022)

Parameters	Regulation standard	MPL	Unit	Measurement Standard
Hydrogen potential (pH)	NOM 021 SEMARNAT-2000	6.6 - 7.3	Neutral	NMX-AA-25-1984
Electrical Conductivity (EC)	NOM 021 SEMARNAT -2000	<1.0	dS/m	NOM 021 SEMARNAT -2000
Arsenic (As)	NOM 147 SEMARNAT/SSA1-2004	22	mg/kg	-
Chromium (Cr)	NOM 147 SEMARNAT/SSA1-2004	280	mg/kg	-
Lead (Pb)	NOM 147 SEMARNAT/SSA1-2004	400	mg/kg	-
Silver (Ag)	NOM 147 SEMARNAT/SSA1-2004	390	mg/kg	-
Titanium (Ti)	-	-	-	-
Total phosphorus (TP)	NOM 021 SEMARNAT -2000	<30	mg/kg	NMX -AA-94-185
Sulfur (S)	-	-	-	-
Total Nitrogen (TN)	NOM 021 SEMARNAT -2000	0.15-0.25	mg/kg	NMX -AA-24-184
Carbon (C)	-	-	-	-
Hydrogen (H)	-	-	-	-
Nitrates (NO_3)	-	-	-	NMX -AA-24-184

**MPL= Maximum Permissible Levels*

Statistical analysis

The statistical analysis of the different parameters was realized by means of an analysis of variance (ANOVA) and the typical error in each variable type. The statistical analysis of the different variables observed in the plants developed with a reduced model of exponential non-linear regression, with the SSPS Statistics 20 software according to each type of irrigation.

Results and Discussion

Characterization of irrigation water

The results of the different parameters monitored in greywater are presented in Table 3. The Total Suspended Solids =TSS= (181 mg/L) exceeded the maximum permissible level (MPL) (30 mg/L) in the Official Mexican Norm NOM-001-SEMARNAT-1996, which regulates pollutants in greywater discharges in national waters and goods. Likewise, the Biochemical Oxygen Demand =BOD= (293.0 mg/L) exceeded the MPL (<30 mg/L) established in NOM-003-SEMARNAT-1997, which regulates pollutants in treated greywater that are reused in public services to the public. The rest of the parameters remained within the MPL or is not regulated by Mexican regulations. Heavy metals were not included in the table because in some they were not detectable by the equipment as Pb (0.1 mg/L), Cd (0.1 mg/L), Cu (0.04 mg/L), Zn (0.01 mg/L), Ni (0.08 mg/L), Cr (0.1 mg/L), Ti (0.01 mg/L), Ag (0.1 mg/L), or were below the MPL established by NOM-001-SEMARNAT like an As (0.01 mg/L).

Table 3. Greywater characterization (Own elaboration, 2022)

Parameter	Regulation standard	MPL	Unit	Media	Typical Error
pH	NOM-001-SEMARNAT	5.5 to 10	Units	7.42	0.06
ORP	-	-	m/V	67.93	0.43
EC	-	-	m/S	0.67	0.02
TSS	NOM-001-SEMARNAT	30	mg/L	181	0.12
VSS	-	-	mg/L	132.33	0.19
TDS	CONAGUA 2017	500	mg/L	0.33	0.06
BOD	NOM-003-SEMARNAT	<30	mg/L	293	0
COD	-	-	mg/L	577	0.04
TP	NOM-001-SEMARNAT	10	mg/L	1.23	0.96
TN	NOM-001-SEMARNAT	25	mg/L	7.67	0.54
NO_2	-	-	mg/L	0.14	0.59
NO_3	-	-	mg/L	9.9	0.58
NH_3	-	-	mg/L	0.17	0.92

Hydrogen Potential (pH), Oxide Reduction Potential (ORP), Electrical Conductivity (ECCE), Total Suspended Solids (TSS), Volatile Suspended Solids (VSS), Total Dissolved Solids (TDS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Phosphorus (TP), Total Nitrogen (TN), Nitrites (NO_2), Nitrates (NO_3) and Ammonia (NH_3).

The results of the different quality parameters monitored in the treated water are presented in Table 4, with its respective statistical calculation, in which the level of the TN (41.53 mg/L) exceeded the MPL (25 mg/L) stablished in the NOM-001-SEMARNAT. Heavy metals were not included in the table because in some cases they were not detectable as Pb, Cd, Cu, Zn, Ni, Cr, Ti, or were below the MPL established by NOM-001-SEMARNAT and NOM-003-SEMARNAT-1997 like an As (0.02 mg/L).

The results of the different quality and safety parameters in tap water are presented in Table 5. These indicate good water quality since all the parameters are within the MPL in the NOM-001-SEMARNAT that regulates the discharge of greywater to goods national and in NOM-127-SSA1-1994, that regulates the quality of tap water, according to the parameter compared. Heavy metals were not included in the table because in some of the cases they were not detectable as Cd, Cu, Zn, Ni, Cr, Ti, Ag or were below the MPL established by NOM-001-SEMARNAT in As (0.02 mg/L) and Pb (0.04 mg/L).

Table 4. Treated water characterization (Own Elaboration, 2022)

Parameter	Regulation standard	MPL	Unit	Media	Typical Error
pH	NOM-001-SEMARNAT	5.5 to 10	Units	7.42	0.08
ORP	-	-	m/V	73	0.24
EC	-	-	m/S	1.11	0.22
TSS	NOM-001-SEMARNAT	30	mg/L	4	0.66
VSS	-	-	mg/L	3	0.88
TDS	CONAGUA 2017	500	mg/L	0.56	0.25
BOD	NOM-003-SEMARNAT	<30	mg/L	12	0
COD	-	-	mg/L	28.33	0.14
TP	NOM-001-SEMARNAT	10	mg/L	1.73	0.75
TN	NOM-001-SEMARNAT	25	mg/L	41.53	0.31
NO_2	-	-	mg/L	0.32	0.83
NO_3	-	-	mg/L	5.57	0.41
NH_3	-	-	mg/L	27.83	0.83

Hydrogen Potential (pH), Oxide Reduction Potential (ORP), Electrical Conductivity (ECCE), Total Suspended Solids (TSS), Volatile Suspended Solids (VSS), Total Dissolved Solids (TDS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Phosphorus (TP), Total Nitrogen (TN), Nitrites (NO_2), Nitrates (NO_3) and Ammonia (NH_3).

Table 5. Tap water characterization (Own Elaboration, 2022)

Parameter	Regulation standard	MPL	Unit	Media	Typical Error
pH	NOM-127-SSA	6.5 to 8.5	Units	7.03	0.04
ORP	-	-	m/V	73.57	0.28
EC	NOM-001-SEMARNAT	-	m/S	0.67	0.07
TSS	CONAGUA 2017	50	mg/L	4.33	1.54
VSS	-	-	mg/L	1	1.73
TDS	NOM-127-SSA	500	mg/L	0.31	0.05
BOD	NOM-003-SEMARNAT	<30	mg/L	0	0
COD	-	-	mg/L	0.67	1.73
PT	NOM-001-SEMARNAT	10	mg/L	0.33	0.92
TN	NOM-001-SEMARNAT	25	mg/L	8.67	0.24
NO_2	-	-	mg/L	0.02	1.62
NO_3	-	-	mg/L	4.53	0.03
NH_3	-	-	mg/L	1.03	1.73

Hydrogen Potential (pH), Oxide Reduction Potential (ORP), Electrical Conductivity (ECCE), Total Suspended Solids (TSS), Volatile Suspended Solids (VSS), Total Dissolved Solids (TDS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Phosphorus (TP), Total Nitrogen (TN), Nitrites (NO_2), Nitrates (NO_3) and Ammonia (NH_3).

Plant development

Table 6 presents a comparison of the different variables evaluated and the behaviour according to the type of irrigation. The plants irrigated with treated water showed greater susceptibility to pests, followed by the plants irrigated with grey water, showing the control a better tolerance to these pathogens, in this sense investigations that contribute to the understanding of the risks associated with invasive outbreaks of pests and diseases in trees, according to their field experiences (Urquharta *et al.*, 2017) in which a correlation is supported as shown in Table 6. The type of irrigation also influenced the nutrition of the plants and obtaining low mortality in gray water irrigation, because it has been recorded that this type of gray and treated water contains Nitrogen (N), Phosphorus (P) and Potassium (K), which contributes to improving the health of ornamental plants (Qian and Mecham, 2005). However, there was minimal variation between the type of irrigation and the number of flowers.

Table 6. Pests and diseases, mortality, quality and quantity by variety (Own Elaboration, 2022)

Plant development	Greywater	Treated water	Tap water
Pets and disease	Aphids, very little	Aphids, little	No presence of aphids
Mortality	30%	0	0
Number of flowers per pot	35	39	30
Flower quality	Good	Good	Good

Plant traits are increasingly used to link environmental conditions, including growth in some annual plants, which responds to the partition of biomass and water stress (Dovrata *et al.*, 2019). The weekly measurements of the plant's growth are shown in Figures 1-7, showing the media growths reached by the plants in comparison among different irrigation types.

The media growth achieved with each irrigation (Figure 1); the greywater irrigation allowed a better growth compared to the other two types of irrigation.

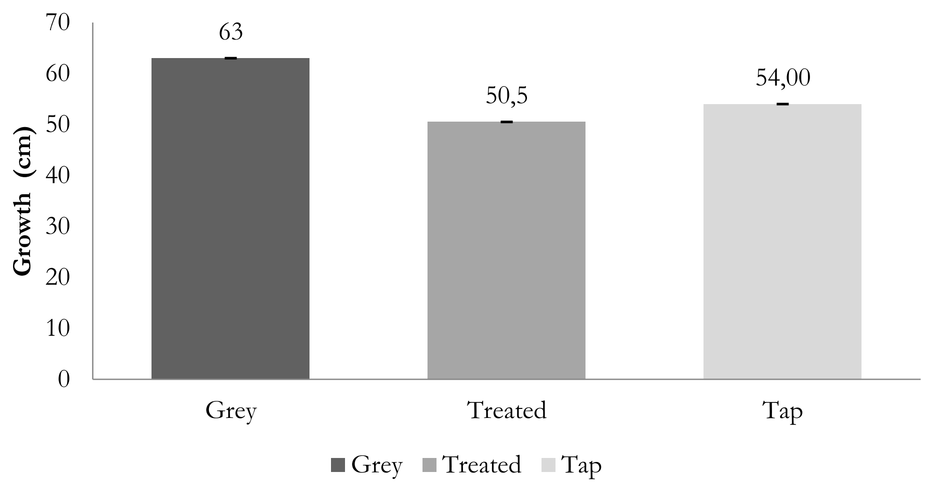

Figure 1. Maximum reached growth *Chrysanthemum morifolium* in centimetres for types of irrigation

Table 7 corresponds relates reports to the recorded data of the non-linear regression model since the data deviate more or less significantly from linear quality, so it was considered an adjustment of a curve other than a line (Freud and Simon, 1994), as it is indicated in the literature. In which at the moment of reducing it, a similar behaviour of the *Chrysanthemum morifolium* growth is observed with the irrigation of treated water and tap water. A good correlation was recorded with the value of R^2 value with magnitudes greater than 0.80; where the maximum values of growth in both irrigation with treated water (75.97 cm) and tap water (75.36 cm) were closer and lower in turn than those recorded by the irrigation of greywater (88.49 cm). The same behaviour was observed in the growth rate, in which the average value of tap water and treated and tap water was 0.11 and in greywater 0.16.

Table 7. Reduced exponential nonlinear regression model (Own Elaboration, 2022)

Parameter	Greywater	Treated water	Tap water	Treated water and Tap water
Maximum Growth Value (cm)	88.49	75.97	75.36	74.8
Growth Rate (cm/week)	0.16	0.1	0.12	0.11
R^2	0.935	0.834	0.955	0.872

Likewise, the behaviour of plants irrigated with treated and tap water was predicted in a model (Figure 2). Figure 3 shows the growth pattern of *Chrysanthemum morifolium* irrigated with greywater. There is research that suggests that ornamental plants have been beneficial and adaptable in the use of constructed wetlands for grey water recovery (Arunbabu *et al.,* 2015), and in other cases flowers are recorded for grey water purification (Morales *et al.*, 2013; Jaramillo *et al.*, 2015). It is also shown in some forage crops that treated water has a lower impact effect than residual grey water, which is reflected in mortality on germination, plant growth and stress (Rekik *et al.*, 2017); however, a comparison was not made in the behaviour of plants irrigated with grey water as in the present investigation.

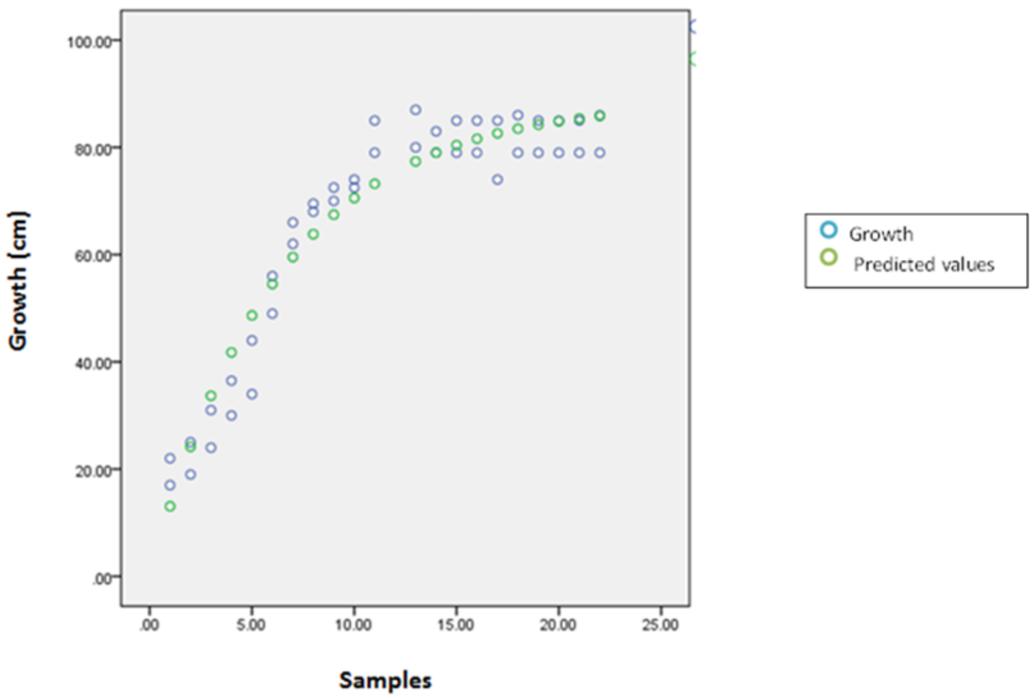

Figure 2. *Chrysanthemum morifolium* growths behaviour irrigated with treated and tap water predicted in a model

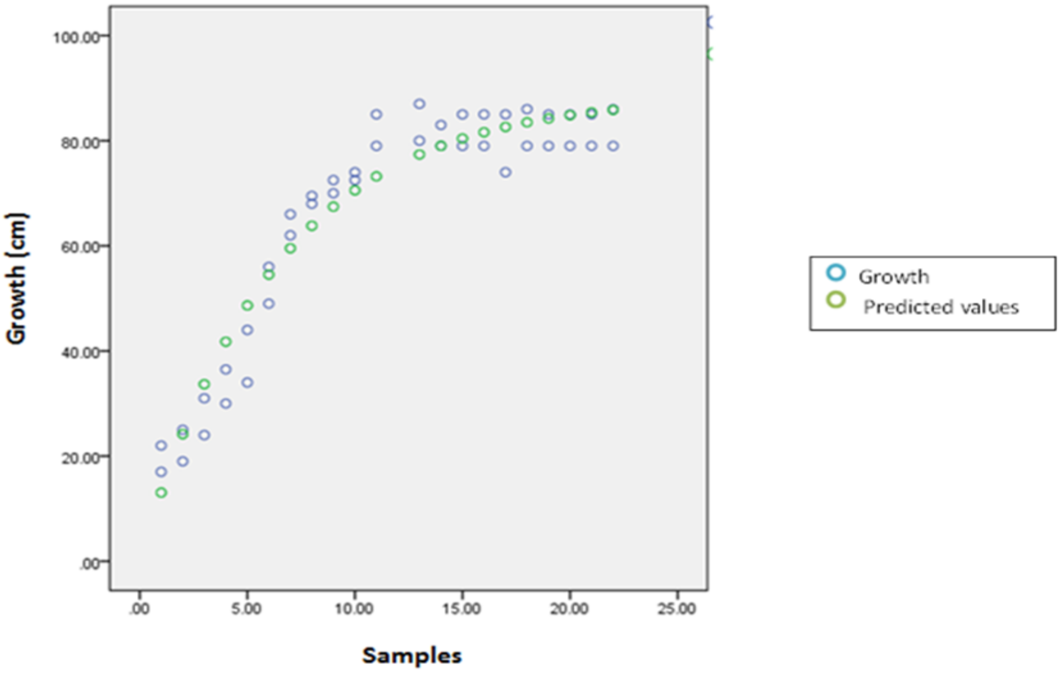

Figure 3. *Chrysanthemum morifolium* growths behaviour irrigated with greywater predicted in a model

Physicochemical parameters in plant

The analysis of elements in plants is shown in Figure 4, according to their concentrations and method of determination. The response of the plants varied according to the irrigation water, since the available nutrients also varied according to the irrigation water (Qian and Mechan, 2005). Under gray water irrigation, the element with the greatest presence (Figure 4) was Ti (15.81 mg/Kg) in the root, while for irrigation with treated water it was (Pb) (14.89 mg/Kg) in the stem and finally, in the for irrigation of with tap water, (As) was the element that reached the most presence (6.45 mg/Kg) in the leaf.

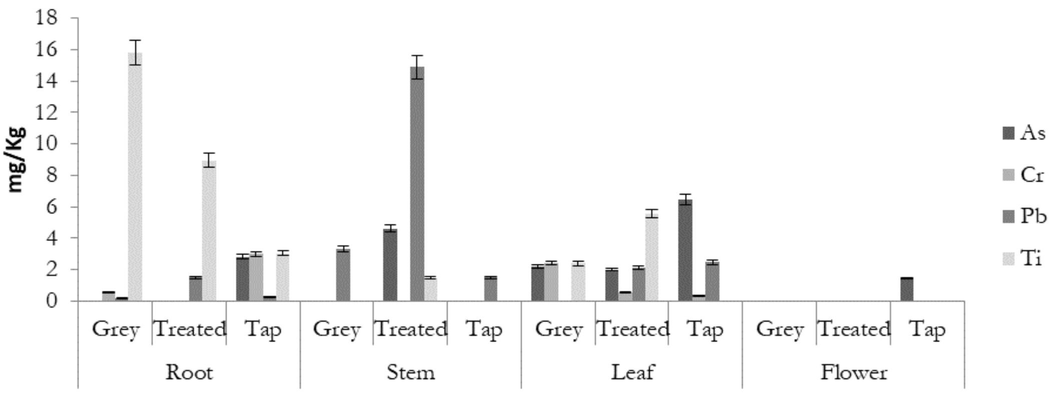

Figure 4. Accumulation of arsenic, chromium, lead and titanium in *Chrysanthemum morifolium* by organ according to irrigation water

The element with the highest accumulation in leaves (Figure 5) was Sulfur (S), and under a gray water irrigation system; accumulating for gray water 2,664.61 mg/Kg, and in treated water 2,806.37 mg/Kg; for its part in tap water 3,256.45 mg/Kg. Among elements, the response at the level of the entire plant was with (S) and Phosphorus (P) since they are elements that are part of the plants, although (P) was fixed in greater quantity in the root and flower under the irrigation of treated water.

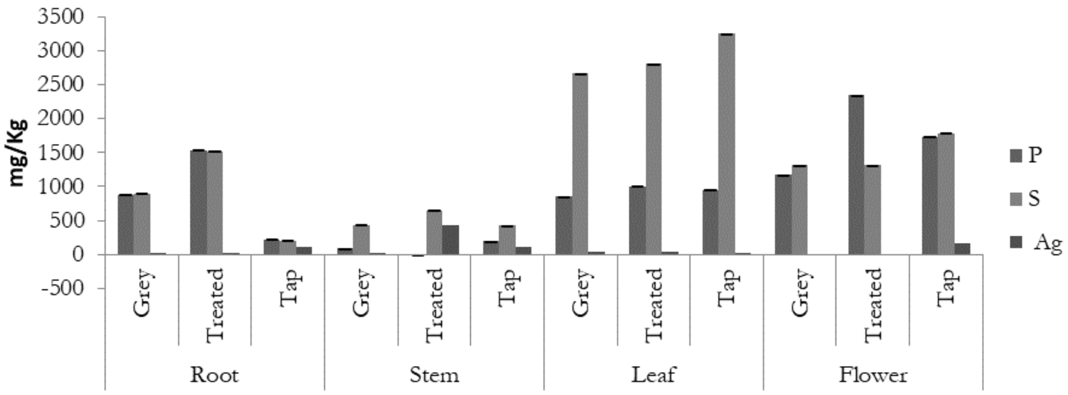

Figure 5. Accumulation of phosphorus, sulphur and silver in *Chrysanthemum morifolium* by organ according to irrigation water

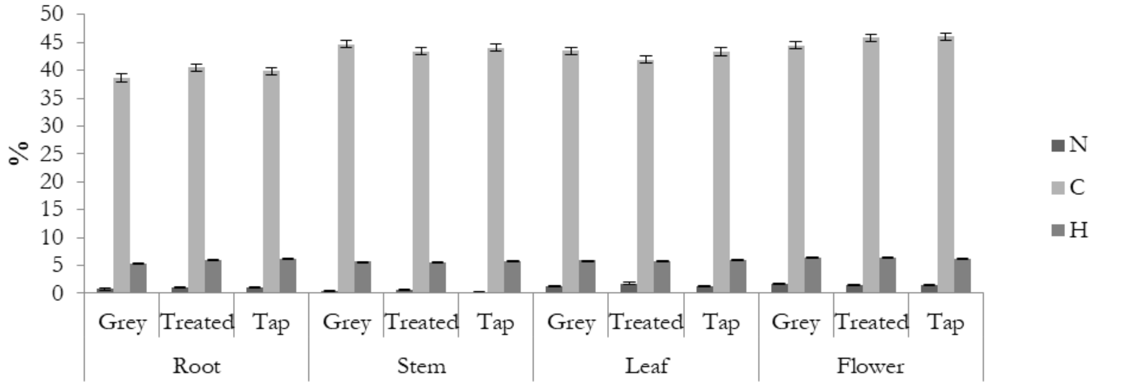

Figure 6. Accumulation of nitrogen, carbon and hydrogen in *Chrysanthemum morifolium* by organ according to irrigation water

Similarities between the elements Nitrogen (N), Carbon (C) and Hydrogen (H), by plant organ (Figure 6) were obtained (Figure 6). A greater accumulation of NO_3 was recorded in the stem, leaves and flowers of those plants irrigated with treated water. In this sense, this treatment stands out with 5,699.24 mg/Kg, 3,652.12 mg/Kg and 3652.12 mg/Kg respectively (stem, leaves and flowers), (Figure 7) compared with that treatment with untreated water.

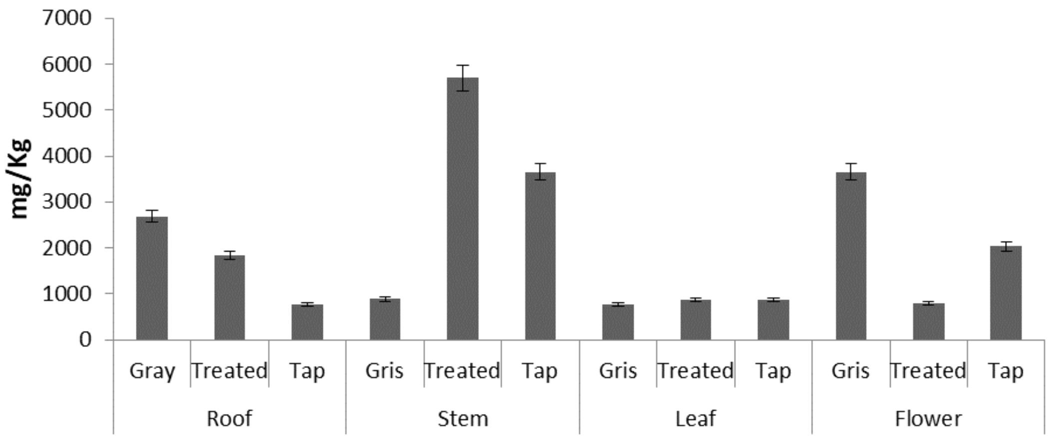

Figure 7. Accumulation of nitrates in *Chrysanthemum morifolium* by organ according to irrigation water

There is a correlation between the characterization of the irrigation water and the responses of the plant. In treated water TN (41.53 mg/L) was detected above the MPL (25 mg/L) of NOM-001-SEMARNAT-1996, generating in the plant greater nitrates content (5699.24 mg/L) in comparison to other waters of irrigation (Figure 7). In the characterization of the greywater the TSS (181.00 mg/L) was detected above the MPL of the NOM-001-SEMARNAT-1996 standard (30 mg/L), which causes a more complicated adaptability because it hinders the absorption of water by the roots and can reach until death. Likewise, the greywater the BOD (293 mg/L) was above the MPL (30 mg/L) of the NOM-001-SEMARNAT-1996, which favoured the growth in centimetres of the plants once adapted. The growth of the plants in treated water and tap water was similar, which was statistically proven by adopting the same model due to the behaviour of its variables (Yoshiaki *et al.*, 2017). That is, the *Chrysanthemum morifolium* showed a less stressful tolerance and adaptability under the irrigation of treated water compared to greywater, in this case greywater as it coincides in other studies (Rekik et al., 2017).

Soil analysis according to the type of irrigation type

The soils classification of the soils turned out to be was different between the types of irrigation water (Table 8). The pH classified the soils into moderately alkaline (7.4 -8.5). The EC classified them as slightly saline (1.1-2 dS/m); in this case it coincides with other studies where the EC is slightly higher in the soils with treated water (Qian and Mechan 2005). The TP classified them into natural horizons (<250 mg/Kg). This criterion is also aligned with the Soil Classified, which is used in archaeology and in the quality control of fertilizers; it and indicates that the soil has not been modified by the man Man's Hand (USDA, 1999). The soils were classified with very low TN content (<0.05), which is favourable since in relation to high concentrations of NO_3 in soils it is being prone susceptible to leaching in the soils when being in high concentrations, what affect the quality of the groundwater, as it happens in some crops (Lu *et al.*, 2019), which could reduce the effectiveness of this treatment of greywater if it were to be done used for sub-surface wetlands for phytoremediation. The soils a it also had a medium to high MO content (3.6-6) of the official norm NOM 021 SEMARNAT-2000 (USDA, 1999).

Table 8. Classification based on NOM 021 SEMARNAT 2000 of soils according to the type of irrigation water (Own Elaboration, 2022)

Parameter	Unit	Scale	Classification	Greywater	Treated Water	Tap Water
pH	0-14	7.4 - 8.5	Moderately alkaline	7.9	7.9	8
EC	dS/m	1.1 - 2.0	Very slightly saline	1.8	2	1.4
TP	mg/Kg	≥ 250	Anthropic horizon	238.765	224.439	232.345
TN	%	< 0.05	Very low	0.035	0.057	0
MO	%	3.6 -6	High	4.2	3.4	4

None of the concentrations of the analysed elements exceeded the MPL of metals and metalloids in soils according to the official norm NOM-147-SEMARNAT/SSA1-2004 for agricultural land use (Table 9), so these conditions were considered favourable for the cultivation of flowers (USDA, 1999).

Table 9. Characterization of soils according to the type of irrigation water (Own Elaboration, 2022)

Parameter	Regulation standard	Unit	MPL	Greywater	Treated water	Tap water
As	NOM 147 SEMARNAT	mg/Kg	22	2.471	2.408	1.237
Cr	NOM 147 SEMARNAT	mg/Kg	280	0	0	0
Pb	NOM 147 SEMARNAT	mg/Kg	400	82.647	74.371	76.533
Ag	NOM 147 SEMARNAT	mg/Kg	390	4.632	5.462	4.694
Ti	-	mg/Kg	-	1.946	16.72	3.755
S	-	mg/Kg	-	85.464	75.42	81.844
C	-	%	-	1.284	0.849	1.13
H	-	%	-	0.526	0.432	0.485
NO_3	-	mg/Kg	-	0.923	0.63	0.95

This research is consistent with some studies of ornamental plants with commercial value of annual production, which provide favourable results under the irrigation of wastewater, both in the purification of water recovery and in their proper development (Zurita *et al*., 2008; Arunbabu *et al*., 2015). However, it broadens the panorama due to the fact that the *Chrysanthemum morifolium* is not found in said literature, and allows us to define its capacity for phytoremediation of greywater at pot level. This research provides statistical management to evaluate the response of the plant to the irrigation of grey and treated waters, as well as the characteristics of the soil and the element accumulation of elements in the different plant tissues.

Part of the importance of this research stands out in the application of technologies in arid zones, where the water resource is a top issue. In addition, the proposed plant *Chrysanthemum morifolium* have a commercial and cultural value supporting the biodiversity of rural and urban ecosystems, such as the *Chrysanthemum morifolium* that and is one of the most sold flowers in Mexico (SIAP, 2018).

Conclusions

The results found results in this research show that the adaptability of *Chrysanthemum morifolium* in growth is positive in the case irrigations with grey and treated water. This is because the indicators of flower quality and productivity like number of flowers produced are not affected, so they remain profitable as a floriculture economic activity. Then, it is advisable to continue with the next stage and test these plants in prototypes of constructed wetlands, in order to measure their capacity to treat this type of water.

It is recommended that other processes parameters involved, such as nutrients and the biodiversity of microorganisms, be valued in detail in order to achieve a better understanding of the physicochemical and biological processes that are carried out realized.

It should be noted that the results obtained allow us to set the standard for the design of a sustainable and reproducible system for the treatment of gray and treated water for this region, which contributes to the improvement of the environment and the sustainable development of the most vulnerable sectors of the region society, fulfilling the objectives set out in this research.

Authors' Contributions

A.Y.R.M. Ran the experiment and wrote the manuscript. M.C.V.A. Designed the experiment. M.T.A.H. Administered the experiment. E.O.R.P. Gave technical support and conceptual advice. R.C.A. Statistical analysis/ analysed data and wrote the manuscript.

All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

References

Al H, Bino M (2010). Effect of treated gray water reuse in irrigation on soil and plants. Desalination 256:115-119. *https://doi.org/10.1016/j.desal.2010.02.004*

Arunbabu V, Sruthy S, Ignatius A, Ramasamy EV (2015). Sustainable greywater management with *Axonopus compressus* (broadleaf carpet grass) planted in sub surface flow constructed wetlands. Journal of Water Process Engineering 7:153-160. *https://doi.org/10.1016/j.jwpe.2015.06.004*

Barrera A, Cabrera J, García F, Alcántara JC, Sánchez E, Cruz J, Granada L (2007). Production of *Chrysanthemum* in Morelos. Technical Brochure No. 27, Morelos, Mexico, pp 20.

Bo W, Weihua Z, Honghan C, Yue Z (2016). Gray water footprint combined with ecological network analysis for assessing regional water quality metabolism. Journal of Cleaner Production 112:3138-3151. *https://doi.org/10.1016/j.jclepro.2015.11.009*

CONABIO (2014). Comisión Nacional para el Conocimiento y Uso de la Biodiversidad. La biodiversidad en Chihuahua: Estudio de Estado. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad. México. Retrieved 26 April 2022 from: *https://dev-chm.cbd.int/doc/nbsap/study/mx-study-chihuahua-es.pdf*

CONAGUA (2017). Comisión Nacional del Agua Estadísticas del Agua en México. Subdirección General de Planeación. Retrieved 20 April 2022 from: *https://sina.conagua.gob.mx/publicaciones/EAM_2017.pdf*

Dovrata G, Meron E, Shachak M, Golodets C, Osem Y (2019). Plant size is related to biomass partitioning and stress resistance in water limited annual plant communities. Journal of Arid Environments 165:1-9. *https://doi.org/10.1016/j.jaridenv.2019.04.006*

Freud J, Simon G (1994). Elementary Statistics. Editorial Pearson Education (8ª ed), Mexico.

Jaramillo ML, Agudelo RM, Peñuela GA (2016). Optimización del tratamiento de aguas residuales de cultivos de flores usando humedales construidos de flujo subsuperficial horizontal. Revista Facultad Nacional de Salud Pública 34(1):20-29. *https://doi.org/10.17533/udea.rfnsp.v34n1a03*

Lua J, Baia Z, Velthofc GL, Wua Z, Chadwickd D, Maa L (2019). Accumulation and leaching of nitrate in soils in wheat-maize production in China. Agricultural Water Management 212:407-415. *https://doi.org/10.1016/j.agwat.2018.08.039*

Morales G, López D, Vera I, Vidal G (2013). Wetlands Constructed with Ornamental Plants for the Treatment of Organic Matter and Nutrients Contained in Sewage. Theoria 22(1):33-46.

NOM-001-SEMARNAT (1996). Official Mexican Standard: That establishes the maximum permissible limits of pollutants in gray water discharges in national waters and goods. Ministry of Environment and Natural Resources, Official Gazette of the Federation, Mexico.

NOM-003-SEMARNAT (1997). Official Mexican Standard: That establishes the maximum permissible limits of pollutants for treated gray waters that are reused in services to the public. Ministry of Environment and Natural Resources, Official Gazette of the Federation, Mexico.

NOM-021-SEMARNAT (2000). Official Mexican Standard: That establishes the specifications of fertility, salinity and soil classification. Studies, sampling and analysis. Ministry of Environment and Natural Resources, Official Gazette of the Federation, Mexico.

NOM-127-SSA1 (1994). Environmental health. Official Mexican Standard: Water for human use and consumption. Permissible quality limits and treatments to which water must be submitted for its purification. Ministry of Health, Official Gazette of the Federation, Mexico.

NOM-147-SEMARNAT/SSA1 (2004). Official Mexican Standard: That establishes criteria to determine the soil remediation materials contaminated by arsenic, barium, beryllium, cadmium, hexavalent chromium, mercury, nickel, silver, lead, selenium, thallium and/or vanadium.

NSF/ANSI (2013). National Science Foundation/ American National Standard Institute, standard 350. Army Public Health Center, Non-Potable Water Substitution and Reuse in the Field. On site Residential and Commercial Water Reuse Treatment Systems, NSF International. Technical Information Paper 32-002-0111.

Palacios OA, Zavala FJ, Ballinas ML, Espino MS, Nevárez GV (2017). Microbiological impact of the use of reclaimed wastewater in recreational parks. International Journal of Environmental Research and Public Health 14(9):1-12. *https://doi.org/10.3390/ijerph14091009*

Qian Y, Mecham B (2005). Long-term effects of recycled wastewater irrigation on soil chemical properties on golf course fairways. Reproduced from Agronomy Journal. Published by American Society of Agronomy 97:717-721. *https://doi.org/10.2134/agronj2004.0140*

Rekik I, Chaabanea Z, Missaouia A, Chenari A, Luptakovab L, Elleucha A, Belbahri L (2017). Effects of untreated and treated wastewater at the morphological, physiological and biochemical levels on seed germination and development of sorghum (*Sorghum bicolor* (L.) Moench), alfalfa (*Medicago sativa* L.) and fescue (*Festuca arundinacea* Schreb.). Journal of Hazardous Materials 326:165-176. *https://doi.org/10.1016/j.jhazmat.2016.12.033*

SIAP (2018). Servicio de Información Agroalimentaria y Pesquera. Atlas Agroalimentario 2012-2018, Primera Edición , Mexico. Retrieved 16 April 2022 from: *https://nube.siap.gob.mx/gobmx_publicaciones_siap/pag/2018/Atlas-Agroalimentario-2018*

UNESCO (2015). United Nations Educational, Scientific and Cultural Organization. Water for a sustainable. The United Nations World Water Development Report. This report is published by UNESCO on behalf of UN-Water. The list of UN-Water Members and Partners can be found on the following website *https://unesdoc.unesco.org/ark:/48223/pf0000231823*

Tollenaar M, Hunter RB (1983). A photoperiod and temperature sensitive period for leaf number of maize 1. Crop Science 23(3):457-460. *https://doi.org/10.2135/cropsci1983.0011183X002300030004x*

Urquharta J, Potter C, Barnett J, Fellenor J, Mumford J, Quine CP (2017). Expert risk perceptions and the social amplification of risk: A case study in invasive tree pests and diseases. Environmental Science and Policy 77:172-178. *https://doi.org/10.1016/j.envsci.2017.08.020*

USDA (1999). United States Department of Agriculture. Natural Resources Conservation Agriculture Handbook. Second Edition by Soil Survey Staff. Service Number 436. Retrieved 2022 February 2 from *https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_051232.pdf*

Wu B, Zeng W, Chen H, Zhao Y (2016). Grey water footprint combined with ecological network analysis for assessing regional water quality metabolism. Journal of Cleaner Production 112:3138-3151. *https://doi.org/10.1016/j.jclepro.2015.11.009*

Xiao Z, Peng L, Yue Y, Wen C (2007). Phytoremediation of urban wastewater by model wetlands with ornamental hydrophytes. Journal of Environmental Sciences 19:902-909. *https://doi.org/10.1016/S1001-0742(07)60150-8*

Yoshiaki N, Masayuki Y, Akihiko I, Toshihiko H (2017). Effectively tuning plant growth models with different spatial complexity: A statistical perspective. Ecological Modeling 36:95-112. *https://doi.org/10.1016/j.ecolmodel.2017.07.018*

Zurita F, De Anda J, Belmont MA, Cervantes J (2008). Stress detection by laser-induced fluorescence in *Zantedeschia aethiopica* planted in subsurface-flow treatment wetlands. Ecological Engineering 33:861-869. *https://doi.org/10.1016/j.ecoleng.2008.02.004*