Universidade Federal Rural do Semi-Árido
Pró-Reitoria de Pesquisa e Pós-Graduação
https://periodicos.ufersa.edu.br/index.php/caatinga

ISSN 0100-316X (impresso)
ISSN 1983-2125 (online)
http://dx.doi.org/10.1590/1983-21252018v31n417rc

FERTIGATION OF SUNFLOWER CROPS USING LANDFILL LEACHATE[1]

DANIELA DA COSTA LEITE COELHO[2]*, ANTONIO OSMAR MEDEIROS JÚNIOR[2], KETSON BRUNO DA SILVA[2], NILDO DA SILVA DIAS[2], RAFAEL OLIVEIRA BATISTA[2]

ABSTRACT – The use of landfill leachate (LL) to produce biomass for energy and biofuel purposes is an alternative that minimizes environmental degradation. In this context, the objective of this work was to evaluate the effect of using different rates of LL in the fertigation of sunflower (*Helianthus annuus* L.) crops. The experiment was conducted in a randomized block design with five treatments and four replications—20 experimental plots. The treatments consisted of control with 100% water from the water supply (WWS) (T_1); 80% WWS + 20% LL (T_2); 60% WWS + 40% LL (T_3); 40% WWS + 60% LL (T_4); and 20% WWS + 80% LL (T_5). The sunflower crops were grown in a eutrophic Red-Yellow Argisol for 81 days, in Mossoró RN, Brazil. The plant characteristics evaluated—plant height, number of leaves, steam diameter and capitulum diameter—was determined. All variables evaluated presented statistical differences between treatments. In general, plants in the treatment 60% WWS + 40% LL presented better performance regarding the characteristics evaluated.

Keywords: *Helianthus annuus* L.. Urban wastewater. Biomass. Biofuel.

PRODUÇÃO DE GIRASSOL FERTIRRIGADO COM PERCOLADO DE ATERRO SANITÁRIO

RESUMO – O uso do percolado de aterro sanitário (PATS) na produção de biomassa para fins energético e biocombustível é uma alternativa que minimiza a degradação ambiental. Neste contexto, objetivou-se neste trabalho, analisar o efeito da aplicação de distintas proporções de percolado de aterros sanitários no cultivo de girassol (*Helianthus annuus* L.). O experimento foi conduzido com delineamento em blocos casualizados, com cinco tratamentos T_1 – 100 % de água da rede de abastecimento – AA (Testemunha); T_2 – 80 % de AA e 20 % de PATS; T_3 – 60 % de AA e 40 % de PATS; T_4 – 40 % de AA e 60 % de PATS; e, T_5 – 20 % de AA e 80 % de PATS, e quatro repetições, totalizando 20 parcelas experimentais. O girassol foi cultivado em ARGISSOLO Vermelho – Amarelo eutrófico, durante 81 dias em Mossoró/RN. Durante o ciclo do girassol foram determinadas as características vegetativas altura de planta (AP), número de folhas (NF), diâmetro do caule (DCaule) e do capítulo (DCapítulo). Comprovou-se que para todas as variáveis estudadas houve diferença estatística entre os tratamentos. Em geral, o tratamento 60 % de AA e 40 % de PATS apresentou melhor desempenho com relação às características vegetativas do girassol.

Palavras-chave: *Helianthus annuus* L.. Resíduo líquido urbano. Biomassa. Biocombustível.

*Corresponding author
[1]Received for publication in 09/27/2016; accepted in 10/23/2017.
Paper extracted from first author's doctoral dissertation.
[2]Department of Engineering and Environmental Sciences, Universidade Federal Rural do Semi-Árido, Mossoró, RN, Brazil; daniela.coelho@ufersa.edu.br - ORCID: 0000-0001-9182-3675, j.osmarx@hotmail.com – ORCID: 0000-0003-1324-5990, ketsonbruno@hotmail.com – ORCID: 0000-0002-2553-0513, nildo@ufersa.edu.br - ORCID: 0000-0002-1276-5444, rafaelbatista@ufersa.edu.br - ORCID: 0000-0002-3083-6808.

INTRODUCTION

The disposal of urban solid residues in landfills cause degradation of their organic material, and generation of a liquid of dark color and unpleasant odor that is highly polluting and has high organic and inorganic load, toxic and recalcitrant substances, commonly called landfill leachate (LL) (MATOS et al., 2013; BEDIN, 2011; MENDONÇA, 2010; LAUERMANN, 2007; BRENTANO, 2006).

LL has a high pollution potential, thus, the lack of treatment or inadequate treatment and management of such liquid waste can cause serious environmental impacts, such as pollution of soil, and surface and underground water resources (MATOS et al., 2013).

The use of LL as fertigation of agricultural crops favors the expansion of the irrigated area, makes it possible to increase crop yield and quality, improves the physical, chemical, and biological characteristics of the soil, and improves environmental and public health, when used together with appropriate agronomic management practices (CHEVREMONT et al., 2013; DUTRA, 2013; LO MONACO et al., 2009; HESPANHOL, 2008).

The volume of LL to be applied in crops must be based on the recommended nutrient rates and estimated water requirement for the crops (LO MONACO et al., 2009), i.e., water must be added to the LL to supply the plant need for nutrients and water.

Sunflower (*Helianthus annuus* L.) is an annual dicotyledonous plant from the Asteraceae family. The name Helianthus refers to the moving of the flower in relation to the sun, a phenomenon known as heliotropism (SOUSA et al., 2012; COSTA, 2012; OLIVEIRA et al., 2005; CASTRO; FARIAS, 2005). It is a remarkable plant because of its economic potential, since all parts of this plant can be commercially used (SOUZA et al., 2013; LIRA et al., 2011; CARRÃO-PANIZZI; MANDARINO, 2005).

Sunflower can be used as human and animal food, as an ornamental plant, and as raw material for biofuel production (LIRA et al., 2011; GAZZOLA et al., 2012). In Brazil, this crop is among the main crop species with potential for renewable energy production (SILVA et al., 2013).

Sunflower is a source of a high-quality oil that is used in the biofuel production. This biofuel does not contain petroleum products; thus, it reduces emissions of pollutants into the atmosphere. According to studies conducted in São Paulo, Brazil, the biofuel originated from sunflower is viable, without the need of adaptation of engines (LIRA et al., 2011), and has technical and environmental feasibility (BONACIN et al., 2009).

Lopes et al. (2009) emphasized the productive potential of renewable energy production of this crop, and its importance as an alternative for producers using crop rotation systems.

Researches on irrigation in sunflower crops showed the importance of water availability for the development of this plant species (FREITAS et al., 2012; SILVA et al., 2007).

Primary macronutrients, especially nitrogen, phosphorus and potassium are essential elements to nutrition and fertilization of sunflower. Nitrogen is the most limiting nutrient to sunflower production and the most absorbed and exported by its grains, followed by potassium, which is involved in the plant's resistance to drought and diseases, and phosphorus, which directly affect root growth and grain filling. Regarding the micronutrients, boron application is important because its deficiency causes the sunflower leaves and capitula to undergo several deformations (GAZZOLA et al., 2012; CÂMARA, 2003; CASTRO et al., 1997).

In this context, the objective of this work was to evaluate the effect of using different rates of LL in the fertigation of sunflower (*Helianthus annuus* L.) crops, and verify the feasibility of this practice for a proper disposal of this leachate in the soil, focused on the production of biomass for energy purposes.

MATERIAL AND METHODS

The experiment was conducted in an area of the Zoobotanical Park of the Federal Rural University of Semiarid (UFERSA), Mossoró RN, Brazil (5º12'31"S, 37º19'07"W, and altitude of 27 m).

The region has a BSwh, dry and very hot climate, according to the classification of Köppen, with a rainy season in summer to autumn, irregular precipitation, annual average precipitation of 673.9 mm, average temperature of 27°C, and average air relative humidity of 68.9% (ALVARES et al., 2013).

According to the analyses performed using the guidelines established by the Brazilian Soil Classification System of the Brazilian Agricultural Research Corporation (EMBRAPA, 2013), the soil of the area is a eutrophic Red-Yellow Argisol, with a practically impermeable layer from the depth of 0.40 m. The physical and chemical characteristics of the soil of the experimental area, before the application of landfill leachate (LL), was determined according to the methodology described by Donagema et al. (2011) and Embrapa (SILVA, 2009) (Tables 1 and 2).

Table 1. Physical characteristics of the soil used in the experiment before the application of landfill leachate.

Layer (m)	Soil density	Sand	Silt	Clay	Gravimetric moisture
	$g\ cm^{-3}$		.... $g\ kg^{-1}$..........		%
0.00-0.20	1.81	660	230	100	12.10
0.20-0.40	1.63	620	130	250	8.66

Table 2. Chemical characteristics of the soil used in the experiment before the application of landfill leachate.

Characteristics		Layer (m)		Characteristics		Layer (m)	
		0.00-0.20	0.20-0.40			0.00-0.20	0.20-0.40
pH		7.47	6.99	Fe		25.93	30.02
$EC_{1:2,5}$	$dS\ m^{-1}$	0.2	0.09				
OM	$dag\ kg^{-1}$	0.69	0.55	Mn		107.4	75.5
N	$g\ kg^{-1}$	0.36	0.4				
P		12.18	5.97	Cu		0.17	0.18
K^{+}	$mg\ dm^{-3}$	145.7	194.31				
Na^{+}		78.52	71.5	Zn		1.94	0.65
Ca^{2+}		2.54	2.32				
Mg^{2+}		1.53	1.74		$mg\ dm^{-3}$		
Al^{3+}		0.00	0.00	Ni		0.05	0.06
H + Al	$cmol_c\ dm^{-3}$	0.35	0.37				
SB		4.77	4.86				
CEC		5.12	5.24	Pb		0.17	0.15
T		4.77	4.86				
V		93.47	92.84				
M	%	0.00	0.00	Cd		0.01	0.00
PES		7.13	6.52				

The experiment was developed from June to September 2015. The LL from the landfill of Mossoró RN, Brazil was taken to the experimental area of the UFERSA in a 1,000-L plastic container. The water from the water supply used in the work was taken from the public water supplied by the Water and Sewage Company of Rio Grande do Norte (CAERN).

Water samples from the water supply and LL were collected biweekly during the study period, and their physical and chemical characteristics were analyzed according to the recommendations in the Standard Methods for the Examination of Water and Wastewater (RICE; BAIRD; CLESCERI, 2012) and Embrapa (SILVA, 2009).

The system used to apply the water from water supply (WWS) and LL consisted of a pressurized irrigation system consisting of: two 1,000-L (1.0 m^3) tanks to store the WWS; two 1,000-L tanks and one 250-L (0.25 m^3) tank to store the LL; two automated motor pump (0.5 cv) with two disc filters with 130-µm openings for each application line; two main lines of polyvinyl chloride (PVC) tubes with diameter of 32 mm, which originated a single main line that was subdivided for the plots; and twenty lateral drip irrigation lines with non-pressure compensating emitters of 1.6 L h^{-1} flow, spaced 0.30 m apart. Each lateral line was placed contouring the four plant rows of each plot (Figure 1).

The sunflower (*Helianthus annuus* L.) variety used was the BRS-324, which was developed by the Embrapa Soja, in partnership with the Embrapa Clima Temperado (Pelotas RS), Embrapa Cerrados (Planaltina DF), Embrapa Tabuleiros Costeiros (Aracaju SE), Embrapa Rondônia (C.E. Vilhena RO), Embrapa Meio Ambiente (Jaguariúna SP) and Embrapa Gado de Leite (Juiz de Fora MG) (CARVALHO et al., 2013). The BRS-324 seeds were launched in 2014 by the Embrapa Produtos e Mercado, Dourados MS, Brazil (CARVALHO et al., 2013).

The sunflower BRS-324 is an early cycle, open-pollinated cultivar, whose grains has high oil content, which adds value to its production. It is suitable for crops in the Brazilian states of Bahia, Goiás, Mato Grosso, Mato Grosso do Sul, Minas Gerais, Paraná, Rio Grande do Sul, Rondônia, São Paulo and Sergipe (CARVALHO et al., 2013).

Figure 1. Experimental plots with sunflower crops and the irrigation line arrangement.

The experiment was conducted in a randomized block design, with twenty experimental plots, five treatments, and four replications. The treatments were based on studies developed by Andrade Filho (2016) and Costa (2012), and consisted of control with 100% WWS (T_1); 80% WWS + 20% LL (T_2); 60% WWS + 40% LL (T_3); 40% WWS + 60% LL (T_4); and 20% WWS + 80% LL (T_5).

The experimental plots had area of 2.0 x 5.0 m (10 m²), with spacing of 2.0 m between blocks and 1.0 m between plots of the same block.

The plots subjected to T1 (control with WWS) received no planting fertilization; however, this area had received some fertilization in a previous experiment (ANDRADE FILHO, 2016). The plots subjected to the other treatments received only the nutrients present in the LL during the experimental period.

The water requirement of sunflower was estimated based on the soil water balance and crop evapotranspiration according to the methodology described by the FAO (Food and Agriculture Organization of the United Nations) using the Penman-Monteith equation (ALLEN et al., 2006) (Equation 1).

$$ET_0 = \frac{0.408\,\Delta\,(Rn - G) + \gamma \frac{900}{T+273} U_2\ (e_s - e_a)}{\Delta + \gamma\,(1 + 0.34\,U_2)} \qquad (1)$$

wherein:
ETo is the reference evapotranspiration (mm day^{-1});
Rn is the surface radiation (MJ m^{-2} day^{-1});
G is the soil heat flow (MJ m^{-2} day^{-1});
T is the air temperature at 2 m height (°C);
U_2 is the wind speed at 2 m height (m s^{-1});
e_s is the vapor saturation pressure (kPa);
e_a is the current air vapor pressure (kPa);
($e_s - e_a$) is the vapor pressure deficit (kPa);
D is the curve slope of the vapor saturation pressure (kPa ^{o}C^{-1}); and,
g is the psychrometric constant (kPa ^{o}C^{-1}).

The meteorological data needed to estimate the reference evapotranspiration (ETo)—wind speed, relative air humidity, insolation, solar radiation, precipitation, and temperature—were obtained from a meteorological station installed in the UFERSA, Mossoró campus.

The crop evapotranspiration (ETc) was estimated using the crop coefficient (Kc) obtained by Cavalcante Júnior (2011) in studies in Apodi RN, and used by Costa (2012) in experiments with sunflower in that region.

According to Cavalcante Júnior (2011), the Kc were 0.52, 0.70, 0.98, and 0.81 for the sunflower development stages I, II, III, and IV, respectively. These Kc were similar to the ones recommended in the Manual 56 of the FAO for sunflower crops.

The irrigation water depth applied intended to meet the water demand of the crop and the fertigation intended to supply the plants with the nutrients contained in the LL.

The fertigation with LL was applied on alternate days from July 24, 2015, that was 21 days after planting (DAP), 14 days after transplanting (DAT), to favor the establishment of the sunflower seedlings in the soil and prevent them from dying at the beginning of the cycle.

Irrigation with WWS was performed in parallel to the fertigation with LL during the crop cycle.

Characteristics of the sunflower crops were assessed in five evaluations with 15-day intervals—July 24, 2015 (21 DAP, 14 DAT), August 08, 2015 (36 DAP), August 23, 2015 (51 DAP), September 07, 2015 (66 DAP), and at harvesting, in September 22, 2015 (81 DAP).

The six central plants of each plot were marked to be used as samples in all evaluations, and their means were used to estimate the characteristics of each plot.

The plant height from the ground level to the capitulum insertion was measured using a scale and expressed in meters. The number of completely open leaves of each sample plant was counted. The stem base diameter (SD) was measured with a digital caliper at a height of approximately 5 cm from the ground, according to the methodology used by Costa (2012), and expressed in centimeters. The capitulum diameter of each sample plant was measured with a digital caliper and expressed in centimeters.

The data of the evaluated characteristics of the sunflower plants were subjected to analysis of variance by the F test at 5% probability, and significant means were subjected to the Tukey's test at 5 % probability, and regression analysis. Statistical analyzes were performed using the Sisvar 5.6 statistical program (FERREIRA, 2014; FERREIRA, 2011).

RESULTS AND DISCUSSION

The means of the plant characteristics evaluated—plant height (PH), number of leaves (NL), stem diameter (SD) and capitulum diameter (CD)—were significant by the F test at 5% probability regarding the landfill leachate (LL) rates applied (treatments) and time of application. The interaction between treatments and time of application had significant effect only on PH and CD (Table 3).

Table 3. Analysis of variance for the variables plant height (PH), number of leaves (NL), stem diameter (SD) and capitulum diameter (CD) of sunflower plants subjected to fertigation with different rates of landfill leachate (LL).

Source of Variation (SV)	Degree of freedom (DF)	Mean Square (MS)			
		PH (m)	NL (unidades)	SD (cm)	CD (cm)
Treatments	4	0.1381**	21.6213**	0.2114**	5.0072**
Time	4	2.0652**	702.5876**	2.3050**	458.1548**
Treatments x Time	16	0.0185*	5.3939$^{n.s.}$	0.0235$^{n.s.}$	2.2809**
Block	3	0.0394**	7.7784$^{n.s.}$	0.1045**	3.1728*
Error	72	0.0083	3.9377	0.0178	0.9963
Coefficient of variation (CV) (%)	-	17.92	12.61	18.77	27.89

Regarding the effects of the LL rates applied, the variables PH, NL, SD, and CD presented significant statistical differences by the Tukey's test at 5% probability.

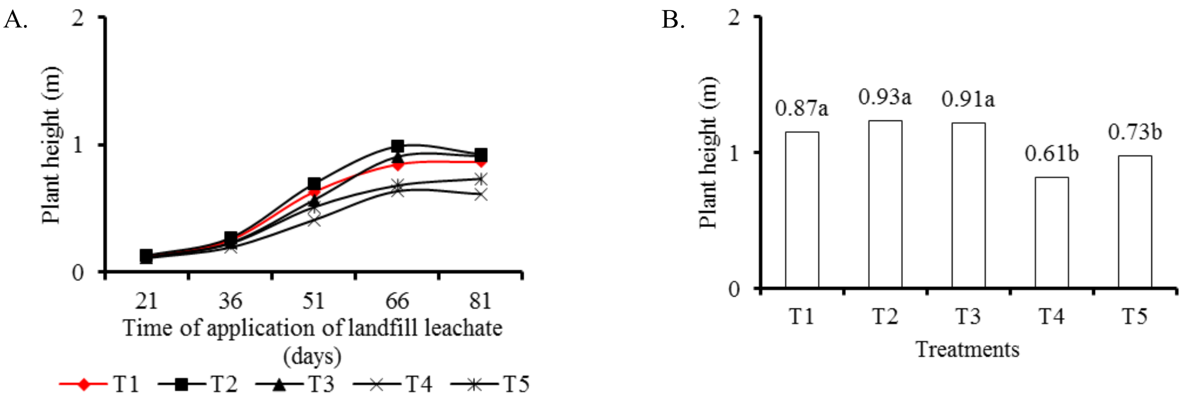
According to the regression analysis, the PH, SD, and CD were significantly affected by the treatments (Table 4).

The treatments with the highest LL rates (T_4 and T_5) provided no satisfactory results regarding the sunflower performance, with lower values than the control (T_1) (Figure 2A).

Table 4. Regression equations of characteristics of sunflower plants as a function of application of landfill leachate rates.

Characteristics	Regression equations
PH	$\hat{PH} = 0.624390 - 0.038730^{**}\,Rates \quad R^2 = 0.54$
SD	$\hat{SD} = 0.836685 - 0.041695^{**}\,Rates \quad R^2 = 0.41$
CD	$\hat{CD} = 4.177840 - 0.199810^{**}\,Rates \quad R^2 = 0.40$

**and *= significant at 1 and 5 % probability by the Tukeys' test, respectively.



T_1 = control with 100% water from the water supply (WWS); T_2 = 80% WWS + 20% LL; T_3 = 60% WWS + 40% LL; T4 = 40% WWS + 60% LL (T_4); and T_5 = 20% WWS + 80% LL. Means followed by at least one equal letter in the columns for each treatment do not differ at 5 % probability by the Tukey's test.

Figure 2. Plant height (PH) of sunflower plants as a function of the time of application of landfill leachate (LL) (A), and LL rates applied as fertigation (B).

The T_2 treatment had the highest PH during the samplings and the highest mean at the end of the crop cycle (Figures 2A and 2B). The plants subjected to LL rates presented no differences at the beginning of the experiment, but presented significant differences at the end of the experiment (Figure 2A).

The mean PH of plants in T_2 at the end of the experiment was 0.93 m; this treatment did not differ statistically from T_1 and T_3. T_4 had the lowest mean PH (0.61 m), and did not differ statistically from T_5. The treatment with 40% LL (T_3) met the sunflower requirements satisfactorily; this treatment did not differ from T_2 and used a higher rate of LL, thus saving good-quality water.

The mean PH of sunflower (variety BRS-324) found by Carvalho et al. (2013) was between 1.70-1.90. The PH found in the present study were lower, however, no additional fertilization was applied, and good-quality water was saved.

The low PH with application of high rates of LL is probably due to the high concentration of salts in the LL, mainly sodium, which increases soil electrical conductivity when used in successive applications, reducing the soil quality and crop biomass production (MESQUITA, 2016; FERREIRA, 2013).

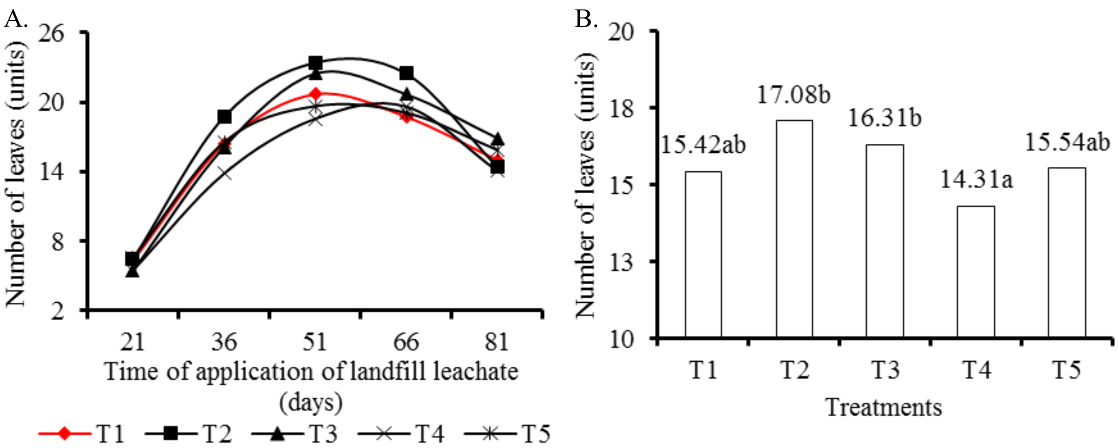
Ferreira (2013) evaluated the effects of increasing rates of wastewater on three soils (Argisol, Cambisol, and Vertisol) with sunflower, and found maximum PH (0.55 m) using 55.4 m^3 of N ha^{-1} on the Vertisol, and the lowest plant growth in the Argisol.

Silva (2014) found PH of 0.79 m for the sunflower variety BRS-323 grown with crude and photo-electrochemically treated leachate, and plants treated with concentrations of 25, 50 and 75% with similar PH.

Mesquita (2016) evaluated soils fertigated with LL for *Pennisetum purpureum* grass and found non-significant effects of treatments on PH. However, Andrade Filho (2016) evaluated the effect of LL in castor bean crops under similar experimental conditions to the present study, and found the highest PH in plants treated with 40% WWS + 60% LL, at the end of the experimental period, and the lowest PH in plants treated with 20% WWS + 80% LL. These results differ from those found in the present study, in which the plants in T_2 (20% LL) presented the highest PH.

The NL increased with the LL rates; plants in T_2 and T_3 had higher NL than the ones in the control (T_1) (Figure 3A). However, treatments with the highest LL rates (T_4 and T_5) caused a decrease in NL.

Plants in T_2 had the highest NL; this treatment presented no statistic difference from T_1, T_3 and T_5; and T_5 did not differ statistically from T_1 and T_4 (Figure 3B).



T_1 = control with 100% water from the water supply (WWS); T_2 = 80% WWS + 20% LL; T_3 = 60% WWS + 40% LL; T4 = 40% WWS + 60% LL (T_4); and T_5 = 20% WWS + 80% LL. Means followed by at least one equal letter in the columns for each treatment do not differ at 5 % probability by the Tukey's test.

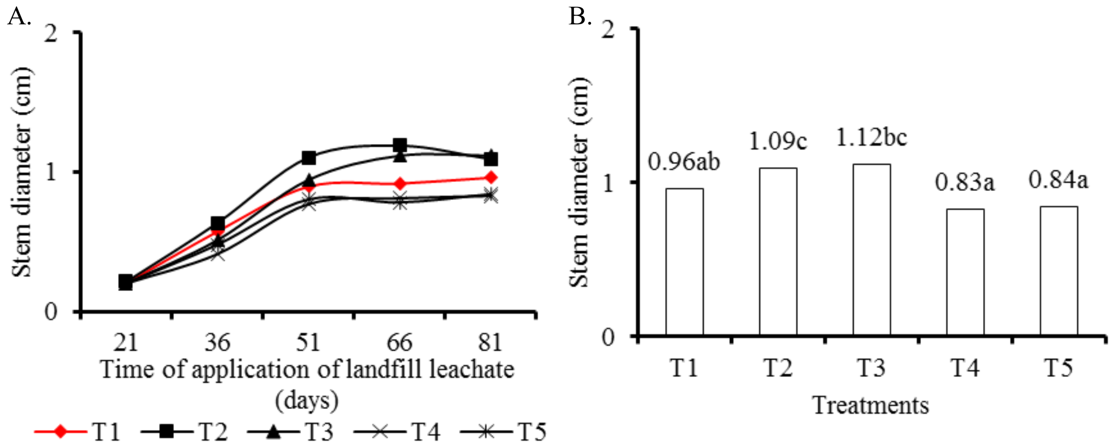
Figure 3. Number of leaves (NL) of sunflower plants as a function of time of application of landfill leachate (LL) (A), and LL rates applied in the fertigation (B).

The NL found were lower than the ones found in the literature—20 to 40 leaves per plant for this species (CASTRO et al., 1997; COSTA, 2012; CALEGARI et al., 1993). The NL of plants in T_2 were close to these values.

Costa (2012) evaluated the application of different rates of domestic wastewater in soils with sunflower crops and, similarly to the preset work, found a slight increase in NL with increasing wastewater rates.

Different results were found by Andrade Filho (2016), who evaluated LL in soils with crops of oleaginous plants and found the highest NL in plants treated with 40% WWS + 60% LL, in all samplings carried out over the study period.

The SD differed statistically between treatments over the experimental period (Figure 4A). The treatments with the lowest LL rates (T_2 and T_3) had plants with larger SD than the ones in T_1 (control). The treatments with the highest LL rates (T_4 and T_5) had plants with lower SD, compared to the other treatments, including T_1.



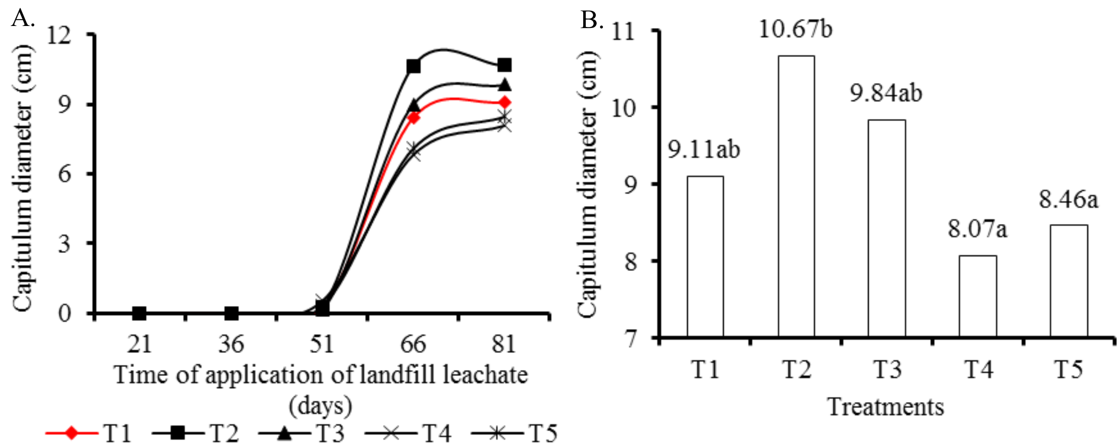
T_1 = control with 100% water from the water supply (WWS); T_2 = 80% WWS + 20% LL; T_3 = 60% WWS + 40% LL; T4 = 40% WWS + 60% LL (T_4); and T_5 = 20% WWS + 80% LL. Means followed by at least one equal letter in the columns for each treatment do not differ at 5 % probability by the Tukey's test.

Figure 4. Stem diameter (SD) of sunflower plants as a function of time of application of landfill leachate (LL) (A), and LL rates applied in the fertigation (B).

Plants in T_3 had the largest mean SD (1.12 cm) at the end of the crop cycle (Figure 4B), but this treatment did not differ statistically from T_1 and T_2. Plants in T_1 did not differ statistically from the ones in T_4 and T_5.

Andrade Filho (2016) found different results; the development of castor bean plants treated with 80% LL was affected negatively, presenting the smallest SD, probably due to the toxic effect of LL in this crop species.

The largest CD were found in plants in T_2, followed by the ones in T_3 (Figure 5A).



T_1 = control with 100% water from the water supply (WWS); T_2 = 80% WWS + 20% LL; T_3 = 60% WWS + 40% LL; T4 = 40% WWS + 60% LL (T_4); and T_5 = 20% WWS + 80% LL. Means followed by at least one equal letter in the columns for each treatment do not differ at 5 % probability by the Tukey's test.

Figure 5. Capitulum diameter (CD) of sunflower plants as a function of time of application of landfill leachate (LL) (A), and LL rates applied in the fertigation (B).

Plants in the treatment with the lowest LL rate (20 %) (T_2) presented the largest mean CD at the end of the crop cycle, but this treatment did not differ statistically from T_1 and T_3.

Similar to PH, NL and SD, the plants presented the lowest CD in T_4 and T_5, thus, the greater the LL rate applied to the soil, the lower the sunflower development.

This can be explained by the sodium applied to the soil with the LL. The high salt concentration in the leachate made the water unavailable to the crop, hindering its full development. In addition, the plant might have absorbed excess nutrients from the soil through phytoextraction. Sunflower crops have been widely studied by plant physiologists because of its high photosynthetic potential, high growth rates, high-water extraction and high-water conduction (MELLO et al., 2006).

The results found in the present study are in accordance with the ones found by Andrade et al. (2012), who reported that the use of wastewater improved significantly the sunflower plant height, number of leaves, stem diameter, and internal and external capitulum diameter. Moreover, Costa (2012) found maximum capitulum diameter of 7.06 cm using fertigation with 49% domestic wastewater.

CONCLUSIONS

The use of landfill leachate for fertigation of sunflower crops is a viable alternative for treatment and final disposal of this liquid residue. This practice can focus on the production of biofuel and vegetal biomass for energy purposes, reduce the erosion of soils that cover the solid urban waste, and save good-quality water resources.

The sunflower plant height, stem diameter, and capitulum diameter are affected by treatments with landfill leachate. The use of the treatment with 60% water from the water supply and 40% landfill leachate resulted in plants with better characteristics.

The application of high rates of landfill leachate in the soil decreases the sunflower quality and biomass production.

ACKNOWLEDGEMENTS

The authors thank the Federal Rural University of Semiarid (UFERSA) and the Environmental Sanitation Company (Sanepav) for the infrastructure, information, and part of the material used in this research.

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