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Bioremediation of salinized soils by the lichen *Cladonia substellata* fomented by a nitrogen source and gamma radiation

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Resumo

O manejo inadequado de técnicas de irrigação tem causado a salinização de solos da região semiárida de Pernambuco. Com base neste postulado, o objetivo principal deste estudo foi avaliar a capacidade do líquen *Cladonia substellata*, associado a uma fonte de nitrogênio ou radiação gama, como possível remediador de Neossolos Flúvicos, salinizados por irrigação não supervisionada, na ilha de Assunção, Cabrobó, Pernambuco. Coletas de líquen e solo foram realizadas para montagem de experimentos sob condições laboratoriais. Um controle de laboratório foi designado e cinco tratamentos foram desenvolvidos, por submissão à radiação gama ou fonte de nitrogênio (ureia), a diferentes concentrações, em três grupos amostrais em triplicata. Foram usadas cúpulas de vidro transparente (15) contendo amostras de solo (500 g) sobrepostas pelo talo liquênico (8 g). A cada 60 dias, por 11 meses, coletaram-se amostras das cúpulas. Foram desenvolvidas análises químicas para quantificação de fenóis produzidos pelo líquen e percolados ao solo, através de espectrofotometria e reação com $FeCl_3$. Ao início e final dos experimentos, avaliou-se a fertilidade química dos solos dos diferentes tratamentos. Foi evidenciado que a radiação gama causou mais efeitos no líquen isoladamente, do que quando em associação com ureia. Foi constatada a hiperprodução de fenóis liquênicos, com percolação ao substrato, o que causou modificação química do solo, como o aumento dos teores de Ca, Mg, P e Na, bem como do pH. Foi possível afirmar que *C. substellata*, associada ou não a uma fonte exógena de nitrogênio, é capaz de, a curto prazo, de alterar quimicamente solos degradados pela salinização, aumentando a biodisponibilidade de elementos essenciais às plantas e organismos do solo.

Palavras-chave: Solos degradados, degradação ambiental, desertificação, ácido úsnico, substâncias liquênicas

Abstract

Inadequate management of irrigation techniques has caused salinization of soils in the semiarid region of Pernambuco. With this in mind, the main objective of this study was to evaluate the capacity of the lichen *Cladonia substellata*, associated with a nitrogen source or gamma radiation, as a possible bioremediator of Fluvic Neosols, salinized by unsupervised irrigation on Assunção Island, Cabrobó County, Pernambuco. Collections of the lichen and soil were carried out to elaborate

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the experiments, under laboratory conditions. A laboratory control was designed and five treatments, submitted to gamma radiation, or a nitrogen source (urea) at different concentrations, in three sampling groups, in triplicate. Fifteen, transparent glass domes were used, where soil samples (500 g) were placed and lichen thalli (8 g) superimposed. Sample collections were performed every 60 days, for 11 months. Chemical analyses for the quantification of phenolics produced by the lichen and percolated into the soil were developed through spectrophotometry and reaction with $FeCl_3$. At the beginning and end of experiments, the chemical fertility of soils from different treatments was evaluated. It was evidenced that gamma radiation causes more effects on the lichen, singly, than in association with urea. Hyperproduction of lichen phenolics, with percolation to the substrate was achieved, which caused chemical modification of the soil, such as an increase of Ca, Mg, P and Na content, as well as pH. It is possible to affirm that *C. substellata*, in association or not with an exogenous nitrogen source, is capable of, in the short term, chemically altering soils degraded by salinization, increasing the bioavailability of elements essential to plants and soil organisms.
Keywords: Degraded soils, environmental degradation, desertification, usnic acid, lichen substances

I. INTRODUCTION

Land degradation has directly affected about 250 million people in developed countries, due to the reduction or loss of biological and economic productivity (REYNOLDS et al., 2007) resulting from progressive degradation of natural ecosystems, influenced by natural factors or human action, and generally of both together (VASCONCELOS SOBRINHO, 1983). Desertification is a dynamic process caught up in vicious cycles, in a chain of events, which has as amplitude, causes that can be converted into consequences (SAMPAIO et al., 2003). The FAO (1986) established that desertification is only an extreme aspect of the deterioration of ecosystems disseminated under the combined pressure of adverse climate and agricultural exploitation.

The UNCCD (1995) considers the Brazilian Northeast an area potentially propitious to the desertification process. The semi-arid region presents a territorial extension of 1,554,387.7 km², of which 180,000 km² are areas in the process of degradation considered serious or very serious (MMA, 2007). Such areas form the desertification nuclei, which are considered the highest levels of degradation with the tendency to expand into surrounding areas, increasing their radius of influence (VASCONCELOS SOBRINHO, 1983).

In the municipality of Cabrobó, which is part of the desertification nucleus of the state of Pernambuco, the most frequent type of irrigation is by flooding and furrows, which forms a layer of water that covers part of the stem of the cultivated plant, this type of irrigation may be facilitated by gravity or pumping. This excess of water leaves the soil flooded, dissolving the existing salts and, upon its evaporation, promotes the ascension of these salts to the most superficial soil horizons (BERNARDO, 1995).

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The recovery of critical areas is a necessary action, through the implementation of containment/minimization measures to limit the desertification process, making the wise management of natural resources fundamental. In this context, the use of lichens was introduced as an alternative proposal for bioremediation of salinized soils. It is known that this biological group plays an important role in the formation of soils and ecological succession. The release of their substances into the substrate provokes effects such as pedogenesis (NASH III, 2008), from the formation of chelates, enabling a chemical recombination of ions contained in rocks or soils; to modification in the composition and fertility of soils underlying them; to interference in their biota (SILVA, 2014). The retention of substances in the thallus is related to water deficit while their release to the substrate occurs during periods of precipitation (VASCONCELOS, 2015; ARMAS et al., 2016). In addition, lichen substances have characteristics that are favorable to bioremediation, especially when in association with organic matter obtained through organic biodecomposers (SILVA, 2018). Thus, the versatility of application of lichens has been demonstrated as an effective alternative in an attempt to recover the fertility of soils in areas experiencing degradation. Therefore, this study aimed to evaluate the bioremediation potential of the lichen *Cladonia substellata*, with emphasis on its main compound, usnic acid (USN), whose hyperproduction was induced by an exogenous nitrogen supply, in the form of urea, or submission of the lichen thalli to a source of gamma radiation. The use of USN biosynthesis intensifiers was intended to increase the chemical alteration of the soil, making it more fertile.

II. Materials and Methods

For the study of the bioremediation of soils impacted by salinization in the semi-arid region of Pernambuco, under laboratory conditions, collections of Fluvic Neosol and lichen were made.

The soil was collected on Assunção Island, municipality of Cabrobó, Pernambuco, Brazil, at the coordinates 8°30′51″ S, 39°18′36″ W (Figure 1). The samples were collected in a zigzag area of 1 hectare, at 20 points. Samples of salinized Fluvic Neosol (1 kg) were collected at a depth of 0 to 20 cm, according to the Soil Collection Manual (EMBRAPA, 2015). They were then dried at room temperature (28°C ± 3°C) and combined into a single sample. This sample was ground and sieved by a granulometric process with sieves of 6.3, 4.0 and 2.0 mm. The sample was then fractionated and deposited in plastic bags of 1 kg each.

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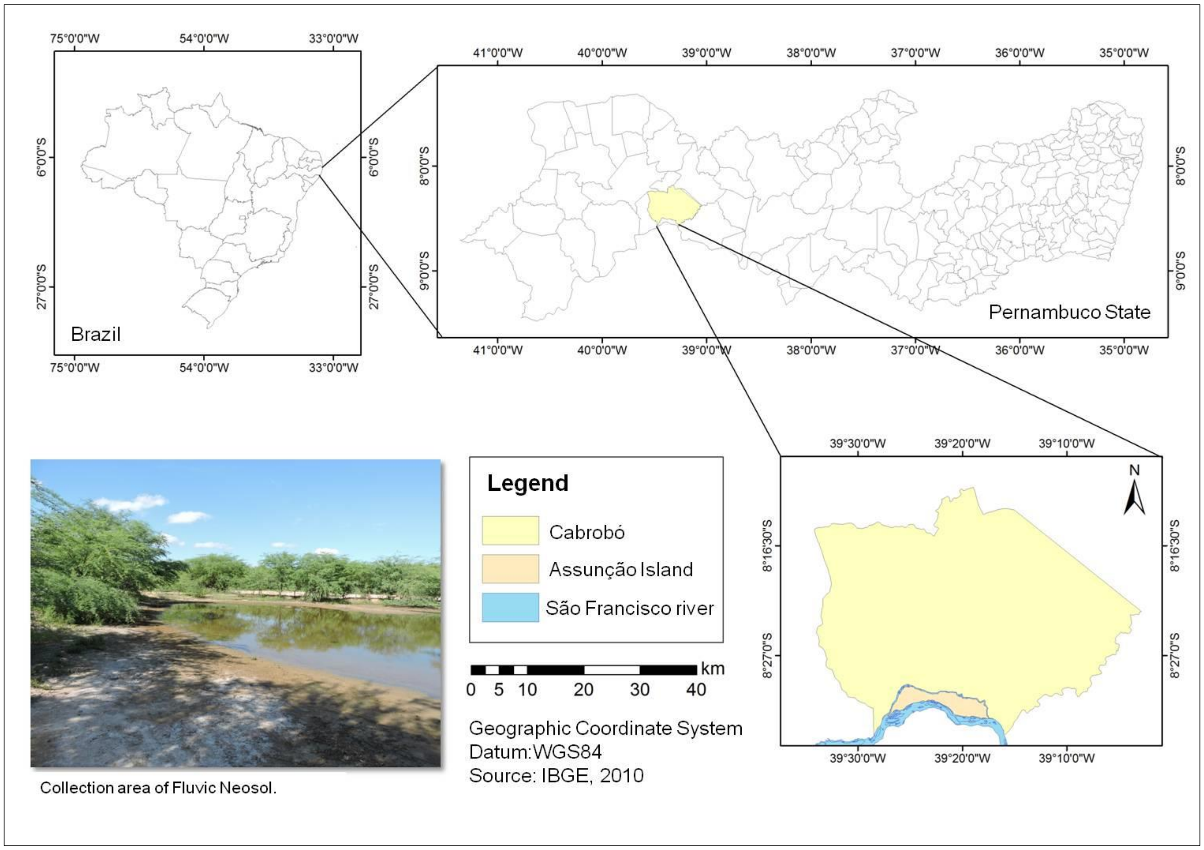

Figure 1 – Collection area of salinized Fluvic Neosol on Assunção Island, municipality of Cabrobó – PE.
Source: IBGE (2010), adapted by the authors.

The lichen *C. substellata* (200 g) was collected in the municipality of Mamanguape - PB, on the shoulder of Highway BR - 101, near the Guaribas Biological Reserve, at coordinates 06°42'42.4" S and 35°07'07.0" W (Figure 2). The lichen was found in areas of coastal *tabuleiros* (plateau or tableland relieve form), where there are patches of edaphic *cerrado* with soils of the Quartzarenic Neosol type (EMBRAPA, 2013). The rainfall characteristics indicate that it is a tropical rainy environment with a dry season in the summer and rains in the autumn and winter, As', according to Köppen's classification. The species *C. substellata* has usnic acid as its principal substance (98.1%) (HOUVINEN and AHTI, 1986), which is one of the most studied substances in lichen chemistry. This lichen is typical in sandy soils, such as in areas of *brejo* forests (humid areas inserted in semi-arid region, due to relieve conditions) and patches of edaphic *cerrado* in the northeastern coastal *tabuleiros* (PEREIRA, 1998; BARBOSA, 2014). The material was identified through morphological and chemical characters of the thallus. A sample was deposited at the Geraldo Mariz UFP Herbarium, under registration number 75,451.

After cleaning to remove exogenous fragments from the lichen, 96 g were selected for submission to gamma radiation in a Gammacell 220 Excel MDS Nordion model Cobalt-60 irradiator, at a dose of 0.5 kGy/s.

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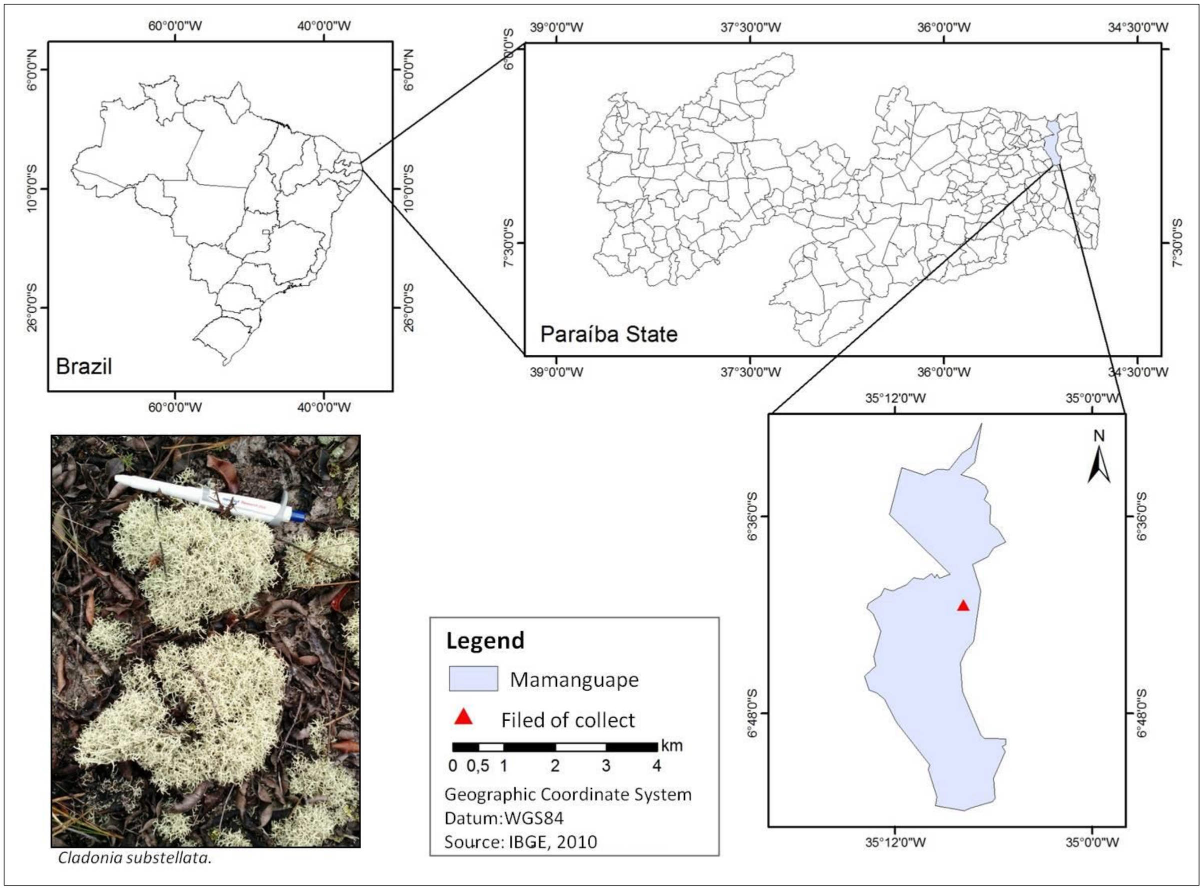

Figure 2– Collection area of the lichen *Cladonia substellata*.
Source: IBGE (2010), adapted by the authors.

Fifteen transparent, colorless, glass domes with a lid were used to set up the experiment, having dimensions of 18 x 20 x 15 cm, where 500 g of salinized Fluvic Neosol and 8 g of *C. substellata* were deposited. The experiment was designed with a laboratory control and four treatments, all composed of three replicates each, namely: a) laboratory control (T-1) - Salinized Fluvic Neosol and *C. substellata* thalli without the use of gamma radiation; b) treatment (T-2) - Salinized Fluvic Neosol and irradiated *C. substellata* thalli; c) treatment (T-3) - Salinized Fluvic Neosol and *C. substellata* thalli irradiated and moistened with urea solution at a concentration of 1.0 mg/mL; (d) treatment (T-4) - Salinized Fluvic Neosol and *C. substellata* thalli irradiated and moistened with urea solution at a concentration of 0.1 mg/mL; (e) treatment (T-5) - Salinized Fluvic Neosol and *C. substellata* thalli irradiated and moistened with urea solution at a concentration of 0.01 mg/mL. The laboratory control and treatment (T-2), in which the thalli were irradiated, were hydrated with 3 mL of deionized

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water weekly. In the treatments with urea solution at different concentrations, the application was made only at 30 days of the experiment. Subsequently, deionized water was used as a source of moisture for the thalli.

Soil and lichen collections were performed every 60 days during the 11 months of the experiments. The phenolic quantification of *C. substellata* and Fluvic Neosol samples of the domes of the different treatments was performed from successive extractions by depletion, according to Silva (2018). Lichen phenols were evaluated spectrophotometrically, from the purification of usnic acid (USN) and preparation of the organic ethereal extract, as described by Martins et al. (2010). The quantification of phenols was estimated using the UV spectrophotometric method by absorbance measured at 220, 290 and 325 nm in a Biochrom Libra S22 spectrophotometer. The analytical curve was constructed with USN (Merck) at concentrations of 2-10 mg/mL. The values obtained were plotted for construction of the curve and calculation of the linear regression line equation, with the 290-nm wavelength showing the best linearity.

The percolated lichen phenols for samples of Fluvic Neosol in the different treatments were also quantified by spectrophotometry by means of a reaction using iron chloride (III), $FeCl_3$, according to Silva (2014).

For the determination of the chemical modifications of salinized Fluvic Neosol in the different treatments, analyses of water pH and chemical fertility of the soil were performed for the levels of Ca, Mg, Na, P, K, Al, H, as described in the Manual and Methods of Soil Analysis (EMBRAPA, 2015), for the field control (material evaluated before the experiments) and at the end of the experiment. From this information, the Exchangeable Sodium Percentage (ESP) was calculated for the samples of salinized Fluvic Neosol, according to Amorim et al. (2010). For the analysis of the results of the experiment with the use of salinized Fluvic Neosol and *C. substellata* thalli, submitted or not to gamma irradiation and urea solutions, randomized blocks were used. Statistical differences were established through the Tukey test, in which $p<0.05$. The calculation of the mean and standard deviation (SD) were performed using the GraphPad Prism 5 program.

III. Results and discussion

The capacity for interaction of lichens in the formation of soils and ecological succession, with the release of substances to the substrate, produces an array of results from pedogenesis (NASH III, 2008), due to the formation of chelates, enabling a chemical recombination of ions contained in rocks or soils (JONES, 1988), to modification in the composition and fertility of soils underlying them, or even interfering in their biota (SILVA,

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2014; 2018). The retention of substances in the thallus is related to water deficit, while periods of precipitation result in their greater release (VASCONCELOS, 2015; ARMAS et al., 2016).

It was found that at 30 days there was an increase in the concentration of USN in all treatments, when compared to the field control submitted or not to gamma radiation. However, at 90 days of experiment there was a reduction in phenolic production by *C. substellata*, and consequent hyperproduction at 150 days (Figure 3). It is possible that the association of urea with gamma radiation interfered in the biosynthesis of the lichen, causing a potentiation of USN. This behavior was also observed by Silva (2014) in an experiment with *Cladonia verticillaris* submitted to gamma radiation superimposed on Luvisol, with an increase in fumarprotocetraric acid at 150 days. Silva et al. (2010) demonstrated in experiments with *C. substellata* and different doses of gamma radiation, that this radioactive source causes an increase in the principal substance produced by the species during the first three months, mainly at lower doses up to the limit of 10 Gy. Accordingly, Melo (2011) pointed out that doses between 5 and 10 Gy tend to stimulate lichen metabolism, as evidenced by an increase in barbatic acid in *Cladonia salzmannii*. This fact may be linked to the morphology of the lichens, which confers enormous resistance to the thallus due to the protection of the upper cortex, formed by a layer of hyphae, associated with the crystallization of its phenolic substances that are deposited on them, both at the cortical and medullary levels (HALE, 1983). This gives the lichens the ability to adapt to adversities, since the crystals function as photoreceptors and/or photoinducers, as a selective character of the radiation that is appropriate to them, depending on the type and amount of radiation they are exposed to (NASH III, 2008).

The effects of ionizing radiation on dry samples of *C. substellata* may have contributed to the permanence of USN production during the 11 months of the experiment. It was evidenced that the association of gamma radiation with higher doses of urea tends to block lichen synthesis. In contrast, the 0.1 mg/mL solution of urea, together with radiation, allowed an intensification of the major phenol of the species. This fact was corroborated by Barbosa (2014), who found that the supplementation of the lichen with nitrogen source caused damage to its structure, especially at a concentration of 1 mg/mL. It is noteworthy that the use of radiation by itself in *C. substellata* thalli resulted in concentrations of USN equal to or higher than the treatments in association with urea solutions. This fact was observed during the entire interval of the experiment. Erbisch (1974) reported the existence of late effects on species of lichens submitted to doses of gamma radiation that can be acute or chronic depending on the dosage used. Such effects are related to the accumulation of radiation inside the lichen thallus, as observed in *Cladonia sylvatica* and *C. verticillata*.

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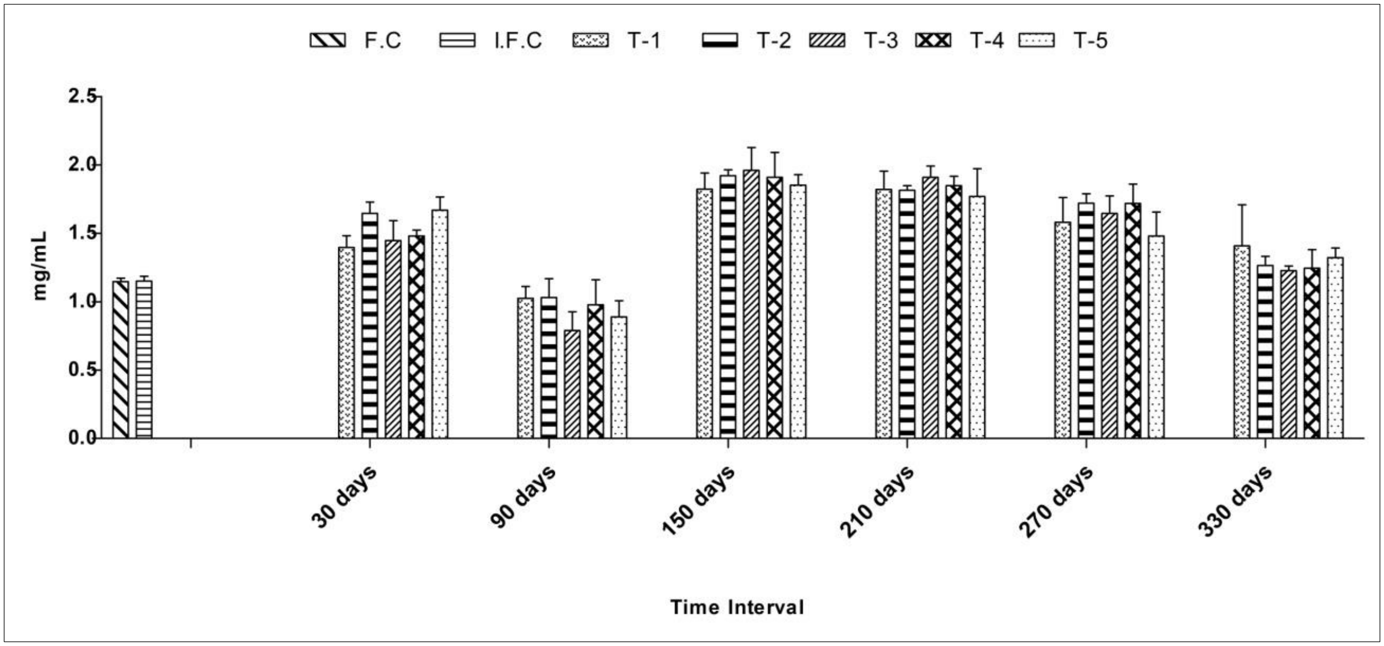

Figure 3 - Concentration of usnic acid in *Cladonia substellata* thalli superimposed on salinized Fluvic Neosol, in different treatments, with or without the use of a nitrogen source and gamma radiation.

Legend: F.C. - Field Control; I.F.C. - Irradiated Field Control; T-1 - Salinized Fluvic Neosol and *C. substellata* thalli without the use of gamma radiation; T-2 - Salinized Fluvic Neosol and irradiated *C. substellata* thalli; T-3 - Salinized Fluvic Neosol and *C. substellata* thalli irradiated and moistened with a urea solution at a concentration of 1.0 mg/mL; T-4 - Salinized Fluvic Neosol and *C. substellata* thalli irradiated and moistened with a urea solution at a concentration of 0.1 mg/mL; T-5 - Salinized Fluvic Neosol and *C. substellata* thalli irradiated and moistened with a urea solution at a concentration of 0.01 mg/mL.

The capacity that lichens have to secrete their substances to the substrate, whether it be rock or soil, conditions biogeophysical and biogeochemical weathering processes, enabling changes in the minerals that make up the rocks and, consequently, dissolution and reaction from the bioformation of new minerals (ADAMO and VIOLANTE, 2000). It was found that *C. substellata* produced and percolated USN to the substrate, Fluvic Neosol, at concentrations higher than those observed in the thallus. Nash III (2008) pointed out that the accumulation of ions in the lichen thallus may lead it to produce substances in excess, which can be released into the environment, in this case into the soil underlying the lichen. This fact was verified throughout the experiment and, specifically, at 90 days and 150 days there is a counterpoint to the concentrations of USN quantified in the lichen thallus. It was observed that at 90 days there was a hyperproduction and release of phenolic compounds produced by *C. substellata*, and at 150 days retention of USN in the thallus, especially in the treatment with exclusive use of gamma radiation (Figures 4 and 5).

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The influence of gamma radiation on the bioproduction of USN in the thallus is confirmed, with emphasis on the treatment using only ionizing radiation. Silva (2014; 2018) confirmed this hyperproductive behavior of the thallus and its consequent transfer to the soil, when lichen species are subjected to exogenous sources of radiation.

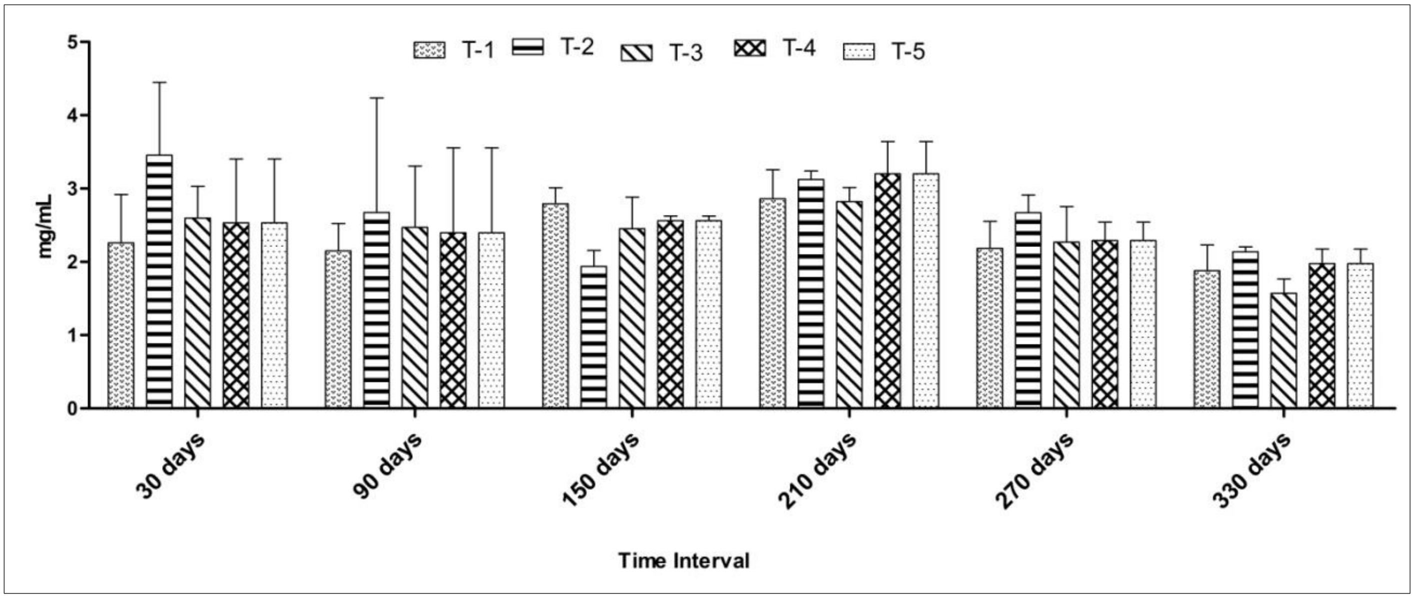

Figure 4 - Concentration of usnic acid produced by *Cladonia substellata* thalli, in different treatments, with or without the use of a nitrogen source and gamma radiation, percolated to salinized Fluvic Neosol.

Legend: T-1 - Salinized Fluvic Neosol and *C. substellata* thalli without the use of gamma radiation; T-2 - Salinized Fluvic Neosol and irradiated *C. substellata* thalli; T-3 - Fluvic Neosol and *C. substellata* thalli irradiated and moistened with a urea solution at a concentration of 1.0 mg/mL; T-4 - Salinized Fluvic Neosol and *C. substellata* thalli irradiated and moistened with a urea solution at a concentration of 0.1 mg/mL; T-5 - Salinized Fluvic Neosol and *C. substellata* thalli irradiated and moistened with a urea solution at a concentration of 0.01 mg/mL.

Adamo et al. (1993) suggested that the ability of lichens to alter the substrate is not related to the morphology of the thallus that adheres with greater or lesser intensity, but to the physiology of the different species. Thus, the substances produced by *C. substellata* will percolate to the soil and will interact with soil ions, causing chelation and/or complexation of the soil chemical elements. In addition, Bjelland and Thorseth (2002) pointed out that one of the factors associated with the chemical weathering caused by lichens is the different compounds released, which, linked to the water retention capacity of the thallus, can increase the chemical dissolution of the substrate. Chen et al. (2000) emphasized that organic substances and inorganic acids excreted by lichens can cause reactions with substrate minerals through mechanical breakdown and crystallization of secondary salts.

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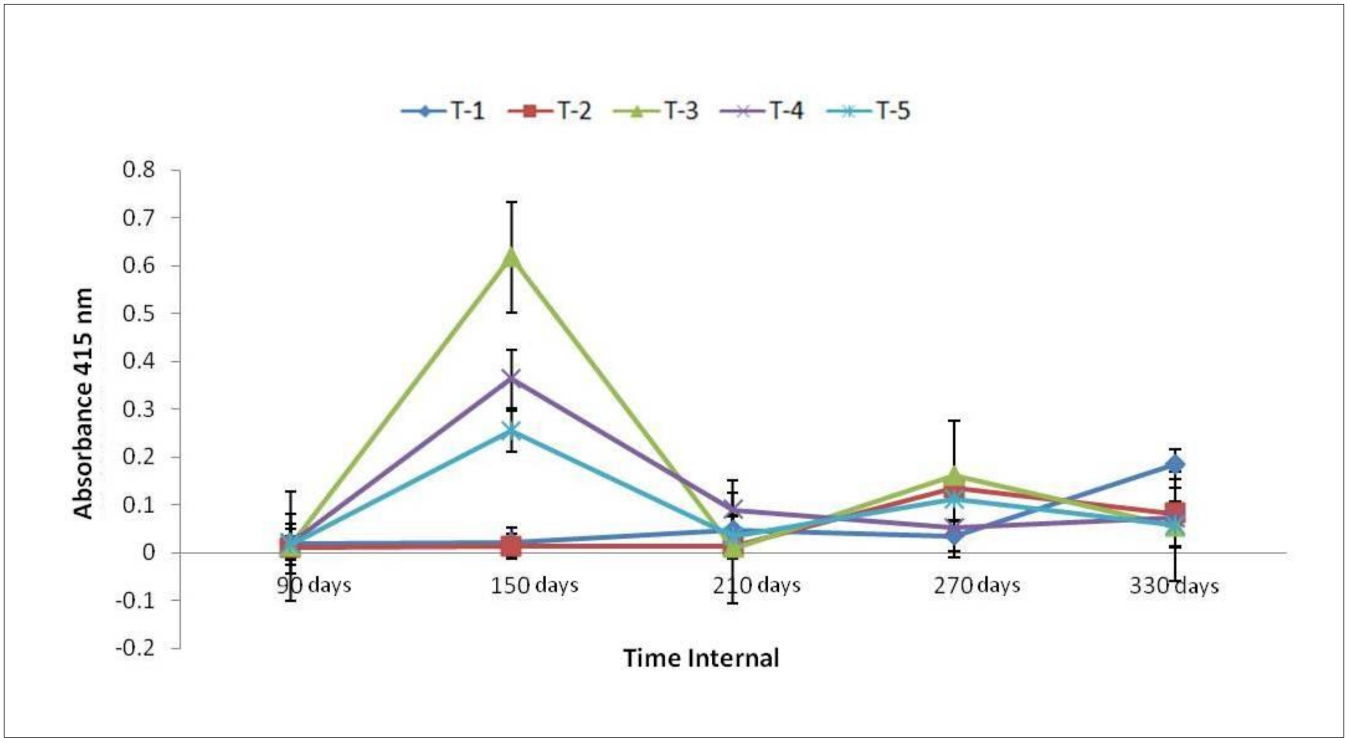

Figure 5 - Quantification of *Cladonia substellata* substances percolated to the salinized Fluvic Neosol underlying the lichen thalli, as determined by reaction with FeCl III.

Legend: T-1 - Salinized Fluvic Neosol and *C. substellata* thalli without the use of gamma radiation; T-2 - Salinized Fluvic Neosol and irradiated *C. substellata* thalli; T-3 - Fluvic Neosol and *C. substellata* thalli irradiated and moistened with a urea solution at a concentration of 1.0 mg/mL; T-4 - Salinized Fluvic Neosol and *C. substellata* thalli irradiated and moistened with a urea solution at a concentration of 0.1 mg/mL; T-5 - Salinized Fluvic Neosol and *C. substellata* thalli irradiated and moistened with a urea solution at a concentration of 0.01 mg/mL.

Adamo and Violante (2000) emphasized that besides the physical weathering performed through the penetration of the hyphae of the thallus, chemical processes are essential due to the release of organic acids, decomposing minerals by the process of biosolubilization (or biodissolution). The release of substances produced by *C. substellata* is in line with the data obtained for the concentrations of USN in the thallus and in the samples of salinized Fluvic Neosol, and in agreement with Silva (2014; 2018) and Silva (2018).

The use of lichens as bioremediators in salinized soils has been shown to be a promising option in improving soil fertility and reducing sodium (SILVA, 2014; 2018) in soils of coastal *tabuleiros* of northeastern Brazil (SILVA, 2018), due to the fact that lichen substances of a phenolic nature (CULBERSON et al, 1977) are involved in the mechanisms of decomposition and physical disintegration of the rock (ADAMO and VIOLANTE, 2000), through the chelation and solubilization of cations (JONES, 1988), acting as complexing agents (RUNDEL,

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1978). The ability of lichens to decompose rocks is also due to the activity of the mycobiont's production of CO_2 as a result of its metabolism (PEREIRA, 1998). In this sense, taking into consideration the economic, social and environmental problems resulting from salinization and loss of soil fertility due to the impacts of desertification in the semi-arid region of northeastern Brazil, the introduction of *C. substellata*, in association with a nitrogen source and gamma radiation, as a bioremediation agent of salinized Fluvic Neosol, becomes feasible, given its ability to modify and release chemical elements retained in the soil solution.

Changes were found in the chemical composition of salinized Fluvic Neosol submitted to different treatments with *C. substellata* when compared to the field control (Table 1). The levels of P, Ca, Mg, Na, K and soil pH increased. The increase in the concentration of P in the soil in all treatments shows that, probably, the influence of the substances produced by *C. substellata* and percolated into the substrate intensified the levels of phosphorus in the soil. Raij (1993) pointed out that phosphorus has very low mobility in soil, which in solid phase is combined in compounds with iron, aluminum, calcium and organic matter. Reimann and Caritat (1998) pointed out that phosphorus is an essential element for all organisms. In addition, Silva (2018) obtained an expressive increase in P content in bioremediation experiments, using *C. substellata*, of salinized Fluvic Neosol in association with organic matter and biofertilizer produced from biodecomposers. Thus, these data demonstrate the capacity of phenols of the species, with emphasis on USN, to bioremediate salinized soils.

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Table 1 - Chemical analysis of samples of salinized Fluvic Neosol in experiments with *Cladonia substellata* thalli overlying the soil in different treatments submitted or not to gamma radiation and a nitrogen source.

	Treatments*	P	pH	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	$A1^{3-}$	H^{+}	SB	CEC	V	ESP
		mg/dm^3	H_2O	------------------------- $cmol_c/dm^3$ -------------------------								---- % ----	
Time zero	F.C.	9	5.7	7.2	6.1	8	0.2	0	1.4	21.6	23.1	94	35
11 mo's	T-1	24	7.8	11	6.7	11	0.4	0	-	29.1	29.1		38
	T-2	19	7.7	10.5	6.9	11	0.3	0	-	28.7	28.7		38
	T-3	19	7.7	10.6	5.1	11	0.3	0	-	27	27		41
	T-4	20	7.7	11.5	7.1	11	0.3	0	-	29.9	29.9		37
	T-5	19	7.6	11.3	6.7	11	0.4	0	-	29.4	29.4		37
Mean	-	19	7.7	10.8	6.7	11	0.3	0	-	-	-	-	-
SD	-	5.0	0.8	1.6	0.7	1.2	0.1	0.0	-	-	-	-	-
CV (%)	-	2.6	1.1	1.5	1.1	1.1	2.5	0.0	-	-	-	-	-

Source: IPA (Instituto Agronômico de Pernambuco), adapted by the authors. SD = standard deviation; CV = coefficient of variation.

Legend: *F.C. - Fluvic Neosol field control; T-1 - Salinized Fluvic Neosol and C. substellata thalli without the use of gamma radiation; T-2 - Salinized Fluvic Neosol and irradiated *C. substellata* thalli; T-3 - Salinized Fluvic Neosol and *C. substellata* thalli irradiated and moistened with a urea solution at a concentration of 1.0 mg/mL; T-4 - Salinized Fluvic Neosol and *C. substellata* thalli irradiated and moistened with a urea solution at a concentration of 0.1 mg/mL; T-5 - Salinized Fluvic Neosol and *C. substellata* thalli irradiated and moistened with a urea solution at a concentration of 0.01 mg/mL.

The intensification of the levels of Ca and Mg demonstrates the capacity of interaction of the organic acids produced by the species, specifically, the USN. Silva (2014), in studies on the capacity of the lichen *C. verticillaris* to recover the fertility of Luvisols degraded by salinization, has already pointed out that lichen substances contribute to an increase in microbial populations, as well as increase levels of Ca and Mg by the complexation of albite and microcline minerals. The variations in the concentrations of Ca, Mg, Na and K, specifically the increase in levels, had an influence on the values of SB and CEC. On the other hand, ESP remained excessively sodic for ESP > 30%, with its percentage in T-3 being higher than in the other treatments. The geochemical effect of lichens on granite rocks affects the mobility of some elements, and this mobility or accumulation depends on the susceptibility of the mineral constituent of the rock. Thus, Na and Ca, in plagioclase minerals, tend to be easily mobilized, unlike K, which has a lower degree of mobility. In addition, Raij (1993) revealed that K, Ca and Mg are found in the soil in ionic form, in solution and as exchangeable cations, where potassium and magnesium participate in the structure of mica and clay minerals of type 2:1, which are effective in less weathered soils, as is typical for soils of the semi-arid Brazilian Northeast. These elements influence the availability of other elements. Specifically, potassium in solution depends on the content of

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calcium and magnesium. Thus, the higher the concentration of K, the lower the levels of Ca and Mg. The increase in the Na content in all treatments when compared to the field control, and being an important factor in salinization, demonstrates its low biodissolution capacity.

It was found that the soil became alkaline, which can be supported in the postulates of Schatz (1963). The author mentions that substances released by lichens tend to increase the pH of the underlying substrate. In contrast, a drop in pH results from the chelation of metals that replace hydrogen ions. This fact confirms that USN is able to cause changes in soil pH, leaving it alkaline.

Agriculture is the main means of subsistence for the Truká indigenous group, the inhabitants of Assunção Island, municipality of Cabrobó, but the use of pesticides and agricultural inputs in conventional agriculture, crops and practices inappropriate for the characteristics of the soil in the region, have caused a process of environmental degradation in large areas and consequent decrease in productivity, loss of fertility and salinization of soil. When the environment reaches such stages of degradation, farmers abandon these areas, which have become unproductive, and turn to occupying other, still preserved, locations, generating a continuous cycle of degradation. Thus, the insertion of sustainable, alternative forms such as, for example, the use of lichen substances in association with different agents that facilitate the chelation process, especially of sodium, can be promising methods for the recovery of fertility in salinized soils, especially given their low cost and easy applicability.

IV. FINAL CONSIDERATIONS

According to the results obtained it is possible to state that gamma radiation in association with a nitrogen source caused an increase in the biosynthesis of USN by *C. substellata*. However, only the use of gamma radiation at a dose of 5 Gy showed levels of USN equal to or higher than the treatments that used exogenous nitrogen source.

The hyperproduction of USN by the lichen thallus in excessive quantities caused greater percolation of the substance to the salinized Fluvic Neosol, with accumulation at levels higher than those of the thallus, which exerted an influence on the soil's chemical properties.

The capacity of chemical modification of Fluvic Neosol by percolated substances from *C. substellata* was evidenced, with a significant increase in Ca, Mg, P and Na levels, as well as in soil pH. The increase in Na concentration may be related to its low biodissolution capacity. Thus, it is possible to affirm that *C. substellata*,

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in association or not with an exogenous nitrogen source, is capable, in the short term, of chemically altering soils degraded by salinization in such a way that increases the bioavailability of elements essential for plants and soil organisms.

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