



Herbaceous biomass yield in the saline soils during the dry and rainy seasons in the municipality of Pentecoste, CE, Brazil

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ABSTRACT: *This study was an endeavor undertaken to assess the biomass yield of the species that are native to a particular region characterized by saline soil, in the Irrigated Perimeter Curu-Pentecoste, in the municipality of Pentecoste-CE, corresponding to the qualities of moisture, pH and electrical conductivity (EC) of the soil. The experiment was conducted in six areas, with area 1, the one nearest to the collecting drain, the end having the highest salinity and area 6, the one furthest away from the collecting drain, the end with the lowest salinity. The factorial design with the 2 x 6 scheme was adopted, in which the first and second factors referred, respectively, to the seasons (drought and rain collection) and collection areas. In each area, eight permanent 5 x 5 m plots were demarcated, which included 8 repetitions per treatment. Within each permanent plot the quantity of forage was gathered within an area of 0.25 x 0.25 m. Soil samples were taken from a depth of 0-20 cm, and the EC, pH and soil moisture were determined. The phytomass was oven dried, after which the water content and yield were recorded. Three subsamples per area were burned in a muffle furnace to determine the percentage of ash content. The resultant high pH and EC values, typical of arid soils and related to the significantly low humidity, can cause harm to most of the crops cultivated in the Northeast of Brazil. However, the biomass yield was substantial, indicating that the species occurring there possessed adaptive mechanisms to enable them to tolerate the conditions of saline soil and water stresses prevalent there.*

Key words: *phytomass, halophytes, salinization.*

Rendimento da biomassa herbácea em solos salinos nas estações seca e chuvosa no município de Pentecoste, CE, Brasil

RESUMO: *O objetivo do trabalho foi avaliar o rendimento de biomassa vegetal de espécies presentes naturalmente em uma área com o solo salinizado no perímetro irrigado Curu-Pentecoste, no município de Pentecoste, CE, correlacionando com os atributos umidade, pH e condutividade elétrica (CE) do solo. O experimento foi realizado em 6 áreas, sendo a área 1 mais próxima do dreno coletor o extremo mais salinizado, e a área 6 mais distante do dreno coletor, o extremo menos salinizado. Utilizamos do delineamento fatorial no esquema 2 x 6, com primeiro fator referente às estações de coleta (seca e chuva), e o segundo relativo às áreas. Foram marcadas em cada uma das áreas 8 parcelas permanentes de 5 x 5 m e em cada parcela permanente foram realizadas coletas da porção forrageira dentro de um quadrado de 0,25 x 0,25 m. Amostras de solo de 0-20 cm de profundidade foram coletadas para a obtenção da CE, do pH e da umidade do solo. A fitomassa foi secada em estufa, onde foram mensurados o seu conteúdo de água e biomassa seca. Três subamostras por área foram queimadas em mufla para a obtenção do seu conteúdo de cinzas. O pH e CE elevados do solo mostraram características típicas de solos de clima árido, que associados a uma significativa diminuição da umidade desse, podem causar prejuízos na maioria dos cultivos no Nordeste brasileiro. Entretanto, o rendimento de biomassa foi elevado, o que demonstra que as espécies ali presentes possuem mecanismos adaptativos para tolerância aos estresses salino e hídrico.*

Palavras-chave: *fitomassa, halófitas, salinização.*

INTRODUCTION

Among the principal abiotic stresses, salinity ranks high in causing soil degradation, negatively affecting agricultural yield, particularly in the arid and semi-arid areas (RIBEIRO et al., 2016). On the contrary, the projected rise in the world population over the next few decades makes the

cultivation of halophytic plants, which included those species that can accomplish their whole life cycle in regions of high soil salinity, a significant achievement for sustainable agriculture. (PANDOLFI et al., 2012). In light of this fact, many of the halophyte species native to the northeastern regions in Brazil with the highly saline soils possess high food potential, such as *Blutaparon vermiculare* (L.) Mears (MEDEIROS;

ALBUQUERQUE, 2014), *Sesuvium portulacastrum* (L.) L. (MEDINA et al., 2008; LOCKANDE et al., 2009), *Salicornia bigelovii* Torr. (ZERAÍ et al., 2010), and *Sarcocornia ambigua* (Michx.) Alonso & Crespo (PINHEIRO et al., 2017); however, this immense potential has not been exploited at all in Brazilian cooking (COSTA; HERRERA, 2016).

Although, they have not yet been capitalized upon, to great degree, the plant biomass produced through halophyte cultivation offers several benefits. It can be utilized as human food, cattle feed / fodder and in the manufacture of bioactive products. These plants can also find use in the phytoremediation projects to counter the anthropogenic impacts unleashed upon coastal environments including marshes, mangroves and coastal dunes (COSTA & HERRERA, 2016).

Research done earlier on assessing the plant biomass yield from the cultivation of halophytic crops have shown promise. In their study, PINHEIRO et al., (2017) estimated the output of the halophyte *Sarcocornia ambigua* with effluents from shrimp farms. They reported satisfactory findings from raising this halophyte hydroponically in association with the production of *Litopenaeus vannamei*, a species of shrimp. In their research, MELO et al., (2016) studied the harvest of the *Atriplex nummularia* under unfavorable conditions of salt and water stresses, where the biomass produced escalated proportional to the rise in the electrical conductivity in the irrigation water used.

From this perspective, the hypothesis proposed in this study implies that plant biomass produced in the saline soils is identical to the yield from the regions with non-saline soil, during the dry and rainy seasons, because the species native to these habitats must possess adaptive mechanisms that support their growth under unfavorable conditions. This research aimed to assess the plant biomass produced and ash content of the native species occurring in the regions possessing soils ranging from low salt soil to highly saline soil, within the Irrigated Perimeter, present in a seasonally dry location, relating these to the variables of moisture, pH and electrical conductivity of the soil. Thus, the objective of this study was to provide data through an *in situ* analysis, which can be used as a subsidy for the exploitation of the unused deserted regions because of such environmental stresses.

MATERIALS AND METHODS

The study extended from May / 2016 to March / 2017, and the samples were gathered

during the seasons of rain (February to May) and dry weather (June to January), within the core D region of the Irrigated Perimeter Curu-Pentecoste, in the municipality of Pentecoste-CE (03° 48' 04.3" S 39° 18' 11.3" W). The climate in this region, based on the Köppen classification, is BSw'h' type, semiarid, with the characteristic hot weather and low precipitation mainly from January to April. With 860 mm average annual rainfall and 1,474 mm average annual evaporation a significant water deficit was evident. The average annual temperature hovers around 27° C and average relative air humidity is about 73.7% (BEZERRA, 2006).

The perimeter contains the typical Neossolo Fluvic soil type, because it lies in the alluvial lowland areas. The water is supplied from the General Sampaio Public Dam, with 322,200,000-m³ storage capacity and the Public Pereira de Miranda Dam, with 395,638,000-m³ storage capacity. The major irrigation system of the Perimeter is made in the furrows on the surface, while drainage occurs through the open drains, the main collection rivers being the Curu and Canindé (BEZERRA, 2006).

Using a piece of abandoned land for agricultural cultivation, the field experiments were conducted. The area closest to the collecting drain of the irrigation system was characterized by highly saline soil (Area 1), and moving away from the collecting drain, five more areas were marked out (Areas 2 to 6), each roughly 20 m long. Eight permanent plots 5 x 5 m in area were demarcated in each area, and the entire herbaceous plant biomass was harvested at ground level within the area of 25 x 25 cm. All the samples were gathered during October (the month with the least rainfall in 2016) and March (the peak of the rainy season in 2017), thus representing the samples of the dry and the rainy seasons, respectively.

At four points of the square from where the biomass was gathered, the soil samples were drawn from 0-20 cm depth using a hand auger. They were then mixed to represent a sample according to each plot. Some of the soil sample portions were stored in plastic bags with suitable identifications and some amount was stored in 200 ml metal pots and hermetically sealed. Table 1 shows the characteristics of the soil from each area.

The weight of the soil samples in the metal pots was measured on an analytical balance and their wet weight was recorded. The samples were then placed in a forced aeration oven at 65° C for drying, until constant weight was achieved. Post drying, the samples were weighed once more and the dry weight was noted.

Table 1 - Soil chemical analysis of the regions located in the experimental area in the Irrigated Perimeter Curu-Pentecoste. Mean \pm standard deviation.

Areas	-----Assortment Complex (Cmolc / kg)-----				(g/kg)	(mg/kg)
	Ca	Mg	Na	K	N	P
1	2.90 \pm 1.08	1.70 \pm 0.36	37.86 \pm 3.18	0.35 \pm 0.05	0.80 \pm 0.08	13.33 \pm 4.04
2	3.90 \pm 0.57	3.90 \pm 0.85	19.08 \pm 0.93	0.36 \pm 0.02	0.87 \pm 0.16	14.50 \pm 3.54
3	9.35 \pm 3.61	8.50 \pm 1.56	7.67 \pm 0.67	0.49 \pm 0.01	1.93 \pm 0.14	7.50 \pm 2.12
4	12.25 \pm 0.92	8.95 \pm 1.34	4.55 \pm 0.22	0.60 \pm 0.18	1.80 \pm 0.39	8.00 \pm 1.41
5	9.55 \pm 0.64	7.40 \pm 0.57	4.65 \pm 2.26	0.58 \pm 0.10	1.86 \pm 0.09	12.50 \pm 10.61
6	6.20 \pm 1.84	4.15 \pm 2.62	0.90 \pm 0.79	0.33 \pm 0.05	1.26 \pm 0.23	6.00 \pm 1.41

The samples in each of the plastic bags were air dried, powdered and passed through a 2 mm sieve. Later, the samples diluted with distilled water were tested for electrical conductivity (soil salinization proxy) and pH analyses. For electrical conductivity, 1:1 dilution and decantation were done over a 24-h period, and for pH 1:2.5 dilution and 1-h decantation period.

Initially, the biomasses were weighed using an analytical balance and their fresh weight was noted. Next, they were oven-dried in a forced aeration oven at 65°C until constant weight was attained, and their dry weight was recorded. Using these values, the dry biomass yield was calculated employing the formula:

$$Y = \frac{SDW}{A}$$

Where:

Y - yield (kg.ha-1)

SDW - sample dry weight (kg)

A - sampled area (ha)

The water content was also calculated relative to the fresh weight, using the formula (MEDINA et al., 2008):

$$SWC = \frac{Fw - SDW}{Fw}$$

Where:

SWC - water content (%)

Fw - fresh sample weight (kg)

SDW - weight with your friend (kg)

In each area, three dry matter subsamples of 1g each, were burned in a muffle furnace at 550°C and the ashes were obtained. We calculated the ash content based on the formula given (MEDINA et al., 2008):

$$AC = \frac{AW}{TDw} * 100$$

Where:

AC - ash content (%)

AW - ashes (g)

TDw - dry matter subsample weight (g)

The factorial design with the 2x6 scheme was adopted, where the first factor involved both collection seasons (drought and rain) and the second included the areas (areas 1 to 6), to account for a total of 12 treatments. Each treatment comprised eight repetitions, relating to the permanent plots demarcated in each area, barring the ash content treatment, for which three repetitions were done with reference to the subsamples. The Shapiro-Wilk test was used to analyze the normality of the data. The analysis of variance (ANOVA) was performed with a 5% F test, after which the means were compared by the Tukey test, to identify the likely variations in the values of soil moisture, electrical conductivity and pH, as well as in the dry biomass yield, water content and ash content of the plant biomass samples. In the absence of any variations between the factors, the influence exerted by the factors alone was assessed.

To estimate the relationship existing between the qualities of the soil and yield of the dry plant biomass, ash and water contents, Pearson's linear correlation analysis was employed. All the statistical analyses were performed using the BioEstat 5.0 program (AYRES et al., 2007).

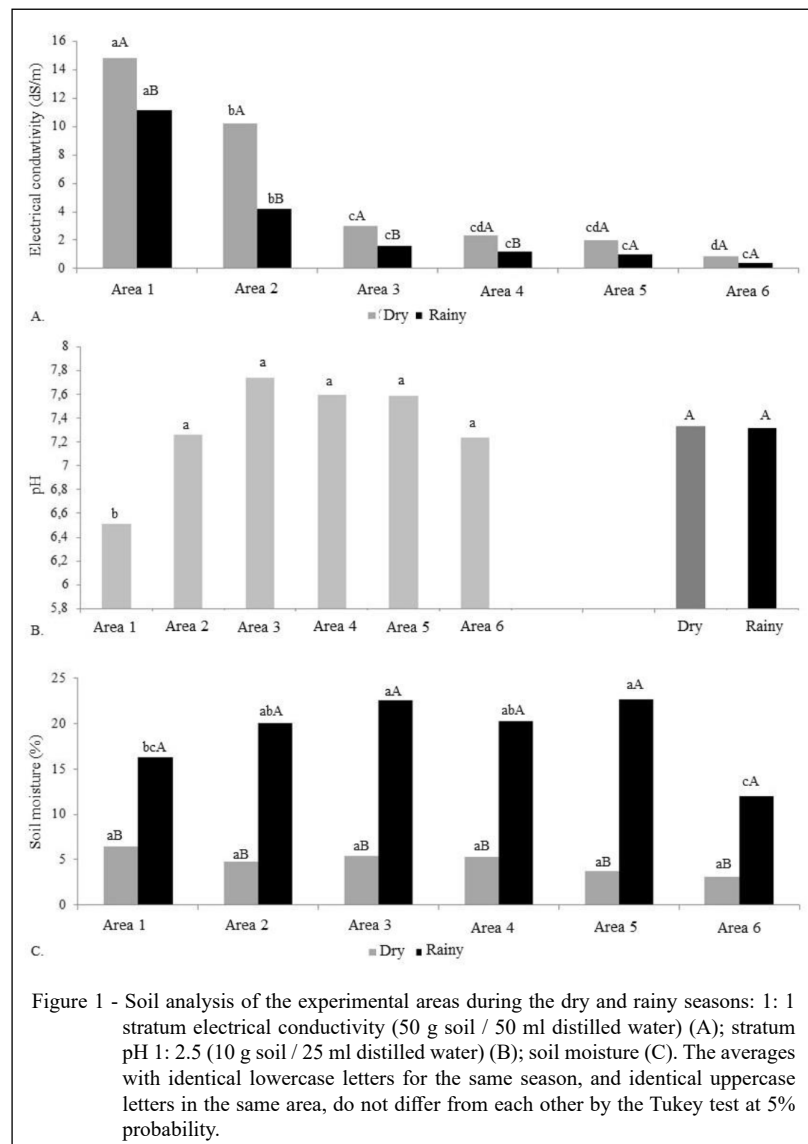
RESULTS AND DISCUSSION

The species listed were identified, with their relative frequencies (frequencies above 5%), when they were gathered during the rainy season: *Blutaparon vermiculare* (L.) Mears (20.98%), *Cyperus rotundus* L. (11.89%), *Malachra fasciata* Jacq. (8.39%), *Sesuvium portulacastrum* (L.) L. (8.39%), *Physalis angulata* L. (7.69%), *Paspalum*

ligulare Nees (6.99%), *Sesbania exasperata* Kunth. (6.29%), *Ipomoea asarifolia* (Desr.) Roem. & Schult. (5.59%) and *Sida rhombifolia* L. (5.59%); and those gathered during the dry season included, *Blutaparon vermiculare* (L.) Mears (52.46%), *Cyperus rotundus* L. (16.39%), *Sesuvium portulacastrum* (L.) L. (9.84%), *Ipomoea asarifolia* (Desr.) Roem. & Schult. (6.56%) and *Malachra fasciata* Jacq. (6.56%).

For both the collection stations, area 1, the one nearest to the collecting drain and the first to be established as having the highest salinity, revealed the highest values of electrical conductivity of the soil, with area 2 being the second (Figure 1A). During the dry season, no difference was evident in the values

of soil electrical conductivity between areas 4 and 5, while during the same season the values of areas 3 and 4 was distinctly higher ($p < 0.001$) than those of areas 5 and 6. When considering the soil pH (Figure 1B), the values showed no variation between the treatments and between the collection stations, the only exception being area 1, which revealed a lower pH value. The treatments during the rainy season, in all the areas, showed higher values for soil moisture (Figure 1C), but no variations were noted between treatments in the dry season. The high values identified for the pH and electrical conductivity were close to the characteristic values reported for arid regions (FERNÁNDEZ et al., 2016).



In such conditions, for both seasons, the electrical conductivity of the soil may induce a lowered yield for most of the crops cultivated in the northeastern backlands (BEZERRA, 2006), because of the reduced osmotic potential, heightened ionic toxicity and imbalance in the absorption of water and nutrients (LIMA-NETO et al., 2015). However, for the halophytic species, MANOUSAKI & KALOGERAKIS (2009) a high tolerance for the soils with values of electrical conductivity in the 10-12 dS.m⁻¹ range was evident, without their development being affected.

During the dry season, compared to the rainy season, the rise in the electrical conductivity of the soil observed can be understood because of the decline in the soil moisture, because it mirrors the

water deficit occurring in the region, which becomes more noticeable at this point in time. Water deficit produces efficient natural leaching, dilution and dissolution which, when related to the rise of the salts through capillary action induced by the high rates of evaporation, liberate an accumulation of ions in the surface layer of the soil horizons (RIBEIRO et al., 2016; ZERAI et al., 2010).

During the rainy season, the treatments in all the areas revealed higher dry biomass yields (Figure 2A) compared to their dry season values. During the dry season; however, areas 2 and 3 showed the highest dry biomass yield values, while areas 5 and 6 revealed the lowest values. Areas 1

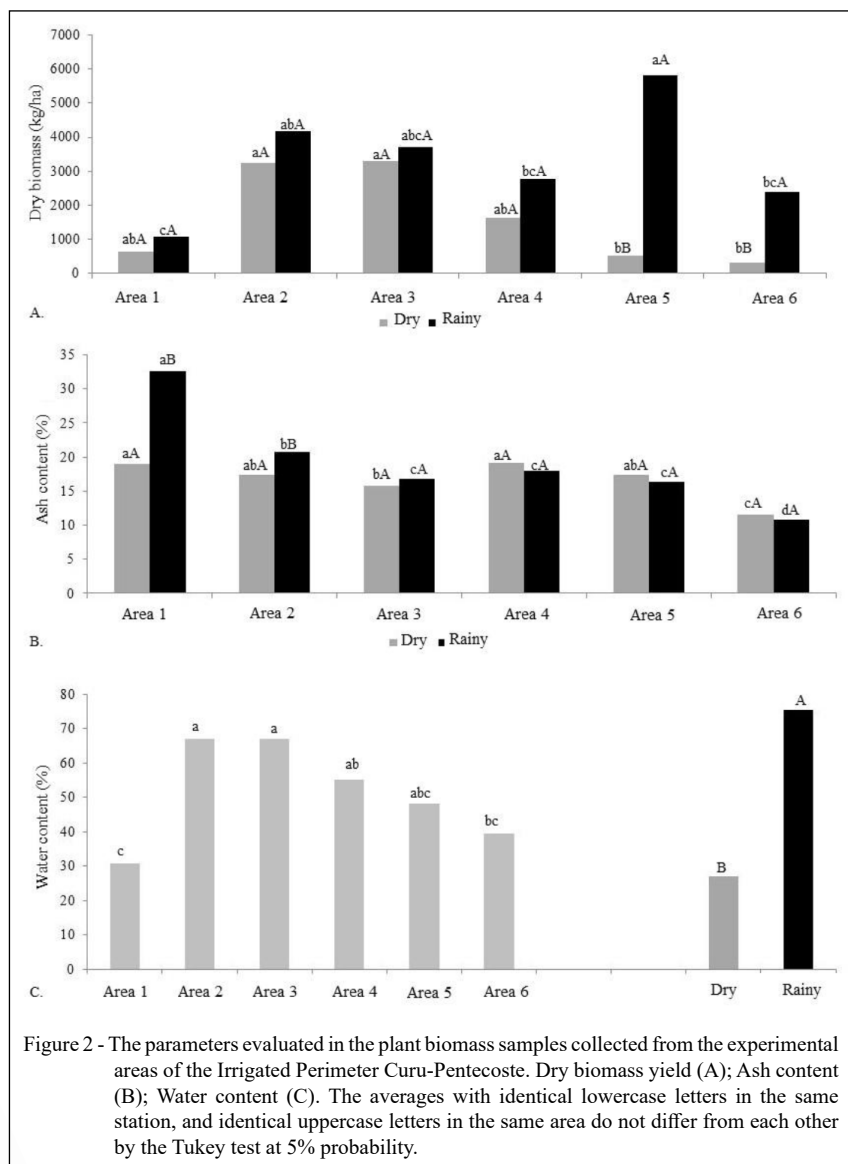


Figure 2 - The parameters evaluated in the plant biomass samples collected from the experimental areas of the Irrigated Perimeter Curu-Pentecoste. Dry biomass yield (A); Ash content (B); Water content (C). The averages with identical lowercase letters in the same station, and identical uppercase letters in the same area do not differ from each other by the Tukey test at 5% probability.

and 2 showed a boost in the ash content (Figure 2B) in the treatments during the dry season, which was not, observed for the rainy season treatments, but no significant variations were noted in the other areas. During the rainy season, the treatment in area 6 revealed the lowest ash content values, while during the dry season, the treatment in this area registered the second lowest values, together with the treatments in the areas 3, 4 and 5 during the dry season. The escalation in the ash contents of the areas 1 and 2 during the dry season over those from the rainy season, were contrary to the values of the electrical conductivity in these areas, which revealed a decline during the same period. This could be attributed to the rise in the soil salinity, which triggered higher ion absorption (Davenport, 2008).

The high frequency of occurrence of the halophytic species in the areas 1, 2, 3, 4 and 5, which included the species *Blutaparon vermiculare* (L.) Mears and *Sesuvium portulacastrum* (L.) L. account for the plant biomass and ash content yields, because the halophyte species possess mechanisms for salinity tolerance that enable them to grow and develop even under unfavorable conditions of high ionic concentrations, and they have the capacity to store these salts within their tissues (BARROSO et al., 2006; FLOWERS & COLMER, 2008). However, it is striking that for particular animal crops, like those for goats and sheep, the salt content in the feed is limited to 10 g of salt per 100 g of dry matter. This limit restricts the usage of halophytic crops as fodder, suggesting that it will be better to mix them with other food sources (MIYAMOTO et al., 1994).

The water content (Figure 2C) of the biomass sampled showed higher values during the rainy season, in fact more than 70%, a reading regarded as high for the non-halophytic plant species, which is indicative of significant adaptive response in the halophyte species (GARCÍA et al., 2008; MEDINA et al., 2008).

The water content during the dry season showed a strong correspondence to the ash content (Table 2), suggesting an inclination for the biomasses having higher water content to also possess a higher ash content, and these parameters could be physiologically consistent with the internal control of ion concentration (MEDINA et al., 2008). In these halophytic plants, the rise in the water content facilitates a boost in the ability of the plant to store salts within its vacuoles, thus enabling osmotic adjustments that can safeguard the plant from the toxic influence of surplus salt (WYN-JONES & GORHAM, 2002).

The dry biomass yield and water content revealed no correlation with any of the soil qualities, in any of the collection stations. The ash content; however, during the rainy season, revealed a strong positive correlation with the soil electrical conductivity (Table 2). The halophytic species have the ability to adapt through compartmentalization and intracellular excretion of sodium, as well as through the generation and storage of organic solutes (FLOWERS & COLMER, 2015; FLOWERS et al., 2010; ROZEMA & SCHAT, 2013), which could possibly throw some light upon the rise in the ash content in response to the increased electrical conductivity of the soil.

Table 2 - Pearson linear correlation matrices between the dry biomass yield, ash content and soil attributes (electrical conductivity, pH and moisture) during the dry and rainy seasons in the Irrigated Perimeter Curu-Pentecoste.

Variables	AC	CC	EC	pH	U
<i>Dry season</i>					
Biomass yield (PB)	0.3752 ^{ns}	0.1686 ^{ns}	0.1124 ^{ns}	0.4099 ^{ns}	0.3367 ^{ns}
Water content (AC)	-	0.9694*	0.4834 ^{ns}	0.0836 ^{ns}	0.8010 ^{ns}
Ash content (CC)	-	-	0.5063 ^{ns}	-0.0349 ^{ns}	0.7195 ^{ns}
Electrical conductivity (EC)	-	-	-	-0.7593 ^{ns}	0.6913 ^{ns}
pH	-	-	-	-	-0.2243 ^{ns}
<i>Rainy season</i>					
Biomass Production (PB)	0.2395 ^{ns}	-0.4691 ^{ns}	-0.5749 ^{ns}	0.6420 ^{ns}	0.4568 ^{ns}
Water content (AC)	-	-0.4555 ^{ns}	-0.4849 ^{ns}	0.5856 ^{ns}	0.5757 ^{ns}
Ash content (CC)	-	-	0.9643*	0.6283 ^{ns}	0.0581 ^{ns}
Electrical conductivity (EC)	-	-	-	-0.7853 ^{ns}	-0.1484 ^{ns}
pH	-	-	-	-	0.6854 ^{ns}

*Significant at 5% probability; ns – Nonsignificant; U – soil moisture.

CONCLUSION

The conclusion drawn was that the plant biomass yield was similar, irrespective of whether the soil was high in salinity or otherwise. The yield showed no variation along the dry and rainy seasons. With respect to the ash content, further studies are necessary to determine the use of these halophytes in animal fodder.

ACKNOWLEDGEMENTS

We thank the Cearense Foundation of Support for Scientific and Technological Development of the State of Ceará (FUNCAP) for the grant to F.Y.E.C. Dias. This study was financed in part by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), Brasil - Finance code 001. We also thank the staff of the Curu Valley Experimental Farm for local support.

DECLARATION OF CONFLICT OF INTERESTS

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

FYECD, OHB, EMPL and CFL designed the study. FYECD, OHB, CFL, DRO and DPO performed the experiments. FYECD, OHB and EMPL performed statistical analyses of experimental data. FYECD, OHB, EMPL and CFL analyzed the data. All the authors contributed to the writing of the manuscript and approved of the final version.

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