

REVISTA AIDIS

de Ingeniería y Ciencias Ambientales:
Investigación, desarrollo y práctica.

DEVELOPMENT OF SUNFLOWER AND CORIANDER GROWN IN HUMAN URINE

* Germário Marcos Araújo¹
Marianna Chaves da Silva¹
Ana Késia Pedrosa Viana¹
Luís Gonzaga Pinheiro Neto²
Iran Eduardo Lima Neto³

Recibido el 14 de marzo de 2021. Aceptado el 25 de octubre de 2021

Abstract

Most of the nutrients that are essential for crops, mainly nitrogen, phosphorus and potassium, are found in human urine in sufficient quantities, and in most cases, they are more adequate and sustainable even when compared to commercial chemical fertilizers. This work evaluated the growth of sunflower (*Helianthus annuus L.*) and coriander (*Coriandrum sativum*) submitted to the use of human urine as a biofertilizer. A treatment was carried out in the urine using the storage method, as a way to decontaminate pathogens. The experimental design used was a randomized block, with 5 treatments and 4 replicates, which were: T1 – only water; T2 – water + 15% urine; T3 – water + 30% urine; T4 – water + 45% urine; and T5 – water + 60% urine for sunflower cultivation. In relation to coriander, it was used in T1 – only water; T2 – water + 5% urine; T3 – water + 10% urine; T4 – water + 15% urine; and T5 – water + 20% urine. The experiment evaluated for sunflower and coriander the following: stem diameter (SD); Plant Height (PH); Leaf number (LN), Root length (RL) and Total Dry Mass of the Plant (PDM). The T1 and T2 treatments in sunflower cultivation showed higher mean values of SD, PH, LN and PDM. The T2 treatment in the cultivation of coriander showed greater development in relation to the variables SD, PH, LN and PDM. Thus, the results indicate that the crops were able to absorb the nutrients contained in human urine, demonstrating that it is possible to replace chemical fertilizers, causing a reduction in their consumption.

Keywords: natural fertilizer, nutrients, reuse.

¹ Departamento de Engenharia Ambiental e Sanitária, Instituto Federal do Ceará, Campus Juazeiro do Norte, Brasil.

² Departamento de Construção Civil, Instituto Federal do Ceará, campus Fortaleza, Brasil.

³ Departamento de Recursos Naturais, Instituto Federal do Ceará, campus Sobral, Brasil.

⁴ Departamento de Engenharia Hidráulica e Ambiental, Universidade Federal do Ceará, Brasil.

* *Corresponding author:* Departamento de Engenharia Ambiental e Sanitária, Instituto Federal do Ceará, Campus Juazeiro do Norte, Brasil. Av. Plácido Aderaldo Castelo, 1646 - Planalto, Juazeiro do Norte – Ceará, Brasil, Postal Code: 63040-540.

Email. germario@ifce.edu.br

Introduction

In Brazil, the sanitary sewage system does not attend the entire population, according to data from the Trat Brazil Institute. Only 52% of the population use a sewage collection network. A large part of untreated sewage reaches water resources, and even the treated ones, since the existing systems are not efficient in removing nutrients, therefore contributing to the supply of nutrients to water bodies, accelerating the eutrophication process.

This issue could be avoided if nutrients were seen as commodities, as they contain essential nutrients for crops. Thus, the agricultural use of organic waste is a sustainable alternative for recycling nutrients and minimizing the negative environmental impacts resulting from the final disposal of sewage. The use of residues as fertilizers in agricultural activity can bring benefits to the development of crop (Magalhães *et al.*, 2014; Araújo *et al.*, 2019; Chipako; Randall, 2020).

Among the residues, yellow water or human urine, stand out, since this liquid contains nitrogen, phosphate and potassium in the dissolved form in reasonable concentrations to meet the nutritional demands of the fertilized crops (Richert *et al.*, 2010; Karak; Bhattacharyya, 2011; Botto *et al.*, 2017). It accounts for approximately 56% of total phosphorus and 80% of total nitrogen found in domestic wastewater (Spångberg *et al.* 2014; Chipako; Randall, 2020).

It can be highlighted several studies on the use of human urine with different crops: barley (Rodhe *et al.*, 2004), wheat (Ganrot *et al.*, 2007); cucumber (Heinonen-Tanski *et al.*, 2007), tomato (Pradhan *et al.*, 2009); sorghum (Germer *et al.*, 2011); okra (Akpan-Idioka *et al.*, 2012); spinach (Sene *et al.*, 2012); pepper (Shrestha *et al.*, 2013); *Chrorella* cultivation (Zhang *et al.*, 2014). Oliveira *et al.* (2010a) and Freire *et al.*, (2017) studied the application of bovine urine in the cultivation of *Lactuca sativa L.*

However, there are few published studies on the use of human urine in Brazil as a biofertilizer. Araújo *et al.* (2015) investigated the application of human urine in the cultivation of corn by evaluating productivity. Botto *et al.* (2017) evaluated the productivity of castor bean cultivar using human urine in small farming.

Medeiros *et al.* (2020) evaluated the use of human urine as a fertilizer in the semiarid in relation to energy demand, environmental aspects and the impacts of crop fertilization, comparing them with the use of mineral fertilizers. Agricultural fertilization using human urine showed more advantages when compared to solid mineral fertilizer.

Assessing crop growth using parameters is extremely important, as it allows a first analysis of production estimates and does not require sophisticated equipment (Hortegal Filha *et al.*, 2018).

Thus, this work evaluates the use of human urine, in different concentrations, in the development of sunflower and coriander, as a biofertilizer.

Sunflower originated in North America, mainly southwestern United States and northern Mexico. It has great adaptability, so it is cultivated almost all over the world. The cultivation has been increasing because of the great capacity to produce high quality vegetable oil and biodiesel (Seabra Filho *et al.* 2021), in addition to the possibility of producing other products such as bran and cake. About 13% of the vegetable oil produced in the world corresponds to sunflower oil (AMABILE *et al.* 2002).

Coriander is an annual vegetable belonging to the Apicaceae family, considered easy to grow. In the Northeast region of Brazil, it is widely consumed, because of its flavor and aroma, and also because it is a source of iron, calcium and vitamins (Dias *et al.* 2021). It is grown mainly in Africa, Europe and Asia in Brazil in the northeast region has the largest plantations (LARIBI *et al.*, 2015).

Material and methods

This experiment was carried out in an experimental area of the IFCE, Fortaleza campus, Ceará State, Brazil within the geographical coordinates 3°74' 48" Latitude (S) and 38° 53' 60" longitude (W).

The climate in Fortaleza is characterized, according to the Köppen's classification, as semi-humid tropical, with a rainy season from January to June and a dry season from August to December. The average monthly temperatures vary between 26°C and 28°C and the average annual rainfall is 1600 mm (IPECE, 2017).

The experimental period lasted from March to August 2019, and the collection, storage of urine and qualitative characterization were carried out firstly, followed by the planting and application of urine in sunflower and coriander crops, followed by the evaluation of the agronomic aspects.

The urine was stored in sealed containers for at least 30 days, a period reported in the literature as being sufficient to eliminate microorganisms. The samples were placed in previously cleaned plastic tanks and transported to the LSA (Laboratory of Environmental Sanitation at IFCE) for physical-chemical analysis, where the pH, electrical conductivity, ammonia and Total Phosphorus and Thermotolerant Coliforms (*E. coli*) were measured. All procedures for collection, conditioning, transportation and analysis of the samples followed the recommendations of APHA (2012).

The seedlings of sunflower (*Helianthus annuus* L.) and coriander (*Coriandrum sativum*) were produced in Styrofoam trays, with 100 cells, and the soil of the region, classified as sandy-loam, was used as substrate.

After 20 days of sowing, the seedlings were transplanted to plastic jars with a capacity of 950 mL, where the experiment was carried out, with three plants per pot. Concomitantly to germination, field capacity was defined using the method of Richards (1954) to determine the amount of water needed for irrigation. After such determination, 100 ml and 50 ml were used daily in each pot for sunflower and coriander crops, respectively.

The experimental design used in the experiment was a randomized block with five treatments and four replications, which were the following for sunflower: T1 – supply water; T2 – supply water + 15% human urine; T3 – supply water + 30% urine; T4 – supply water + 45% urine; T5 – supply water + 60% urine and, for coriander, they were: T1 – supply water; T2 – supply water + 5% urine; T3 – supply water + 10% urine; T4 – supply water + 15% urine; T5 – supply water + 20% urine. It is worth mentioning that irrigation was carried out daily in the morning, with the aid of a watering can.

The characterization of the culture growth was carried out from June to August 2019, using the classical non-destructive analysis method, following the methodology used by Silva *et al.* (2014), in which the plants are carefully removed and separated in properly identified paper envelopes. In the laboratory, the following parameters were analyzed: Stem diameter (SD), in mm; Plant height (PH), in cm; Root Length (RL), in cm and number of leaves (LN). For this, the following equipment was needed: graduated measuring tape to determine the stem height and digital caliper to check the diameter and leaf count.

The plants were removed from the jars and their stem, leaves and roots were separated. Then, the parts of the sunflower plants were subjected to drying in a greenhouse at a temperature of 65°C, for 24 h, until the constant weight of the dry mass of the plant (PDM) was obtained, which were determined with the aid of a digital precision scale.

The data were analyzed by the F test and when significant, they were submitted to the test of Tukey at the level of 1% and 5% probability. For crop growth analysis, they were submitted to regression analysis, seeking to fit equations with biological significances. The Assistat 7.7 Beta software (Silva and Azevedo, 2009) was used in the experiment.

Results and discussion

Table 1 shows the mean values of the parameters analyzed in the urine before and after the storage period. The pH is one of the most important parameters that influence the stabilization processes of human urine. According to Zancheta (2007); Zhang *et al.* (2014); Botto *et al.* (2017) and Chipako and Randall (2020) the formation results in the raise of pH. This is explained when the process of urea hydrolysis catalyzed by the enzyme urea occurs, releasing ammonia and

bicarbonate. This raise in pH is essential, as in samples with a pH above 8.0, there is trend towards nullity in relation to thermotolerant coliforms, which occurred after the storage period, which was the phase used in the experiments.

Table 1. Mean values obtained in the urine before and after storage.

Parameter	Urine without treatment	Urine after 30 days of storage
pH	6.3	9.0
Electric conductivity	16.2 mS.cm ⁻¹	47.6 mS.cm ⁻¹
Ammonia	80.1 mg.L ⁻¹	700.1 mg.L ⁻¹
Total phosphorus	1012.88 mg.L ⁻¹	304.45 mg.L ⁻¹
Thermotolerant coliforms	1.6 x 10 ² NMP.100mL ⁻¹	Absence

The pH is one of the most important parameters that influence the stabilization processes of human urine. According to Zancheta (2007); Zhang *et al.* (2014); Botto *et al.* (2017) and Chipako and Randall (2020) the formation results in the raise of pH. This is explained when the process of urea hydrolysis catalyzed by the enzyme urea occurs, releasing ammonia and bicarbonate. This raise in pH is essential, as in samples with a pH above 8.0, there is trend towards nullity in relation to thermotolerant coliforms, which occurred after the storage period, which was the phase used in the experiments.

Fresh stored human urine had an initial pH of 6.3 and after 30 days in a closed reservoir it increased to 9.0 units. Close results were obtained by Zhang *et al.* (2014); Qadir and Shukat (2019); Chipako and Randall, (2020), in which values close to neutrality was obtained for fresh urine. However, with the storage process, the pH tended to stabilize and reaching a value close to 9.0.

The raise in the pH, resulting from the hydrolysis of urea, also interferes with the values of electrical conductivity. Thus, an EC of 16.2 mS cm⁻¹, was observed in fresh urine, and after the storage period, there was a significant increase, reaching 47.6 mS cm⁻¹, an increase also observed by Martins (2016), with EC of 54 mS cm⁻¹ and by Zancheta (2007), who observed values between 17.3 and 49.0 mS cm⁻¹. High values of EC may hamper in the long run, the use of urine as a biofertilizer, since salts can fill empty spaces in the soil, negatively affecting the growth of the crop.

Botto (2013) and Chipako and Randall (2020) report that the increase in the concentration of ammonia occurs from the process that urine undergoes when it is stored, especially when storage occurs in a closed reservoir. As a result, urea is chemically hydrolyzed and biologically degraded. These reactions, as during hydrolysis, are responsible for increasing the pH and, as a consequence, the formation of bicarbonate ions occurs and the conversion of urea to ammonia, as a result.

An increase in ammonia of 80.1 mg L^{-1} was observed in fresh urine and 700.1 mg L^{-1} after the storage period. Under a high pH condition, ammonia is volatile. The high concentration was important to make nitrogen available to the soil, even though part of the ammonia was lost due to volatilization.

Phosphorus is found in human urine predominantly in the form of orthophosphate, as reported by Udert *et al.* (2003) and Zancheta (2007). For these authors, the decrease in the amount of P during the storage period is due to the precipitation in alkaline pH. The reduction is an indication that hydroxyapatite crystals are being formed and that their precipitation starts with the lowest pH and depending on the calcium already present in the urine. There is also the precipitation of struvite, which occurs with the raise in pH and after ammonification (Bichler *et al.*, 2002).

This fact can be evidenced with the reduction in levels of P, where fresh urine had a P content of $1012.88 \text{ mg/L}^{-1}$ and after 30 days in a closed reservoir, this value dropped to 304.45 mg L^{-1} , which is similar to that obtained by Martins (2016), that after four weeks, the P level was 300 mg L^{-1} .

The raise in urine pH, which occurs naturally after urea hydrolysis, destroys harmful pathogens in the urine (Von Münch; Winker 2011; Chipako; Randall, 2020). Thus, the presence of thermotolerant coliforms (TC) was observed in fresh human urine, however, it is noteworthy that humans do not excrete bacteria that belong to the coliform group through the urinary path, with the contamination of the urine occurring at the exit of the urethra, except the cases in which there is urinary infection (Martins, 2016).

The presence of TC was found in fresh urine, but after the 30-day storage period they were eliminated, which is caused by the adverse conditions for microorganisms, in which the raise in pH is one of them. Similar results were obtained by Zancheta (2007), Rios (2008) and Martins (2016).

Table 2 shows the mean values, statistical differences by the test of Tukey and the coefficients of variation of the parameters studied in sunflower and coriander crops, respectively. Significant differences were found, and in some cases, similarities between the treatments used in the two crops, according to the test of Tukey.

The results will be better discussed with the presentation of Figures 1 to 5 where each agronomic aspect will be approached separately.

Table 2. Mean values of SD, PH, RL, LN and PDM for different dilutions of human urine in natural water.

Water-diluted urine	SD (mm)	PH (cm)	RL (cm)	LN	PDM (g)
Sunflower					
0%	0.0414 ab	30.48 a	5.47 a	12.58 a	0.64 a
15%	0.0604 a	19.51 b	5.3 a	9.25 ab	0.44 ab
30%	0.0577 ab	13.27 bc	3.47 a	6.92 bc	0.33 bc
45%	0.0375 ab	10.73 c	4.23 a	3.83 cd	0.19 c
60%	0b	10.23 c	3.99 a	2.58 d	0.12 c
CV	59.12	20.62	18.33	25.49	29.84
Coriander					
0%	0.013 a	16.93 a	13.41 a	22.81 a	0.70 ab
5%	0.014 a	18.78 a	11.86 ab	26.13 a	0.922 a
10%	0.011 ab	14.88 a	9.39 abc	19.36 a	0.452 bc
15%	0.006 bc	6.68 b	6.04 bc	7.4 b	0.153 c
20%	0.002 c	4.82 b	3.48 c	6.13 b	0.129 c
CV	33.44	19.44	34.32	23.96	11.40

Means followed by the same letter in the column are not statistically different by the test of Tukey at 5% probability.

Stem diameter (SD)

The results of the analysis for SD in the cultivation of sunflower and coriander are shown in Figure 1. It was observed that during the experiment, the stem diameter showed a quadratic behavior in relation to the dilutions used in the experiment. It was observed that T2 obtained the best result, even when compared with T1. Then, the second-best dose observed was T3, also higher when compared to T1. The other dilutions were smaller and decreasing, reaching zero in treatment T5, where, it is statistically equal to treatments T1, T3 and T4.

The comparison between the treatments allowed to observe small variations between the dilutions used, however, it is observed that the largest dilutions were not well absorbed by the crops as they may be used in an excess of volume.

In sweet pepper grown with human urine, Muller *et al.* (2019) reported the smallest SD value of 8.84 mm for 8% dilution of urine and the highest was 15.58 mm for dilution of 30%. The percentage of urine used in the experiment directly influences productivity, and it can be beneficial or harmful according to the concentration used, thus, in the cultivation of sunflower, which reached 0.0604 mm as the best SD, for a 15% dilution, which shows that the optimal dosage of urine depends on the culture and on the amount applied per day.

In the analysis of the use of waste water and organic fertilization in the cultivation of sunflower, carried out by Souza *et al.* (2010), the SD found was 9.41 mm, which was irrigated at two different periods, using 10 mL in the morning and 10 mL in the afternoon, totaling a volume of 20 mL per day, for 28 days.

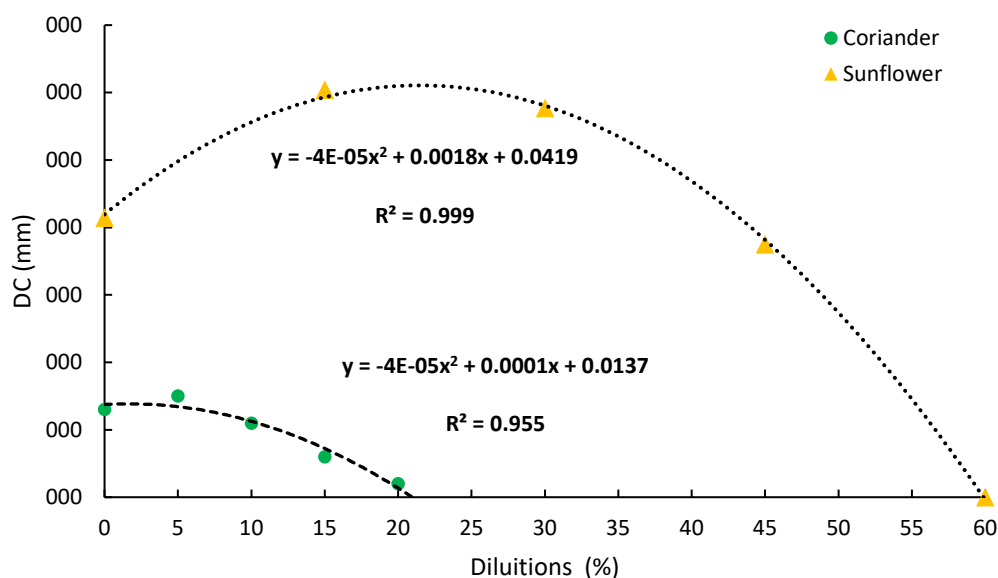


Figure 1. SD of sunflower and coriander according to the dilution of human urine in natural water.

Although the duration of the studies was similar, a factor that may have had a negative impact on the SD was the volume used for irrigation, 100 mL. Although the pot used in the study had a drain at the bottom, this volume (water + urine) may have caused a leaching of micronutrients present in the soil, since, at the beginning of the study, the plants showed an adequate initial growth; however, the plants did not grow over time and with the greatest dilutions.

Coriander (Figure 1) showed similarities between the T1 (0%), T2 (5%) and T3 (10%) treatments, which did not differ statistically from each other in relation to the SD, where the treatment that used 5% of human urine obtained the best result. The other dilutions also produced good results, but were reduced as the concentrations were increased, results similar to those obtained by Rios (2008) regarding the application of urine in *Lactuca Sativa L.* plantation, where the results of treatments with 0%, 5 %, and 10% did not differ from each other, however there was a difference between 15% and 20% of human urine.

The regression analysis in both crops showed that the equation with the best fit was the second-degree polynomial, with R^2 of 0.99 for sunflower and 0.96 for coriander. This fact demonstrates that the increase in dosages does not always mean an increase in the level of nutrients in the crop phytomass.

Plant height (PH)

It can be seen in Figure 2 the results obtained in the period studied for PH. It was possible to observe a decreasing behavior in the cultivation of sunflower, as the dilution values were increased. The T1 treatment showed the best result, reaching a value equal to 30.48 cm and with statistically differences from the other dilutions. The T2 and T3 treatments also showed the results, 19.51 cm and 13.27 cm, respectively and did not present any statistical differences between them. The other treatment continued in a decreasing way, obtaining a value of 10.23 cm for T5 (Figure 2).

The fact that the highest result was obtained using the T1 treatment (water only) indicates that the dilutions used in the experiment may have been high, since the use of urine may have hampered the growth of the plant.

In the regression analysis, the equation with the best fit for sunflower data was the quadratic polynomial, with a coefficient of determination (R^2) of 0.99, showing a decrease in PH as dilutions were incremented. This reinforces the idea that it was used high dilutions in this crop.

In the study by Freitas *et al.* (2012), a linear behavior was observed in the growth of sunflower under irrigation with different types of water and fertilization, with a determination coefficient (R^2) of 0.87, and the highest mean for PH equal to 112.4 cm. While in the study by Freitas *et al.* (2012) the best means of PH were for irrigation with reused water, in the period of 90 days. The best means for this study were observed when irrigation with water was performed.

Although the studies had similar cultivation periods, this experiment obtained better means for PH when irrigated with water; however, with the dilutions of 15% and 30%. This reinforces the idea that dilutions or the amount of urine applied were high for sunflower cultivation.

Souza *et al.* (2010) found, for the PH variable, a value of 81.00 cm for the sunflower irrigated with 20 mL of supply water. The factors that may have influenced Souza *et al.* (2010) to obtain a higher PH than that of the present study were the irrigation volumes that they used and the fact that they carried out the experiment in a local that was covered and protected from the weather.

For the cultivation of coriander, a result similar to that obtained in the stem diameter parameter was observed. The 0%, 5% and 10% dilutions did not differ statistically in relation to the height of

the coriander plants, where it was used the treatment with 5 % urine. The other dilutions also showed good results, but reduced as the concentrations were increased, confirmed in the regression analysis, where the equation with the best fit for the data was the polynomial, with a coefficient of determination (R^2) of 0.87 (Figure 2).

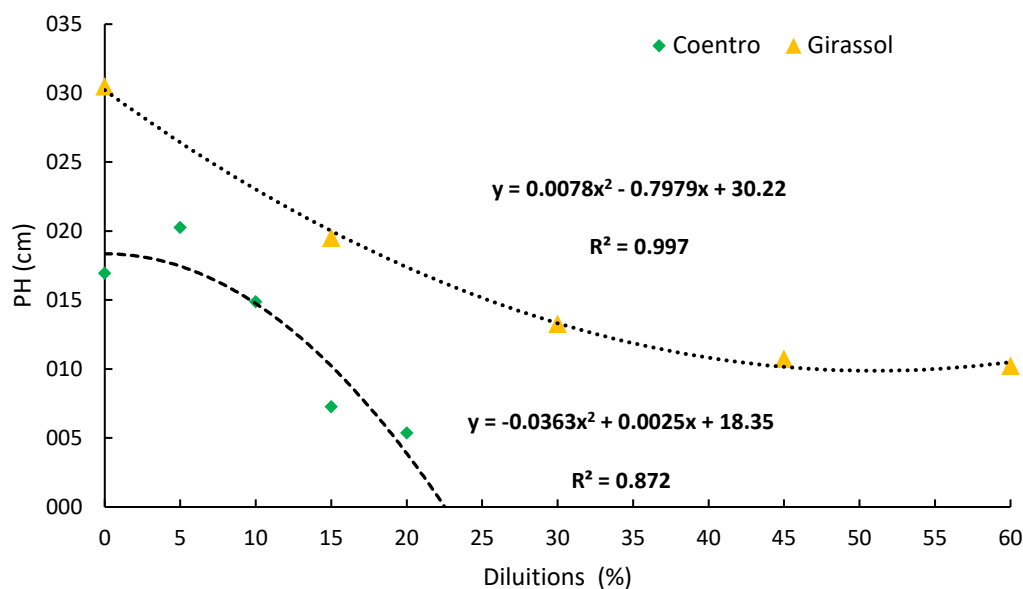


Figure 2. PH development in sunflower and coriander crops according to the dilutions used in the treatments.

As in this study, Rios (2008) also obtained similar results regarding the application of urine in *Lactuca sativa* plantations, where the results of treatments with 0%, 5%, and 10% did not differ, however, a difference between 15% and 20% in human urine was found.

In a study by Silva (2010) on the use of bovine urine for irrigation of coriander, the best results were obtained for plant height when the plants received 100% urine, achieving 46.75 cm, differing from the results obtained in this research. However, the coriander evaluated by Silva (2010) was irrigated every 7 days with different dilutions (0.25%; 50%; 75% and 100%), which may have contributed to the better absorption of nutrients by the crop.

Leaf number (LN)

It can be seen in Figure 3 the values obtained during the evaluated period for LN. Likewise, the behavior during the experiment was a decrease for the cultivation of the sunflower. The highest LN obtained was with the T1 treatment, presenting a value of 12.58 leaves. Then, the second-best

treatment observed was T2, with a value of 9.25 leaves. Both T1 and T2 did not differ statistically. As dilutions increased, the LN values decreased, with an inversely proportional behavior. The T5 treatment was, again, the one with the lowest value, with LN equal to 2.58 leaves, statistically differing among the other dilutions.

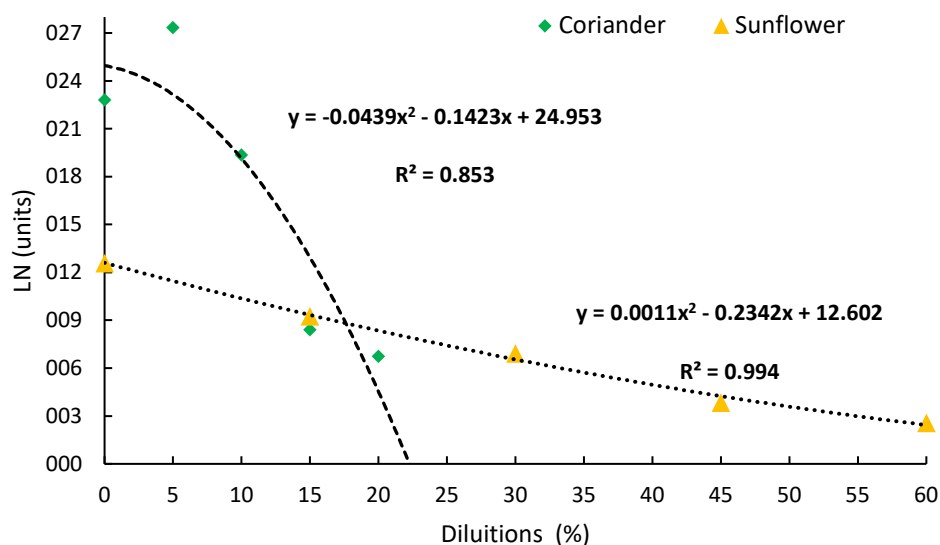


Figure 3. Development of the LN in the cultivation of sunflower and coriander according to the dilutions used in the treatments.

In the cultivation of coriander, like the SD and PH parameters, the LN obtained the same statistical design, where the dilutions 0%, 5%, 10% did not differ statistically, but showing that 5% of urine was a result that stood out in relation to the other dilutions.

It was observed in the regression analysis of sunflower cultivation the equation with the best data fit was the polynomial, with a determination coefficient (R^2) of 0.99 and for the coriander cultivation, the equation with the best data fit was also the polynomial, with a coefficient of determination (R^2) of 0.85. Despite being different cultures, this behavior observed in most of the analyzed parameters reinforces the idea that smaller dilutions can act more efficiently in terms of nutrient use by the crops.

Root length (RL)

Figure 4 shows the values obtained in the evaluated period for RL, in sunflower cultivation. The best results were for treatment T1 and T2, with a RL equal to 5.47 cm and 5.3 cm, respectively. In

the T3 treatment, the lowest mean value was 3.47 cm. Then, there was a growth in the following dilutions, with 4.23 cm for T4 and 3.99 cm for T5. The values obtained in this analysis showed a different behavior from the other variables under study. All results obtained in the experiment did not differ statistically.

Seeking the best fit of the data in the regression analysis, the polynomial equation was the one with the best fit, with (R^2) of 0.69 for sunflower cultivation.

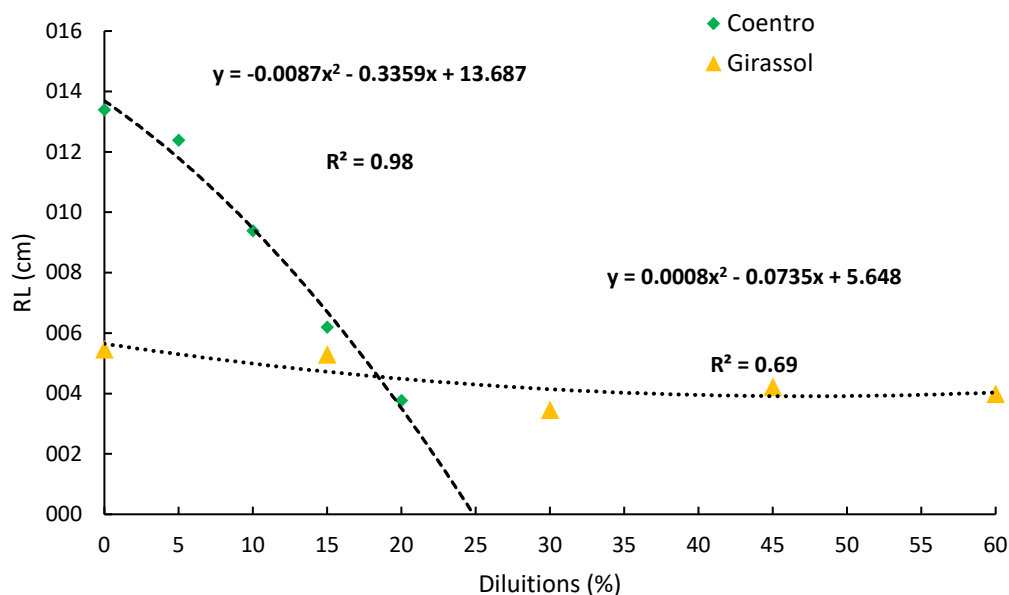


Figure 4. RL development in sunflower and coriander cultivation according to the dilutions used in the treatments.

The results of the RL analysis for the cultivation of the coriander are shown in Figure 4. It could be observed that there was a similarity between the results of the irrigation only with water and those with 5% and 10% of urine, which did not differ statistically between each other where T1 (0% dilution) obtained a better result compared to the others. Then, the second-best result was 5%. The other dilutions were smaller and decreasing.

According to the regression analysis, the equation with the best data fit was the quadratic polynomial, with a coefficient of determination (R^2) of 0.98, showing to be constant and decreasing, where the 0% dilutions were observed as a value greater than the 20%, the lowest value referring to the root length.

Another factor that may have contributed to the reduction in the length of the root is related to the matter of the electrical conductivity of the samples, which for treatments that use urine, even diluted, present high concentrations, considering the high value in the stored urine.

This fact is corroborated by Oliveira *et al.* (2010) who used salt substances for irrigation of coriander, observing that the root lengths were affected as the salinity of the irrigation water increased (0.5; 1.5; 3.0; 4.5 and 6.0 dS.m⁻¹). Like this study, the length of the coriander root was reduced as human urine concentration were increased.

Plant dry matter (PDM)

Figure 5 shows the mean values obtained during the evaluated period for PDM regarding sunflower cultivation. The results were similar to those obtained in most of the evaluated parameters, with a decreasing behavior. The highest mass was obtained in the treatment (T1), which presented a value equal to 0.64 g. Then, the T2 treatment, presenting PDM equal to 0.44 g. The T1 and T2 treatments did not differ statistically. With an inversely proportional behavior between the dilutions and the PDM, the lowest value obtained was for T5, with 0.12g, followed by the T4 treatment, with 0.19g. Both treatments were statistically different from each other.

The equation with the best data fit was the quadratic polynomial with a determination coefficient (R²) of 0.99.

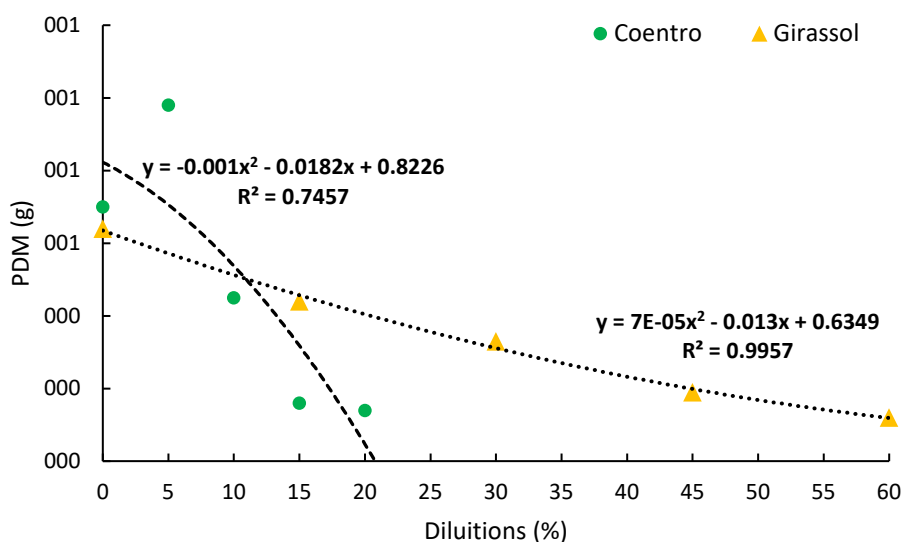


Figure 5. Development of PDM in sunflower and coriander cultivation according to the dilutions used in the treatments.

For the cultivation of coriander, a similarity in the behavior was observed with the other evaluated parameters. The treatments T1 and T2 did not differ statistically, but T2 showed a dry mass higher than the control T1. However, the other treatments did not differ and obtained results with lower values when compared with T2. In the regression analysis, the equation with the best data fit was the polynomial, with a coefficient of determination (R^2) of 0.75.

Rios (2008) obtained results similar to those of this experiment in the analysis of the use of human urine in *Lactuca sativa*, where it was observed that in the summer cultivation, dry and wet mass showed better results in treatments with smaller levels of urine, as well as Araújo (2017) who also obtained better results at lower dosages in fertigation with urine and cassava waste water.

Oliveira *et al.* (2010) and Rebouças *et al.* (2013) in their studies with the application of salt water in the cultivation of coriander, also obtained a reduction in the volume of dry mass of plants irrigated with a greater amount of salts, which may also have occurred in this study considering that the increase in amount of urine hampered the amount of dry mass of the plant.

It is important to highlight that urine can be collected in urinals or in separating vessels, which, even though it is not so widespread, the separation technique has been used in other parts of the world for many years. Sweden is one of the pioneers in formulating these urine-diverting systems, they started to develop this technique and in the 90's they built the first porcelain urine-diverting system. Another example we have is in China, where urine is separated in simple toilets and after being collected, it is used as fertilizer on the property where the collection took place (Jönsson, 2004; Zancheta, 2007). After collected and stored, these can be sent to the cultivation fields.

The commercialization of human urine-based fertilizers has shown a self-sustainable economic potential. The financial payback of 7.8 years was estimated in a business model of struvite production from human urine in Brazil (Oyama, 2013). The costs of labor and transportation of residential human urine stored and delivered to a farm of up to 56 km in the United States showed feasibility (Atlee *et al.*, 2019). As well as in South Africa (Etter *et al.*, 2015). In places with limited access to mineral fertilizers and sanitation, the economics of recovering nutrients from human excreta can be estimated based on the increased production of the fertilized crop (Medeiros *et al.* 2020).

Conclusions

This study shows that human urine can be used in the cultivation of coriander as the nutrients were assimilated by the crop. However, for the cultivation of sunflower, the dosages used for the cultivation were high, which had a negative impact on the evaluated agronomic aspects. Another factor that may have contributed to the worsening of the results was the amount of 100 mL of urine used daily. This may have caused a leaching of micronutrients present in the soil, restricting the growth of the crop.

In the stored urine, hydrolysis of urea occurred, producing ammonia, therefore increasing the pH and creating favorable conditions for the elimination of thermotolerant coliforms.

The values of agronomic aspects obtained in the cultivation of coriander were higher in the T2 treatment (5%) in the following aspects: LN; PH; SD and PDM when compared to the control 0% (water only). The 0% control obtained better results only in the RL parameter.

References

- Akpan-Idiok A. U., Udo I. A., Braide E. I. (2012) The use of human urine as an organic fertilizer in the production of okra (*Abelmoschus esculentus*) in *South Eastern Nigeria. Resources, Conservation and Recycling*, **62**, 14-20.
- AMERICAN PUBLIC HEALTH ASSOCIATION – APHA. (2012). Standard Methods for the Examination of Water and Wastewater, 22th Edn, Washington, D.C. American Society of Civil Engineers/Water Environment Federation.
- Amabile, R. F., Fernandes, F. D., Sanzonowicz, C. (2002) Girassol com alternativa para o sistema de produção do cerrado. Embrapa Cerrados-Circular Técnica. <https://www.infoteca.cnptia.embrapa.br/infoteca/bitstream/doc/559946/1/cirtec20.pdf>
- Araújo, N. C. de., Lima, V. L. A., Sena, L. F., de Lima, G. S.; Andrade, E. M. G., Cardoso, J. A. F. E., Oliveira, S. J. C. (2019) Produção de milho Potiguar fertirrigado com água amarela e manipueira. *Revista de Ciências Agrárias*, **42**(1), Lisboa mar. <http://dx.doi.org/10.19084/RCA18170>.
- Araújo, N. C., Coura, M. de A., Oliveira, R., Sabino, C. M. B., Oliveira, S. J. C. (2015). Cultivo Hidropônico de Milho Fertirrigado com Urina Humana como Fonte Alternativa de Nutrientes. *Revista Irriga, Botucatu*, **20**(4), p. 718-729, outubro – dezembro. ISSN ONLINE 1808-8546/ISSN CD 1808-3765.
- Araújo, N. C., de Lima, V. L. A., Sena, L. F., Ramos, J. G., Borges, V. E., Bandeira, F. A., (2017) Produção Orgânica da Alface Em Substrato Fertilizado Com Água Amarela e Manipueira. *Revista Brasileira de Agricultura Irrigada*, Fortaleza, **11**(8), p.2111-2119, 30 dez. 2017. INOVAGRI. <http://dx.doi.org/10.7127/rbai.v11n800689>.
- Atlee, J., Noe-Hays, A., Nace, K., Schreiber, T., Davis, A., Lally C., Dotson S. (2019). Guide to Starting a Community-scale Urine Diversion Program (first ed.), Rich Earth Institute, Brattleboro.
- Bichler, K. H.; Eipper, E.; Naber, K.; Braun, V.; Zimmermann, R.; Lahme, S. (2002). Urinary infection stones. *International Journal of Antimicrobial Agents*. **19**, p. 488-498.
- Botto, M. P. (2013) *Utilização da Urina Humana como Biofertilizante para Produção de Alimentos e Energia: Caracterização, uso na agricultura e recuperação de nutrientes*. Tese (Doutorado em Eng. Civil) – Universidade Federal do Ceará, Departamento de Engenharia Hidráulica e Ambiental, Fortaleza – CE, 270 pp.
- Botto, M. P., Muniz, L. F., Aquino, B.; Dos Santos, A. B. (2017). Produtividade da Mamona Cultivar BRS Nordestina Fertilizada com Urina Humana na Agricultura de Pequeno Porte. *Revista AIDIS de Ingeniería y Ciencias Ambientales: Investigación, desarrollo y práctica*. **10**(1), 113 – 124.
- Chipako T.L., Randall D.G. (2020). Urine treatment technologies and the importance of pH, *Journal of Environmental Chemical Engineering*. **8**. Issue1. <https://doi.org/10.1016/j.jece.2019.103622>
- Dias, F. H. C., Abreu, K. G., Lima, M. A. D. C., Lopes, A. S., Silva, E. G. D. F. (2021). Fitonematoides associados à cultura do coentro (*CORIANDRUM SATIVUM*). *Revista Multidisciplinar de Educação e Meio Ambiente*, **2**(2), 68. <https://doi.org/10.51189/rema/1086>
- Etter B., Udert, K. M., Gounden, T. (2015) VUNA Final Report Swiss Federal Institute of Aquatic Science and Technology (Eawag) Dübendorf Switzerland.

- Freire, J. L. de O., Silva J. E., Lima J. M., Arruda, J. A., Rodrigues C. R. (2017). Desempenho fitotécnico e teores clorofilianos de cultivares de alfaces crespas produzidas com fertilização à base de urina de vaca no Seridó paraibano. *Revista Agropecuária Científica no Semiárido ACSA*, Patos-PB, **12**(3), 258-267.
- Freitas, C. A. S. de., Silva, A. R. A da., Bezerra, F. M. L., Andrade, R. R. de., Mota, F. S. B., Aquino, B. F. (2012). Crescimento da Cultura do Girassol Irrigado com Diferentes Tipos de Água e Adubação Nitrogenada. *Revista Brasileira de Engenharia Agrícola e Ambiental*. **16**(10), 1031-1039.
- Ganrot, Z., Dave, G., Nilsson, e., Li, B. (2007) Plant availability of nutrients recovered as solids from human urine tested in climate chamber on *Triticum aestivum* L. *Bioresource Technology*, **98**(16), 3122–3129.
- Germer, J., Addaib, S., Sauerborn, J. (2011) Response of grain sorghum to fertilisation with human urine. *Field Crops Research*, **122**(3), 234-241.
- Heinonen-Tanski, H., Sjöblom, A., Fabritius, H., Karinen, P. (2007) Pure human urine is a good fertiliser for cucumbers. *Bioresource Technology*, **98**(1), 214–217.
- IPECE, Instituto de Pesquisa e Estratégia Econômica do Ceará (2017). Perfil Básico Municipal – Fortaleza. Secretaria de Planejamento e Gestão – Governo do Estado do Ceará. Acesso em: 02 de abril de 2020. Disponível em http://www.ipece.ce.gov.br/perfil_basico_municipal/2017/Fortaleza.pdf.
- Jönsson H., Stinzing, A. R., Vinneras, B., Salomon, E. (2004) Guidelines of the Use of Urine and Faeces in Crop Production, EcoSanres Publication Series 2004-2 Stockholm Environment Institute Sweden.
- Karak, T., Bhattacharyya, P. (2011) Human urine as a source of alternative natural fertilizer in agriculture: A flight of fancy or an achievable reality. *Resource Conservation and Recycling*, **55**(4), 400 – 408.
- Laribi, B., Kouki, K., M'hamdi, M., Bettaieb, T. (2015). Coriander (*Coriandrum sativum* L.) and its bioactive constituents. *Fitoterapia*. Jun;103:9-26. <http://doi.org/10.1016/j.fitote.2015.03.012>. Epub 2015 Mar 14. PMID: 25776008.
- Magalhães, A.G., Rolim, M. M., Duarte, A. S., Bezerra Neto, E., Tabosa, J. N., Pedrosa, E. M. R. (2014) - Desenvolvimento inicial do milho submetido à adubação com manipueira. *Revista Brasileira de Engenharia Agrícola e Ambiental*, **18**(7), 675–681. <http://dx.doi.org/10.1590/S1415-43662014000700001>
- Martins, E. S. C. S. (2016). *Efeito do armazenamento sobre as características de urina e águas amarelas*. Dissertação (Mestrado Ciência e Tecnologia Ambiental) Universidade Estadual da Paraíba, Centro de Ciências e Tecnologia, Campina Grande, 86 pp.
- Medeiros, D. L., Queiroz, L. M., Cohim, E., de Almeida Neto, J. A., Kiperstok, A. (2020). Human urine fertiliser in the Brazilian semi-arid: Environmental assessment and water-energy-nutrient nexus. *Science of Total Environment* 136145. **713** April.
- Muller, P., Freitas, C. H. C., Pedro, J. P. B. (2019). Urina humana como fertilizante: Experimento com pimenta de cheiro (*Capiscum spp.*) na Amazônia Central. Meio Ambiente em Foco, volume 7, 1ª edição, Belo Horizonte, editora Poisson.
- Oliveira N. L. C., Puiatti, M., Santos R. H. S., Cecon, P. R., Bhering, A. S. (2010a). Efeito da urina de vaca no estado nutricional da alface. *Revista Ceres* **57**(4), Viçosa July/Aug. <https://doi.org/10.1590/S0034-737X2010000400011>
- Oliveira, K. P., Freitas, R. M. O., Nogueira, N. W., Praxedes, S. C., Oliveira, F. N. (2010b). Efeito da irrigação com água salina na emergência e crescimento inicial de plântulas de coentro cv. verdão. *Revista Verde de Agroecologia e Desenvolvimento Sustentável*, Mossoró, v. **5**(2), 201-208.
- Oyama, C. (2013) Nutrientes da urina humana como fertilizante agrícola: análise de viabilidade econômica de modelo de produção baseado na Economia Solidária e na Agricultura Instituto de Pesquisas Tecnológicas (IPT), São Paulo.
- Pradhan S. K., Holopainen J. K., Heinonen-Tanski H. (2009) Stored Human Urine Supplemented with Wood Ash as Fertilizer in Tomato (*Solanum lycopersicum*) Cultivation and Its Impacts on Fruit Yield and Quality. *Journal of Agricultural and Food Chemistry*, **57**(16), 7612–7617.
- Qadir, M. I., Shaukat, H. (2019). Muster of Urine pH with exercise. *Journal of Medical Practice and Review* **3**(5), 537-538.

- Rebouças, J. R. L., Neto, M. F., Dias, N. S., Sousa Neto, O. N. de., Diniz, A. A., Lira, R. B. de., (2013). Cultivo hidropônico de coentro com uso de rejeito salino. *Revista Irriga, Botucatu*, **18**(4), 624-634, dez. 2013. ISSN: 1808-3765.
- Richards, L. A. (1954) ed. Diagnosis and improvement of saline and alkali soils. Washington – DC, US Department of Agriculture, 160p. (USDA Agricultural Handbook, 60).
- Richert, A., Gensch, R., Joensson, H., Stenstroem, T.A., Dagerskog, L. (2010) Practical Guidance on the Use of Urine in Crop Production. Stockholm: Stockholm Environment Institute (SEI). Disponível em: http://www.ecosanres.org/pdf_files/ESR2010-1-
- Rios, E. C. (2008). *Uso de águas amarelas como fonte alternativa de nutriente em cultivo hidropônico da alface (Lactuca sativa)*. Dissertação (Mestrado)-Curso de Engenharia Ambiental, Departamento de Centro Tecnológico, Universidade Federal do Espírito Santo, Vitória, 2008, 85 pp.
- Rodhe, L., Stintzing, A. R., Steineck, S. (2004) Ammonia emissions after application of human urine to a clay soil for barley growth. *Nutrient Cycling in Agroecosystems*, **68**(2), 191–198.
- Seabra Filho, M., Vieira, L. R., Menezes, A. S., Pinheiro Neto, L. G., Azevedo, B. M. de., Sousa, P. G. R. (2021) Produção de óleo e produtividade de girassol sob diferentes frequências de irrigação no semiárido cearense. *Revista Brasileira de Agricultura Irrigada*, **14**, 4297-4304.
- Sene, M., Hijikata, N., Ushijima, K., Funamizu, N. (2012) Adequate human urine application pattern for agriculture. *International Research Journal of Agricultural Science and Soil Science*, **2**(1), 38-45.
- Shrestha, D., Srivastava, A., Man Shakya, S., Khadka, J., Sharma Acharya, B. (2013) Use of compost supplemented human urine in sweet pepper (*Capsicum annuum L.*) production. *Scientia Horticulturae*, **153**, 8–12. <http://doi.org/10.1016/j.scienta.2013.01.022>
- Silva, F. A. S., Azevedo, C. A. V. (2009). Principal components analysis in the software assistant statistical attendance. In: World Congress on Computers in Agriculture, 7. Reno- NV-USA. American Society of Agriculture and Biological Engineers.
- Silva, L. V. B., Lima, V. L. A., Silva, V. N. B., Sofiatti, V., Pereira, T. L. P. (2014). Torta de mamona residual irrigação com efluente sobre crescimento e produção do algodoeiro herbáceo. *Revista Brasileira de Engenharia Agrícola e Ambiental*. **17**(12), 1264 – 1270.
- Souza, R. M., Nobre, R. G., Gheyi, H. R., Dias, N. S., Soares, F. A. L. (2010). Utilização da água residuária e de adubação orgânica no cultivo do girassol. *Revista Caatinga, Mossoró*. **23**(2), 125 – 133.
- Spångberg, J., Tidåker, p. and Jönsson, H. (2014) Environmental impact of recycling nutrients in human excreta to agriculture compared with enhanced wastewater treatment. *Science of The Total Environment* **493**, 209-219.
- Udert, K.M., Larsen, T.A., Biebow, M. and Gujer, W. (2003) Urea hydrolysis and precipitation dynamics in a urine-collecting system. *Water Research* **37**(11), 2571-2582.
- Von Münch, E. And Winker, M. (2011) Technology review of urine diversion components: overview of urine diversion components such as waterless urinals, urine diversion toilets, urine storage and reuse systems, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Eschborn, Germany.
- Zancheta, P. G. (2007) Recuperação e Tratamento da Urina Humana Para Uso Agrícola. Dissertação (Mestrado em Engenharia Ambiental) – Curso de pós-graduação em Engenharia Ambiental da Universidade Federal do Espírito Santo. Vitória.
- Zhang, S., Lim, C. Y., Chen, C. L., Lui, H., Wang, J. Y. (2014) Urban nutrient recovery from fresh human urine through cultivation of *Chlorella sorokiniana*. *Journal of Environmental Management*. **145**, 129-136.