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Barium and sodium in sunflower plants cultivated in soil treated with wastes of drilling of oil well

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ABSTRACT
This study aimed to evaluate the effects of the application of two types of oil drilling wastes on the development and absorption of barium (Ba) and sodium (Na) by sunflower plants. The waste materials were generated during the drilling of the 7-MGP-98D-BA oil well, located in the state of Bahia, Brazil. The treatments consisted of: Control – without Ba application, comprising only its natural levels in the soil; Corrected control – with fertilization and without wastes; and the Ba doses of 300, 3000 and 6000 mg kg^{-1}, which were equivalent to the applications of 16.6, 165.9 and 331.8 Mg ha^{-1} of waste from the dryer, and 2.6, 25.7 and 51.3 Mg ha^{-1} of waste from the centrifugal. Plants cultivated using the first dose of dryer waste and the second dose of centrifugal waste showed growth and dry matter accumulation equal to those of plants under ideal conditions of cultivation (corrected control). The highest doses of dryer and centrifugal wastes affected the development of the plants. The absorption of Ba by sunflower plants was not affected by the increase in the doses. Na proved to be the most critical element present in the residues, interfering with sunflower development.

Palavras-chave:
metais pesados
Helliantus annus
salinização

Bário e sódio em plantas de girassol cultivadas em solos tratados com cascalho de perfuração

RESUMO
Objetivou-se, neste trabalho, avaliar os efeitos da aplicação de dois resíduos gerados na perfuração de poços de petróleo no desenvolvimento e absorção de bário e sódio por plantas de girassol. Os resíduos foram gerados durante a perfuração do poço 7- MGP-98D-BA localizado na Bahia. As doses dos resíduos utilizadas foram: Testemunha – sem aplicação de bário; compreendendo apenas os teores naturais do solo; Testemunha – corrigida (com adubação e sem resíduo) e doses de 300, 3000 e 6000 mg kg^{-1} de bário equivalentes à aplicação de 16,6, 165,9 e 331,8 Mg ha^{-1} do resíduo do secador e 2,6, 25,7 e 51,3 Mg ha^{-1} do resíduo da centrífuga. As plantas cultivadas na primeira dose do resíduo do secador e na segunda dose do resíduo da centrífuga, apresentaram crescimento e acúmulo de massa seca iguais aos das plantas sob condições ideais de cultivo (Testemunha corrigida). As maiores doses dos resíduos do secador e da centrífuga afetaram o desenvolvimento das plantas. A absorção de bário pelo girassol não foi afetada com o aumento das doses. O sódio mostrou-se o elemento mais crítico presente nos resíduos, interferindo no desenvolvimento do girassol.

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Introduction

Throughout the 20th century, oil and its derivatives have become one of the main primary sources of the global energy matrix and inputs for various industrial sectors. The society is aware of the need for changes in the current energy matrix, but in the next decades, oil will continue to be the most used source (Goldemberg & Villanueva, 2003). The increment in oil exploration and its refinement have caused the increase of environmental pollution, because of the high waste generation. The wastes generated during oil-well drillings consist of a mixture of ground rocks and drilling fluids (Bauder et al., 2005; Ball et al., 2011). Barite ($BaSO_4$), caustic soda (NaOH), sodium chloride (NaCl) and other synthetic components (Kisic et al., 2009; Magalhães et al., 2014a) are among the most used components in drilling fluids. Therefore, the generated waste has high contents of barium (Ba) and sodium (Na) (Pozebon et al., 2005; Ball et al., 2011).

The disposal of drilling waste in the soil and the effect of Ba and Na on plant growth are still poorly studied. Magalhães et al. (2011; 2012; 2014a;b) and Lima et al. (2012) observed that the risks of phytotoxicity caused by the absorption of Ba occurred only when rice plants were grown under flood (reducing) conditions, i.e., with redox potential close to -250 mv. These authors consider Na as the most limiting element for plant growth. However, Guedes (2014) reported increase in dry matter caused by waste application and did not observe electrical conductivity values higher than 2.0 dS m^{-1}. Plants showed higher contents of calcium, magnesium, potassium, iron and manganese, and this effect was attributed to the availability of these nutrients.

The production of oil and gas in onshore areas has significant economic importance and the largest reserves are located in the northeast of the country, where the cultivation of oil plants for biodiesel production is also found (ANP, 2014). However, the expansion of areas of oil plants destined for the production of biodiesel can increase the consumption of fertilizers (Bermann, 2008). Oil drilling wastes, when conveniently disposed, could be incorporated in these production areas, in order to supply nutrients to these crops.

This study aimed to evaluate the effects of the application of oil drilling wastes in the soil on sunflower growth and absorption of Ba and Na.

Material and Methods

The experiment was carried out in a greenhouse, at the Federal Rural University of Rio de Janeiro – UFRRJ. The waste material used in this study was collected during an oil well drilling in the state of Bahia, Brazil, from the pile of cuttings generated by the dryer and the centrifuge. The dryer waste showed pseudo total contents of 40.174 mg kg^{-1} of Ba and 16.201 mg kg^{-1} of Na, and the centrifuge waste showed 259.532 and 20.481 mg kg^{-1} for these elements, respectively. The analyses were performed according to ISO (1995).

The soil in the surroundings of the drilling area, in the municipality of Pojuca-BA, was classified as Red Yellow Argisol, and soil samples were collected until the depth of approximately 20 cm. Soil chemical characterization is shown in Table 1.

Different Ba doses were tested, based on the guiding values proposed by CONAMA (2009), using the drilling wastes as the source of Ba. The treatments consisted of the following Ba contents:

- Control - substrate without Ba application
- Corrected control - with mineral fertilization
- 300 mg kg^{-1} - Investigation Value for the agricultural scenario of Maximum Protection Area - APMax (CONAMA, 2009) (Dose 1)
- 3000 mg kg^{-1} - Ten times the Investigation Value (Dose 2)
- 6000 mg kg^{-1} - Twenty times the Investigation Value (Dose 3)

The amounts of waste and the contents of Ba and Na applied in each treatment are shown in Table 2.

The soil was mixed with the respective amounts of waste using a concrete mixer. Then, the experimental units were placed in plastic bags and accommodated in pots with capacity of approximately 10 dm^3, which were kept at 70% of field capacity for about 40 days. After this period, five seeds of sunflower (cultivar Catissol 01) were planted in each pot and 15 days after emergence only one plant was left.

The contents of nutrients added to the soils were determined based on the soil chemical analysis (Table 1) and on the recommendation for the crop. Fertilization was divided into two applications. The amounts equivalent to 10 kg ha^{-1} of N, 80 kg ha^{-1} of P_2O_5 (single dose) and 40 kg ha^{-1} of K_2O were applied at planting, while the amounts equivalent to 20 kg ha^{-1} of N and 10 kg ha^{-1} of K_2O were applied 30 days after planting, as top dressing. Besides the conventional fertilization with macronutrients, weekly applications of micronutrients were also performed using the Hoagland's solution at ¼ of ionic strength.

The experiment was set in a completely randomized design in a 2 x 3 + 2 factorial scheme, with three replicates, and the treatments consisted of three doses of two wastes (dryer and centrifuge) and two control treatments, totaling 24

Table 2. Amount of wastes applied in the soil and contents of barium and sodium in the different doses

	Dose 1	Dose 2	Dose 3
		Dryer	
Amount of waste (Mg ha^{-1})	16.5	165.9	331.8
Barium (mg kg^{-1})	300.0	3000.0	6000.0
Sodium (mg kg^{-1})	483.9	4839.4	9678.8
		Centrifugal	
Amount of waste (Mg ha^{-1})	2.5	25.7	51.3
Barium (mg kg^{-1})	300.0	3000.0	6000.0
Sodium (mg kg^{-1})	94.7	947.0	1894.0

Table 1. Chemical characteristics of the soil collected in the surroundings of the drilling area

Layer	Na	Ca	Mg	K	H + Al	Al	S	T	V	m	n	pH_{water}	C_{org}	P	K	Ba	Na
(cm)	cmol$_c$ dm^{-3}								%			1:2.5	%	mg dm^{-3}		mg kg^{-1}	
0 – 20	0.040	0.9	0.4	0.01	4.1	3.5	1.35	5.45	25	71.9	1	4.4	0.63	1	4	317	95

experimental units. The two control treatments consisted of one absolute control (pure soil) and another corrected control (soil with mineral fertilization).

The growth of the seedlings evaluated along the cultivation, through the parameters plant height and stem diameter at 5 cm from the soil, measured using a steel tape measure and a caliper, respectively, with measurements in centimeters.

Sunflower plants were collected just before completing the cycle and divided into root, stem, leaves, capitulum, full grains and empty grains. Then, the material was dried in a forced-air oven. After reaching constant weight, plants were weighed, ground and digested (Tedesco, 1995).

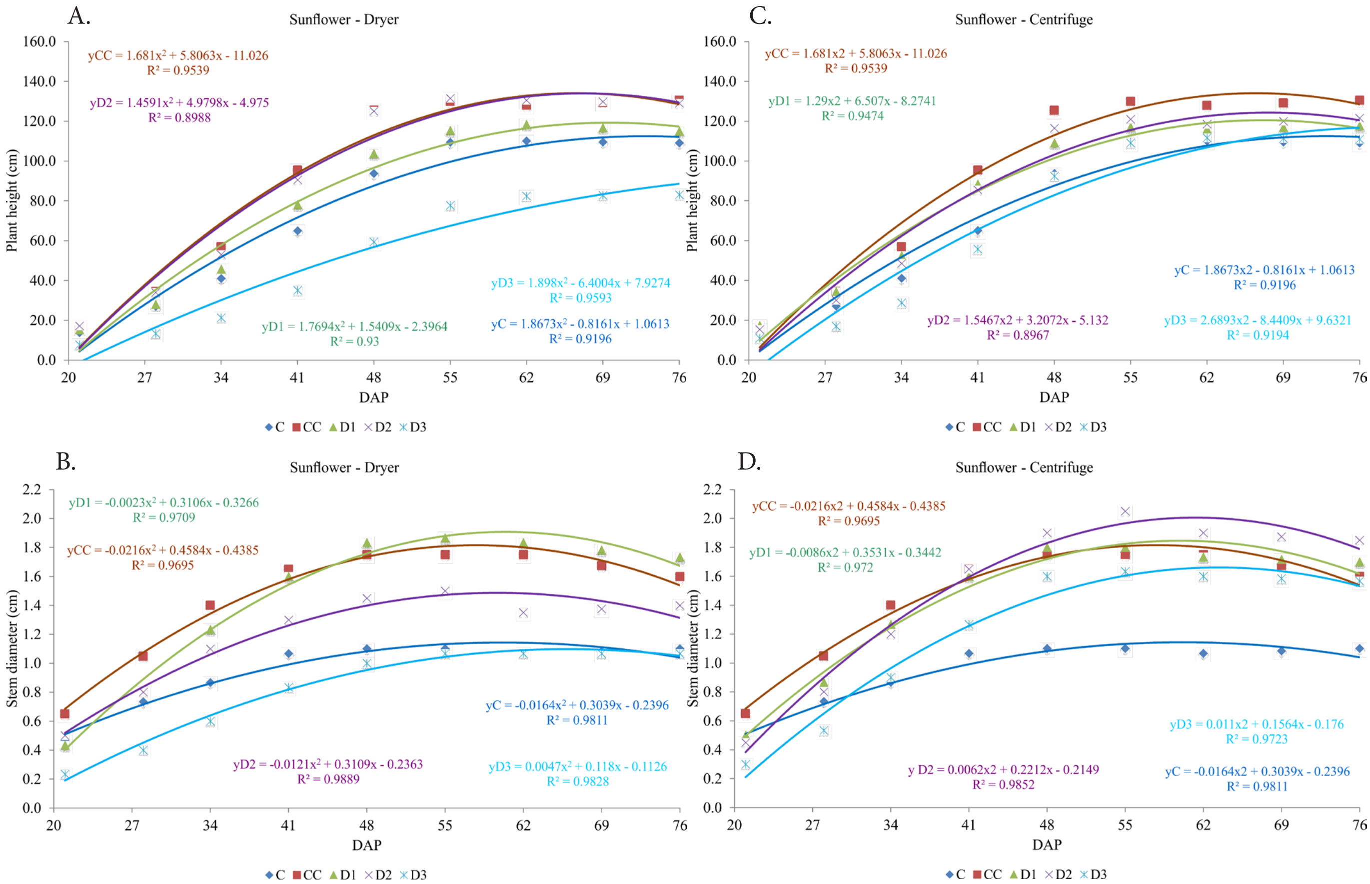
The Ba contents in soil and plant extracts were quantified using an inductively coupled plasma optical emission spectrometer (ICP-OES) (Perkin Elmer® - OPTIMA 3000), with detection limit (DL) of 0.036 mg kg^{-1} and quantification limit (QL) of 0.36 mg kg^{-1}. The Na contents in soil and plant extracts were quantified using a flame photometer (Digimed® - DM-62), with DL of 0.5 mg kg^{-1} and QL of 1.0 mg kg^{-1}. The detection limit of the method was calculated using the mean of the values of the blanks plus three times the standard deviation of the blanks of all analyses (10 replicates). The determination of the pseudo total contents of Ba and Na in the soil and in the plants was validated using the following certified reference materials: NIST SRM 2709a - San Joaquin Soil, with Ba content of 979 ± 28 mg kg^{-1} (95% recovery) and Na content of 12.2 ± 0.3 g kg^{-1} (96% recovery) and SRM 1573a - Tomato Leaves, with Ba content of 63 mg kg^{-1} (93% recovery) and Na content of 136 ± 4 mg kg^{-1} (92% recovery). The results of the certified reference materials were within the intervals considered as normal for soil and plant samples, according to the National Institute of Standards and Technology (NIST).

The data were subjected to analysis of variance by F test ($\rho < 0.05$), and the mean values were compared by the Tukey test ($\rho < 0.05$). All the statistical analyses were performed using the programs SISVAR and SAEG (Version 9.0).

Results and Discussion

Plant height and stem diameter of sunflower in the different treatments, as a function of days after planting, for dryer and centrifugal wastes, are shown in Figure 1.

Sunflower plants showed similar behaviors of plant height and stem diameter for both wastes. In the first three weeks, plant growth was slow and similar for all treatments. From the fifth week on, the plants showed higher development, especially the corrected control (ideal cultivation conditions) and the Dose 1 of the dryer waste. For the centrifugal waste, plants cultivated using the Dose 2 also showed good development with respect to the parameters height and diameter. According to Silva et al. (2011a), sunflower plants develop well in soils with medium fertility, but high productions are only reached when pH and the contents of nutrients available in the soil are adequate.



DAP – Days after planting; C – control, no waste application; CC – corrected control, with fertilization and without waste; D1 – Dose 1; D2 – Dose 2; D3 – Dose 3

Figure 1. Analysis of sunflower growth (plant height and stem diameter) throughout the experiment as a function of the treatments and the types of wastes

In the eighth week, sunflower plants showed slow growth again, probably due to the formation of capitula. In this growth stage, the plant reserves its photoassimilates for seed filling. Castro & Oliveira (2005) observed that the highest absorption of water and nutrients and, consequently, higher development, occur close to the flowering stage.

In the control treatment, the sunflower plants did not develop as the others and showed symptoms of nutritional deficiency, such as yellowing of the leaves and reduced growth. In addition, these plants failed to form the capitulum in the same period as the others. The natural low contents of nutrients in the soil (Table 1) possibly impaired the normal development of the crop. Biscaro et al. (2008) pointed out that N plays an important role in the metabolism and nutrition of sunflower plants and its deficiency is the most limiting factor for production, while its excess causes decrease in the percentage of oil.

Plants cultivated using the Dose 3 showed lower development compared with the other treatments. However, despite the shorter size, they did not show symptoms of nutritional deficiency and formed the capitula in the same period as the others.

The biomass production of leaves, stem, roots, full grains, empty grains and capitula of sunflower plants is shown in Table 3.

For the dryer waste, there was significant difference between the doses, and the Dose 1 caused the highest production of total dry matter, not differing from the corrected control (ideal conditions). There was a decrease in dry matter production for the Doses 2 and 3, which were statistically different, with totals of 79.43 and 27.83 g, respectively.

Plants cultivated using centrifugal wastes showed higher development and total dry matter accumulation, compared with plants cultivated using dryer wastes, except for the lowest dose.

For the centrifugal waste, there was no difference between the corrected control and Doses 1 and 2. The highest dose caused a decrease in total dry matter production, but the plants showed a higher development compared with the control, differing significantly. These results were probably due to the lower amounts of the centrifugal waste added to the soil; thus, the supply of soluble salts like Na and K was lower, causing lower influence on the development of sunflower plants. According to Munns (2002), plants cultivated under saline conditions show changes in the growth parameters associated with the osmotic, toxic and nutritional effects caused by the excess of salts in the soil. Nobre et al. (2010) observed linear reduction in plant height, stem diameter, shoot dry matter, beginning of flowering and diameter of capitula of sunflower, due to the salinity. Magalhães et al. (2014a) observed that rice plants cultivated in soils treated with oil well drill cuttings also showed reductions in growth and dry matter production with the increase in the waste dose, which were attributed to the high contents of Na in the waste.

The Ba contents in the dry matter of sunflower plants cultivated using the two wastes, in the different doses, are shown in Table 4.

For the dryer waste, there was no significant difference in Ba contents in the roots with the increase in the doses. However, for the centrifugal waste, the Dose 1 showed significant reduction in Ba contents compared with the other treatments, except for the highest dose. In the comparison between both wastes, only the lowest dose showed significant difference and the highest contents were observed in plants cultivated using dryer waste.

The lowest dose caused the highest Ba contents in the stem of plants cultivated using dryer waste. For the centrifugal waste, there was no significant difference in Ba contents with the increase in the doses. In the comparison between both wastes, for the lowest dose, the highest contents were observed in plants cultivated using dryer waste, while for the highest doses they were observed in plants cultivated using centrifugal waste.

For the dryer waste, only the Dose 2 caused significant reduction in Ba contents in the leaves, compared with the corrected control and the lowest dose; for the centrifugal waste, there was no significant difference in Ba contents. In the comparison between both wastes, the Dose 2 caused a significant difference in Ba contents and the highest values were observed in plants cultivated using the centrifugal waste.

The Dose 2 of dryer waste caused the highest Ba contents in the full grains, statistically differing from the other treatments. The lowest Ba contents were observed in the corrected control;

Table 3. Dry matter production (g) of sunflower plants cultivated using different doses of dryer and centrifugal wastes

	Wastes	C	CC	Dose 1	Dose 2	Dose 3	CV
Root	Dryer	4.72^{ns}	10.82^{ns}	5.93^{ns}	4.7^{ns}	2.02^{ns}	23.83
	Centrifugal	4.72^{ns}	10.82^{ns}	8.71^{ns}	8.6^{ns}	5.16^{ns}	
Stem	Dryer	13.56 Ba	26.33 Aa	28.64 Aa	24.09 Ab	7.57 Bb	11.61
	Centrifugal	13.56 Ca	26.33 ABa	21.66 Bb	29.16 ABa	23.19 ABa	
Leaf	Dryer	9.29 Ba	25.98 Aa	23.41 Aa	13.68 Bb	4.34 Cb	11.57
	Centrifugal	9.29 Ca	25.98 Aa	17.96 Bb	22.93 Aa	17.36 Ba	
FG	Dryer	2.25 Ca	7.67 BCa	16.17 Ab	5.18 BCa	2.95 Ca	16.11
	Centrifugal	2.25 Ca	7.67 Ba	28.49 Aa	3.36 Ca	2.01 Ca	
EG	Dryer	4.03 BCa	2.64 BCa	2.87 BCb	8.46 Ab	1.71 Ca	13.85
	Centrifugal	4.03 CDa	2.64 CDa	5.78 Ba	11.33 Aa	1.24 Da	
Capitulum	Dryer	7.38 Ca	29.24 ABa	27.19 ABa	23.33 Bb	9.22 Cb	10.99
	Centrifugal	7.38 Ca	29.24 Aa	22.58 Bb	30.79 Aa	15.13 Ca	
Total	Dryer	41.25 Ca	102.69 Aa	104.24 Aa	79.46 Bb	27.83 Cb	9.31
	Centrifugal	41.25 Ca	102.69 Aa	105.20 Aa	106.18 Aa	64.11 Ba	

Means followed by the same letter (lowercase in columns and uppercase in rows) do not differ significantly by Tukey test at 0.05 probability level. C – control, without residue application; CC – corrected control, with fertilization and without waste; Dryer: Dose 1 = 16.5 Mg ha^{-1}; Dose 2 = 165.9 Mg ha^{-1}; Dose 3 = 331.8 Mg ha^{-1}; Centrifugal: Dose 1 = 2.5 Mg ha^{-1}; Dose 2 = 25.7 Mg ha^{-1}; Dose 3 = 51.3 Mg ha^{-1}. FG – Full grains; EG – Empty grains; CV – Coefficient of variation; ^{ns} Not significant

Table 4. Barium contents (mg kg^{-1}) in roots, stem, leaves, capitulum and grains of sunflower plants cultivated using different doses of dryer and centrifugal wastes

	Wastes	C	CC	Dose 1	Dose 2	Dose 3	CV
Root	Dryer	59.9 ABa	68.50 ABa	61.64 ABa	72.62 Aa	53.26 Ba	12.5
	Centrifugal	59.9 ABa	68.50 Aa	32.08 Cb	53.3 ABa	44.0 BCa	
Stem	Dryer	15.75 Ba	24.88 Ba	46.75 Aa	11.50 Bb	12.25 Bb	30.2
	Centrifugal	15.75 Ba	24.88 Ba	20.58 Bb	31.38 ABa	48.25 ABa	
Leaf	Dryer	52.17 BCa	60.0 ABa	77.50 Aa	32.17 Cb	52.50 BCa	16.2
	Centrifugal	52.17 Ba	60.02 ABa	75.63 ABa	79.16 ABa	54.25 Ba	
FG	Dryer	15.54 Ba	11.38 Ca	16.63 Ba	43.88 Aa	15.50 Ba	6.1
	Centrifugal	15.54 Ba	11.38 Ca	16.00 ABa	18.88 ABb	15.10 Ba	
EG	Dryer	16.88 Ba	23.63 Aa	27.35 Aa	11.63 Bb	13.88 Bb	12.4
	Centrifugal	16.88 Ba	23.63 ABa	17.75 Bb	22.00 ABa	19.38 ABa	
Capitulum	Dryer	13.79 Ca	53.88 Aa	29.00 Ba	19.38 Ca	8.17 Da	10.0
	Centrifugal	13.79 Ba	53.88 Aa	11.92 Bb	13.59 Bb	10.24 Ba	

Means followed by the same letter (lowercase in columns and uppercase in rows) do not differ by Tukey test at 0.05 probability level. C – control, without waste application; CC – corrected control, with fertilization and without waste; Dryer: Dose 1 = 16.5 Mg ha^{-1}; Dose 2 = 165.9 Mg ha^{-1}; Dose 3 = 331.8 Mg ha^{-1}; Centrifugal: Dose 1 = 2.5 Mg ha^{-1}; Dose 2 = 25.7 Mg ha^{-1}; Dose 3 = 51.3 Mg ha^{-1}. FG – Full grains; EG – Empty grains

for the centrifugal waste, only the corrected control showed significant reduction in Ba contents. In the comparison between both wastes, only the Dose 2 caused a significant difference in Ba contents, and the highest values were observed in plants cultivated using dryer waste.

For the empty grains, the highest Ba contents were observed at the lowest dose and in the corrected control, which significantly differed from the other treatments for the dryer waste. For the centrifugal waste, the treatments did not show significant difference. In the comparison between both wastes, for the highest doses, the highest Ba contents were observed in plants cultivated using centrifugal waste. For the lowest dose, the highest contents were observed in plants cultivated using dryer waste.

The capitula showed a significant reduction in Ba contents as the doses increased, compared with the corrected control, and the highest contents were observed for the dryer waste. For the centrifugal waste, the highest contents were observed in the corrected control, which differed statistically from the other treatments. In the comparison between both wastes, a significant difference was observed only for Doses 1 and 2, with the highest contents in plants cultivated using dryer waste.

Coscione & Berton (2009), studying Ba extraction potential of sunflower cultivated in soil contaminated with $BaSO_4$, observed that plants did not show significant difference in development until 47 days of cultivation, up to the dose of 300 mg kg^{-1}, and reported shoot Ba content of 21.3 mg kg^{-1} for this dose.

Only a few studies report Ba contents within the range considered normal for plant tissues, but values from 90 to 106 mg kg^{-1} were observed in maize plants cultivated in soil treated with sewage sludge (Nogueira et al., 2010) and a value of 4970 mg kg^{-1} was observed in soybean in hydroponic cultivation (Suwa et al., 2008).

Pearson's correlation coefficients between the total dry matter of sunflower, Ba contents in each plant part and Ba contents available in the soil are shown in Table 5. The correlation coefficients between the analyzed parameters and Ba contents available in the soil are low for both wastes, except in the stem for the centrifugal waste. These results can be explained by the low solubility of barite ($BaSO_4$) and, consequently, low Ba contents in the fraction extracted with 1 M $MgCl_2$ (bioavailable).

Table 5. Pearson's correlation coefficients between the evaluated parameters and barium contents available in the soil, in the planting of sunflower

Correlation	Dryer	Centrifugal
[Ba] root	-0.1989	-0.4280
[Ba] stem	-0.4063	0.6986**
[Ba] leaf	-0.3991	0.1589
[Ba] full grains	0.4667*	0.4816*
[Ba] empty grains	-0.5943**	0.0477
[Ba] capitulum	-0.5974**	-0.5317*
Total dry matter	-0.4318	0.0617

*, ** Significant at 0.05 and 0.01 probability level, respectively

The low Ba contents in labile forms confirm the low solubility of barite, mainly composed of barium sulfate (Nowka et al., 1999; Snyder et al., 2007; Sposito, 2008), which is used as a component of the drilling fluid (Neff et al., 2000). These results show that the low development of the plants at the highest doses may not have been caused by the application of Ba through the wastes.

Na contents in the different parts of sunflower plants cultivated using both wastes are shown in Table 6. The highest Na contents in the roots were observed at the highest doses of dryer waste, but only the Dose 3 showed significant difference for the lowest dose. For the centrifugal waste, there was a significant increase in Na contents with the increase of the doses, especially in the highest doses.

For the dryer waste, there was a significant increase in Na contents in the stem and leaves with the increase of the doses; for the centrifugal waste, the increase was not significant. The lowest Na contents in the full grains were observed at the lowest and the highest dose of dryer waste, which differed statistically from the other treatments. For the centrifugal waste, the highest Na contents were observed at the highest dose, which differed statistically from the corrected control and the lowest doses. The Na contents in the empty grains did not show significant difference in any of the treatments for any of the two wastes.

There was no significant difference in the Na contents of the capitulum for the dryer waste as the doses increased; however, for the centrifugal waste, the highest contents were observed for the Dose 2, which differed from the other treatments.

Despite the lower amount of Na applied, plants cultivated in soil incorporated with centrifugal waste showed higher Na contents, compared with those cultivated using dryer waste,

Table 6. Sodium contents (mg kg^{-1}) in roots, stem, leaves, capitulum and grains of sunflower plants cultivated using different doses of dryer and centrifugal wastes

	Wastes	C	CC	Dose 1	Dose 2	Dose 3	CV
Root	Dryer	10.3 BCa	10.2 BCa	9.4 Cb	20.5 ABb	25.6 Ab	14.7
	Centrifugal	10.3 Ca	10.2 Ca	40.7 Ba	75.1 Aa	83.7 Aa	
Stem	Dryer	7.96 Ca	10.34 Ca	8.93 Ca	28.44 Ba	60.28 Aa	13.4
	Centrifugal	7.96 Ba	10.34 ABa	7.88 Ba	10.25 ABb	14.04 ABb	
Leaf	Dryer	9.94 Ca	12.23 Ca	12.60 Ca	18.74 Ba	24.15 Aa	8.8
	Centrifugal	9.94 Ba	12.23 ABa	10.2 Bb	12.07 ABb	13.55 ABb	
FG	Dryer	9.55 Aa	9.24 Aa	7.70 Ba	9.77 Aa	6.95 Bb	4.38
	Centrifugal	9.5 ABa	9.24 Ba	8.14 Ca	8.62 BCb	10.21 Aa	
EG	Dryer	11.31^{ns}	11.26^{ns}	9.20^{ns}	8.71^{ns}	8.67^{ns}	7.78
	Centrifugal	11.31^{ns}	11.26^{ns}	8.76^{ns}	8.84^{ns}	9.20^{ns}	
Capitulum	Dryer	8.14 ABa	7.13 Ba	7.08 Bb	9.28 ABb	7.39 ABb	8.91
	Centrifugal	8.14 Ca	7.13 Ca	11.35 Ba	13.68 Aa	11.57 Ba	

Means followed by the same letter (lowercase in columns and uppercase in rows) do not differ significantly by Tukey test at 0.05 probability level. C – control, without waste application; CC – corrected control, with fertilization and without waste; Dryer: Dose 1 = 16.5 Mg ha^{-1}; Dose 2 = 165.9 Mg ha^{-1}; Dose 3 = 331.8 Mg ha^{-1}; Centrifugal: Dose 1 = 2.5 Mg ha^{-1}; Dose 2 = 25.7 Mg ha^{-1}; Dose 3 = 51.3 Mg ha^{-1}. FG – Full grains; EG – Empty grains; ^{ns} Not significant

probably due to the lower trapping of Na by the short carbon chains that are present in lower amounts in the centrifugal waste, increasing its bioavailability.

The excess of soluble salts and/or exchangeable Na that characterizes soils as saline, saline-sodic or sodic, hampers the absorption of water by plants, induces the toxicity of specific ions (especially sodium and chloride), causes nutritional imbalance and prevents water infiltration in the soil, causing reductions in growth and yield of the crops (Silva et al., 2011b).

Despite the high Na contents observed especially at the highest waste doses, sunflower plants showed good tolerance. Katerji et al. (2000) pointed to the potential of sunflower to develop in saline soils, being classified as tolerant to salinity. In spite of that, Ashraf & Tufail (1995) observed great variation in tolerance to salinity among sunflower genotypes. Azevedo Neto et al. (2011), studying the possibility of using chlorophyll fluorescence to select sunflower genotypes tolerant to salinity, observed that the genotypes AG-960 and AG-975 were the only ones that showed contrasting results in all the variables, being characterized as sensitive and tolerant to saline stress, respectively.

The control treatment did not differ significantly from the highest dose, and both showed the lowest development. The low dry matter production at the highest dose of the waste was probably due to the high Na contents. For the control, the development was affected by the high Al contents associated with low pH values.

Pearson's correlation coefficients between the total dry matter of sunflower plants, Na contents in each plant part and Na contents available in the soil are shown in Table 7.

Table 7. Pearson's correlation coefficients between the evaluated parameters and sodium contents available in the soil, in the planting of sunflower

Correlation	Dryer	Centrifugal
[Na] root	0.9712**	0.8292**
[Na] stem	0.9979**	0.8097**
[Na] leaf	0.9611**	0.6808**
[Na] full grains	-0.5053*	0.5924**
[Na] empty grains	-0.6742**	-0.3267
[Na] capitulum	0.1508	0.4987*
Total dry matter	-0.6964**	-0.5847**

*, ** Significant at 0.05 and 0.01 probability levels, respectively

High positive correlation was observed between Na contents in the roots, stem and leaves and Na contents available in the soil, for both wastes. A high negative correlation was also observed between dry matter production and Na contents available in the soil, indicating that the application of increasing doses of the wastes caused an increment in the Na available in the soil. This favors the increase of Na absorption by plants (Table 6) and, as a consequence, the reduction in development and dry matter production (Table 3).

Conclusions

1. The lowest dose of the waste favored the development of sunflower plants.
2. The highest doses of the wastes negatively affected plant development.
3. Sodium was the element in the waste that proved to be critical for sunflower.

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