

## ESTABLISHMENT OF YOUNG “DWARF GREEN” COCONUT PLANTS IN SOIL AFFECTED BY SALTS AND UNDER WATER DEFICIT<sup>1</sup>

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**ABSTRACT** - The aim was to analyze the establishment of young “Green Dwarf” coconut plants in soils affected by salts and under water stress, by evaluating leaf area, biomass production and allocation. In the experiment, conducted in protected environment in Fortaleza, CE, in statistical design of randomized blocks in a split plot arrangement, the effects of different water deficit levels (plots) were evaluated, by imposing different percentages of replacement of water losses by potential crop evapotranspiration - ET<sub>pc</sub> (20, 40, 60, 80 and 100%), associated with subplots consisting of increasing soil salinity levels (1.72, 6.25, 25.80 and 40.70 dS m<sup>-1</sup>) provided by soil collected at different parts of the Morada Nova Irrigated Perimeter - PIMN. Leaf area and biomass production were sharply reduced by the conditions of water stress and high soil salinity, apparently being more critical to the crop under water restriction condition. The degree of water stress can increase the susceptibility to salinity and plants can be considered, in general terms, as moderately tolerant to the effects of salinity, when combined with water deficiency. Coconut seedlings show full capacity of establishment in PIMN saline soils, corresponding to the level of electrical conductivity of 6.50 dS m<sup>-1</sup>, but only when the water supply remains adequate. For higher salinity levels, plants survive, but their size is reduced by around 50%, even when fully irrigated.

**Index terms:** *Cocos nucifera* L., initial growth, multiple stresses, salinity, drought.

## ESTABELECIMENTO DE PLANTAS JOVENS DE COQUEIRO-“ANÃO- VERDE” EM SOLOS AFETADOS POR SAIS E SOB DEFICIÊNCIA HÍDRICA

**RESUMO** - Objetivou-se analisar a capacidade de estabelecimento de plantas jovens de coqueiro, cultivar “Anão-Verde”, em solos afetados por sais e sob deficiência hídrica, mediante a avaliação da área foliar, da produção e da alocação de biomassa. No experimento, conduzido em ambiente protegido, em Fortaleza-CE, avaliaram-se, sob delineamento estatístico de blocos casualizados, no arranjo de parcelas subdivididas, os efeitos de diferentes níveis de deficiência hídrica (parcelas), mediante a imposição de distintos percentuais de reposições das perdas de água por evapotranspiração potencial da cultura - ET<sub>pc</sub> (20; 40; 60; 80 e 100%), associados às subparcelas, constituídas pelos crescentes níveis de salinidade do solo (1,72; 6,25; 25,80 e 40,70 dS m<sup>-1</sup>), proporcionados pelos solos coletados nos diferentes pontos do Perímetro Irrigado Morada Nova - PIMN. A área foliar e a produção de biomassa das plantas são acentuadamente reduzidas pelas condições de restrição hídrica e de elevada salinidade do solo, sendo aparentemente mais crítica à cultura a condição de restrição hídrica. O grau de estresse hídrico é capaz de acentuar a suscetibilidade à salinidade, e as plantas qualificam-se, em termos gerais, como moderadamente tolerantes aos efeitos decorrentes da salinidade, quando combinados com a deficiência hídrica. As plantas jovens de coqueiro mostram plena capacidade de estabelecimento nos solos salinizados do PIMN, até o nível de condutividade elétrica correspondente a 6,50 dS m<sup>-1</sup>, porém apenas quando o suprimento hídrico se mantém adequado. Para os níveis de salinidade mais elevados, as plantas sobrevivem; contudo, o porte das mesmas reduz-se em torno de 50%, mesmo quando plenamente irrigadas.

**Termos para Indexação:** *Cocos nucifera* L., crescimento inicial, múltiplos estresses, salinidade, seca.

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## INTRODUCTION

Currently, salinity is seen as one of the major abiotic agents capable of compromising the performance of crops, greatly in arid and semiarid regions. This process is associated with the excessive accumulation of salts, being routinely indicated as a direct implication of inadequate management of soil and water resources, even leading to the abandonment of such areas for becoming unsuitable for farming (Coelho et al., 2014).

Salt stress causes progressive decrease in plant growth, possibly caused by decrease in osmotic potential and / or excessive accumulation of ions, which can induce ionic toxicity, nutritional imbalance or both (Souza et al., 2014).

A practice that can enable the use of saline soils is the use of species and / or varieties that have good tolerance to this abiotic factor (Cruz et al., 2003). Among the cultivated species, coconut (*Cocos nucifera* L.) has been suggested as having potential for growing in areas affected by salts, taking into account existing plantations confirmed in high-salinity areas, such as coastlines, for example. In addition, some research results have shown the adaptation of coconut to irrigation with high-salt waters (MARINHO et al., 2005).

Coconut is considered one of the perennial species of greatest importance worldwide, since its cultivation has the capacity to generate employment and income in many countries through the consumption of fresh fruits or “coconut water”, or by the fruit processing, and the use of other plant parts, such as root, stipe, inflorescence, leaf and palm heart, originating more than 100 products and by-products of significant economic value. In addition, coconut is used as an ornamental plant, adorning private and public spaces (SILVA; JERÔNIMO, 2012).

Under field conditions, plants are routinely submitted to a combination of different abiotic stresses, greatly in arid and semiarid regions, as it relates to water supply, primarily for water deficit (MUNNS, TESTER, 2008).

According to Echer et al. (2010), water deficit is one of the most severe environmental stresses, being potentially able to harm even more than all the other stresses combined due to water essentiality and implications observed in plant growth and productivity in conditions of water scarcity. This underscores the importance of evaluating the performance of the plant species regarding their tolerance to low water content in the soil, in combination with other stressors, such as salinity, for example (Souza et al., 2011).

Processes that result in plant growth are especially sensitive to the effects of water deficit and salinity, so that growth rate and biomass production are good criteria for evaluating the degree of stress, because they allow inferences about the plant capacity to tolerate these adverse conditions (SCALON et al., 2011).

Although there are many publications on water deficit (GOMES et al, 2010;. GOMES, PRADO, 2007) and salinity of irrigation water in coconut crops (LIMA, 2014;. MARINHO et al, 2005), works that relate tolerance or adaptation of species to conditions of interactions between abiotic stresses inherent to arid and semi-arid regions, such as water deficit and soil salinity, are still scarce in literature.

In this context, this work aims to support the selection of plant species of economic importance for revegetation of areas affected by salts in northeastern Brazil by assessing the capacity of establishment of young coconut plants “Dwarf-Green” cultivar under different water deficit and soil salinity combinations.

## MATERIAL AND METHODS

The experiment was conducted in greenhouse-type protected environment between October 2013 and February 2014 at the Experimental Area belonging to the Department of Agricultural Engineering, Pici Campus, Federal University of Ceará, Fortaleza-CE, in the geographical coordinates: 03 ° 45 ‘S; 38 ° 33 ‘W and 19 m asl.

Inside the greenhouse, the average temperature, relative humidity, light and water evaporation values, measured in Class A type tank during the experimental period were  $29.14 \pm 2.97$  ° C;  $68.48 \pm 12.60\%$ ;  $0.076 \pm 0.22$  W m<sup>-2</sup> (wavelength 555 nm) and  $5.70$  mm  $\pm$  0.70 day<sup>-1</sup>, respectively.

The experiment was conducted under experimental design of randomized blocks in a split plot arrangement, with plots consisting of different levels of water stress - D, by imposing five different percentages of replacement of water losses by potential crop evapotranspiration - ETpc (D1 = 100% of ETpc; D2 = 80% of ETpc; D3 = 60% of ETpc; D4 = 40% of ETpc and D5 = 20% of ETpc), and subplots consisted of increasing soil salinity levels - S (S1 = 1.72 dS m<sup>-1</sup>; S2 = 6.25 dS m<sup>-1</sup>; S3 = 25.80 dS m<sup>-1</sup> and S4 = 40.70 dS m<sup>-1</sup>). Six replicates, with one plant per pot, for a total of one hundred and twenty experimental units were used.

Coconut seedlings “Dwarf-Green” cultivar of *Brazil de Jiqui* at 40 days post-germination were transplanted to flexible plastic pots, with volumetric

capacity of 25 L, filled on average with 32.57 kg of Fluvisol soil type coming from four different points of the Morada Nova Irrigated Perimeter located in the municipalities of Morada Nova and Limoeiro do Norte, state of Ceará (5°10 'S, 38°22'W and 80 m asl). Soil samples were collected from pots for the characterization of the physical and chemical soil properties, which results are shown in Tables 1 and 2, respectively. According to results, chemical correction was performed with synthetic fertilizers. The applied amount was defined as Fontes et al. (1998), who suggest the use of 200 g of formulation containing 15-10 - 15 nitrogen, phosphorus and potassium, respectively. The equivalent of 30 g of FTE BR 12 commercial formulation was also applied to meet the requirements for micronutrients.

The drip irrigation system was adopted, using self-compensating emitters with nominal flow rate of 4 L h<sup>-1</sup>. The irrigation management method adopted was based on weather conditions. To determine the potential crop evapotranspiration - ETPC, the methodology proposed by Bernardo et al. (2006) was adopted. To determine the daily estimation of reference evapotranspiration - Eto, Class A type evaporimeter tank was used, installed inside the protected environment, considering the tank adjustment factor (Kt) of 1.0.

To determine the daily estimation of potential crop evapotranspiration - Etpc, cultivation coefficient (Kc) equal to 0.65 was adopted, which was determined by Miranda et al. (2007) for the stage corresponding to the vegetative development in the soil and weather conditions of Ceará.

After transplanting the coconut seedlings, the experiment was irrigated with water blade equivalent to 100% of the potential crop evapotranspiration - ETPoc in order to ensure the initial establishment up to the beginning of differentiation of treatments, which occurred 30 days after transplanting - DAT, by varying the irrigation time, controlled by independent valves.

All cultural and phytosanitary treatments required were performed (Fontes et al., 1998). At 120 days after transplanting, leaf area and biomass production and partitioning were evaluated. To determine leaf area, an area integrator (LI-3100, LI-Cor, Inc. Lincoln, NE, USA) was used. To determine plant biomass production, plants were harvested at ground level. After collection, each plant was divided into shoot and roots, and then packaged in paper bags and left to dry in an oven with forced air circulation, keeping the temperature from 65 to 70 ° C up to obtaining constant mass.

With dry biomass data, the root: shoot ratio

was estimated (relationship between dry weight of root and shoot<sup>-1</sup>) and the salinity tolerance indexes proposed by Gheyi et al. (2010). For the calculation of these ratios, treatment with lower salinity (1.72 dS m<sup>-1</sup>) and appropriate water supply was used as a reference (ETpc 100%).

Data obtained were submitted to analysis of variance. As significant effect was denoted, data were analyzed by linear regression. When significant effect on interactions among factors studied was observed, data were analyzed according to procedures inherent to multiple linear regression analysis, and response surfaces were plotted.

The mathematical models were chosen based on the significance of regression coefficients using the “t” test in the determination coefficient and biological phenomenon under study. Statistical analyses were performed with the help of the Microsoft Excel (version 2007), ASSISTAT (version 7.6 beta) and STATISTICA software (version 7.0).

## RESULTS AND DISCUSSION

The summary of the analysis of variance for leaf area - LA (m<sup>2</sup> plant<sup>-1</sup>), root dry biomass - BSR (g plant<sup>-1</sup>), shoot dry biomass - BSPA (g plant<sup>-1</sup>), total dry biomass - BST (g plant<sup>-1</sup>), and the dry biomass / shoot dry biomass ratio (BSR BSPA<sup>-1</sup>), and it was found that the variation of the main effects of water deficit and soil salinity was significant by the F test ( $p \leq 0.05$  and  $p \leq 0.01$ ) in almost all the above variables, except for the isolated influence of drought on variable root dry biomass ( $p \geq 0.05$ ). In addition, the water deficit x soil salinity interaction was always significant ( $p \leq 0.01$ ) as a result of the dependence between these factors, according to the F test (Table 3).

Figure 1a and Table 4 show the response surface and its mathematical model for variable leaf area - AF (m<sup>2</sup> plant<sup>-1</sup>) in response to combinations of different levels of water stress and soil salinity 120 days after transplanting.

According to the proposed mathematical model, the coconut leaf area is linearly increased by 0.0019 m<sup>2</sup> plant<sup>-1</sup> at each unitary increase of ETpc and also linearly reduced, with decreases of approximately 0.0004 m<sup>2</sup> plant<sup>-1</sup> at each increase in EC, and the association of effects reflected in reductions in leaf area of the order of 2.35. 10<sup>-5</sup> m<sup>2</sup> plant<sup>-1</sup> at every association of isolated factors (Figure 1a; Table 4).

Thus, the response surface analysis for the coconut leaf area data, regarding the associations of stress factors water deficit and soil salinity, allows

predicting that the variable in question, although influenced by the interactions among them, proved to be more sensitive to water deficit effects in detriment of soil salinity effects (Figure 1a; Table 4).

This can be seen due to the expression of slope gradients of lines that make up the response surface, and the mathematical parameters of the model are more expressive for the water deficit levels when compared to soil salinity levels (Figure 1a).

For variable leaf area, it was estimated that the level of water replacement that provides maximum value for this variable ( $0.3428 \text{ m}^2$  per plant) is 100% ET<sub>pc</sub> associated to salinity of  $1.72 \text{ dS m}^{-1}$ . Moreover, the combination of the highest water supply level (100% ET<sub>pc</sub>) and maximum soil salinity value ( $40.70 \text{ dS m}^{-1}$ ) results in lower leaf area values ( $0.1200 \text{ m}^2$  per plant), which is approximately 65% lower compared to the maximum value obtained for this variable (Figure 1a; Table 4).

As salinity generally shows morphological symptoms similar to water stress, it could be inferred that the reduced leaf expansion can be a survival strategy able to allow water conservation during critical periods, since lower leaf surface results in reduction of total transpired water (Oliveira et al., 2012). Mesquita et al. (2012) reported that reduced leaf area is also convenient to plants for reducing  $\text{Na}^+$  and  $\text{Cl}^-$  charging in the xylem and enabling water conservation in plant tissues.

For results obtained in this study, it could be assumed that the significant interaction found between water deficit stress and soil salinity contributed to the adverse effects of salinity and specifically for variable leaf area. Its dramatic reduction in higher salinity levels reflects the outstanding osmotic potential effect of the soil solution, inhibiting the water absorption by the plant, since applying less water, especially in the more severe water deficit conditions results in less dilution of salts present in the soil, reducing the osmotic potential, therefore reducing the capacity to absorb water through the root system (Farias et al., 2003).

Furthermore, under suitable water supply conditions, this effect was lessened, considering that for electrical conductivity of  $40.70 \text{ dS m}^{-1}$ , the leaf area measured under condition of 100% ET<sub>pc</sub> showed higher value of approximately 74% when compared to that obtained under severe water stress conditions (20% ET<sub>pc</sub>). A similar response was verified in lower salinity condition ( $1.72 \text{ dS m}^{-1}$ ), in which the application of 100% ET<sub>pc</sub> provided greater leaf area of approximately 63% of that obtained at 20% ET<sub>pc</sub> (Figure 1a, Table 4).

However, the lower leaf area of plants grown

under the mutual influence of 100% ET<sub>pc</sub> and  $\text{EC} = 40.70 \text{ dS m}^{-1}$  compared to association of 100% ET<sub>pc</sub> and  $\text{EC} = 1.72 \text{ dS m}^{-1}$  ratifies the effect of salt concentration, to the point of restricting the magnitude of variable response regarding to water supply, again highlighting the significant effect of soil salinity on this variable.

It is noteworthy that damages caused by excess salt in vegetables occur not only due to osmotic and even oxidative effects, but may also occur as a result of direct and / or indirect toxic and nutritional effects. These components, together, will directly reflect on the leaf area production, given that the damages mentioned absolutely compromise the prosperity of photosynthetic processes, which are directly responsible for the production of photoassimilates to be used in the growth of the different plant organs and for the emergence of new leaves (QUEIROGA et al., 2006).

These results are consistent with those obtained by Silva Júnior et al. (2002), who evaluated the effects of water stress and irrigation with water of different salinity levels on "Gigante-do-Brasil" coconut responses and found that one of the first consequences of water stress and the accumulation of salts in the soil for the species was reduction in leaf area, to which is attributed loss of leaves and reduction in the emergence of new leaves, as a strategy to adapt to stressors.

For variable root dry biomass, Figure 1b and Table 4 showed positive and significant linear effects for ET<sub>pc</sub> and EC factors, with estimated increases of  $0.0186$  and  $0.0102 \text{ g plant}^{-1}$ , for each respective unit increment in the above factors, and the interaction between them also resulted in positive linear effects, with contribution of  $0.0008 \text{ g plant}^{-1}$ , also due to increases in combined factors. However, the adjustment of the regression equation showed low determination coefficient ( $R^2 = 0.3283$ ), despite the significance of parameters estimated in the model.

Based on results (Figure 1b; Table 4), it was estimated that the lowest value ( $14.22 \text{ g plant}^{-1}$ ) was obtained in plants submitted to association between 40% ET<sub>pc</sub> and  $\text{EC} 25.80 \text{ dS m}^{-1}$ , while the highest value ( $18.61 \text{ g plant}^{-1}$ ) was observed in plants without water restriction (100% ET<sub>pc</sub>) at the highest salt levels ( $40.70 \text{ dS m}^{-1}$ ).

The results of this study do not agree with those of Echer et al. (2010), who reported that among the basic mechanisms adopted by plants to resist drought, the increase and / or the deepening of roots stands out, either by growth (cell elongation) or dry weight gain (growth and increased thickness of cell walls), given that in this case, the water supply,

expressed by increments in ETpc tended to result in increases in root biomass values.

Regarding the effects of salinity, it was found that the increase in the electrical conductivity of the soil saturation extract provided stimuli to root development, which was reflected in increased root biomass (Figure 1b; Table 4).

These increases in root dry biomass due to the saline treatment imposed to the culture are more related to an apparent morphological strategy adopted by the species under adverse conditions, with the likely purpose of absorbing water, even under low osmotic potential conditions. The results obtained in this study contradict the general trends presented by plants, given that the effects of salinity on root growth are almost always harmful due to the reduced expansion of cell walls of roots, commonly observed under salt conditions (MOSQUE et al., 2012). For these authors, roots are highly susceptible to salt stress, given that the action of this stressor results in considerable decrease in dry biomass, since the root growth is characterized by a high metabolic activity, coupled with the fact that the root is actually the only plant organ directly exposed to excess salts in the soil.

The effect of the interaction among study factors allows inferring that the greater accumulation of biomass in the root system resulted from the association between higher levels of water replacement and salinity, highlighting the influence of water availability, which is observed by the high value for this parameter in the mathematical model, coupled with the higher slope gradient shown in Figure 1b.

Given this response, it is assumed that adequate water supply is able to mitigate any possible deleterious effects inherent to salinity on the root dry biomass and maximize the response amplitude under high salinity conditions (Figure 1b).

The significant interaction between factors water stress x salinity for the shoot dry biomass (BSPA) is shown in Figure 1c. The mathematical model to which data are better suited for plants grown under variations in the levels of the study factors was the linear model, whose additions on BSPA were  $0.8782 \text{ g plant}^{-1}$  for each unit increase in ETpc. When plants were submitted to increasing salinity, there was a decrease in BSPA values by  $0.3984 \text{ g plant}^{-1}$  for each EC unit increase (Table 4).

In addition, the association between ETpc and EC strengthened the harmful effects of salinity, leading to declines of approximately  $0.0221 \text{ g plant}^{-1}$ , given the respective unit increments. However, we must again emphasize the most pronounced effect

of water deficit at the expense of soil salinity on this variable (Table 4).

It was estimated that the lowest values for this variable ( $47.21 \text{ g plant}^{-1}$ ) was obtained in the association of 60% ETpc and salinity level corresponding to  $25.80 \text{ dS m}^{-1}$ , whereas cultivation under 100% ETpc and salinity equivalent to  $1.72 \text{ dS m}^{-1}$ , led to higher shoot biomass production ( $130.49 \text{ g plant}^{-1}$ ), which in turn is higher than by about 176.40% when compared to the latter (Figure 1C, Table 4).

Water restriction acts reducing the speed of physiological and biochemical processes in the plant, and as a result, coconut plants in reduced water supply conditions have lower shoot development. Water stress restricts dry matter production and this reduction depends, in part, on the proportions with which water stress has affected areas of photosynthetic activity (COSTA; PINHO; PARRY, 2008).

Regarding the effect of salinity on this variable, it could be considered that the reduced shoot biomass, given the increasing EC levels, is a direct implication of the reduced photosynthetic rate and the deviation of part of energy that would be designated to growth for the activation and maintenance of a number of metabolic activities which together are capable of providing the plant adaptation to salinity. Among these changes, the following stand out: maintaining the integrity of membranes, synthesis of organic solutes for osmoregulation and / or protection of macromolecules and regulation of transport and ion distribution in various organs or even inside the cells (SILVA JÚNIOR et al., 2012).

Unlike what was observed in root dry biomass, associations between levels of study factors indicate the probable antagonism between water favoritism and salinity, regarding the accumulation of dry biomass in shoots; considering that the increase in the saline level restricted the expression of the plausible beneficial effect exerted by the increase in water supply, indicating, therefore, reductions in the response expression over the salinity gradient (Figure 1c).

Figure 1d shows the response surface for total dry biomass, expressed in  $\text{g plant}^{-1}$  of coconut seedlings “Green Dwarf” cultivar in response to combinations of different water stress and soil salinity levels 120 days after transplanting. According to the linear model proposed for the factors studied, increases followed by decreases in this variable for unit increments of ETpc and EC, with contributions of about  $0.8723$  and  $-0.3649 \text{ g plant}^{-1}$ , respectively, and the interaction among the factors responsible

for restricting, even more intensely, dry biomass production under stressful factors, with estimated decreases of approximately  $0.0213 \text{ g plant}^{-1}$  (Table 4).

In the total dry biomass production, it is possible to estimate that the point of maximum value ( $145.15 \text{ g plant}^{-1}$ ) was found in the water replacement level corresponding to 100% ET<sub>pc</sub> and soil salinity of  $1.72 \text{ dS m}^{-1}$ ; however, the lowest values ( $63.09 \text{ g plant}^{-1}$ ) was obtained as a result of association between the level corresponding to 20% ET<sub>pc</sub> and soil salinity of  $40.70 \text{ dS m}^{-1}$ , which, in turn, is lower by approximately 57% when compared with each other (Figure 1d; Table 4).

The response surface study for total dry biomass production showed the opposite relationship between the study factors, whereas under conditions of high salt content in the soil even with the increase in water availability, dry biomass production was sharply, antagonistically and reciprocally restricted. Under low salinity conditions, water scarcity ends up by limiting the total dry biomass production potential of coconut seedlings (Figure 1d; Table 4). This assertion can be confirmed when considering the estimated increase in dry biomass production between levels corresponding to 20 and 100% ET<sub>pc</sub> was approximately 92% under low salinity conditions (1.72%), while under high salinity conditions ( $40.70 \text{ dS m}^{-1}$ ), this increase was restricted to only about 14%.

In coconut tree, one of the first responses to water stress deriving from water scarcity and / or high salt content is the stomatal closure, since the diffusive resistance to water vapor reduces transpiration and reduces the photosynthetic capacity, since  $\text{CO}_2$  supply becomes low. This will reflect in growth, a fact also evidenced by the performance shown by variable leaf area and even more evident in the dry biomass production yield (Gomes et al., 2010). Thus, it is believed that stomata and leaf area influence plant biomass production. Regarding the first factor, because it controls  $\text{CO}_2$  absorption; and second, because it determines the light interception potential (COSTA; MARENCO, 2007).

In addition, according to Silva and Amorim (2009), the high concentration of ions in soil can cause the breakdown of the water potential balance of the soil-plant system and also ionic imbalance, causing toxicity and obstacles to growth and biomass production, possibly due to restrictions in the acquisition of essential nutrients.

Regarding the main effects of soil salinity, it could be considered that these results are consistent with those obtained by Lima (2014), who assessed five salinity levels in irrigation water of coconut crop

(0.9, 5.0, 10.0, 15.0 and  $20.0 \text{ dS m}^{-1}$ ) during the phase of seedling formation and found that, for total dry biomass production, significant influence of salinity levels were observed, with decreasing linear behavior with increasing salinity of irrigation water.

These results are also consistent with Marinho et al. (2005), who found that different salinity levels of irrigation water (2.2, 5.0, 10.0, 15.0 and  $20.0 \text{ dS m}^{-1}$ ) during the initial growth of coconut plants "Green Dwarf" cultivar significantly affected the total biomass production, reducing it linearly.

According to Gomes et al. (2010), in coconut tree, as short-term responses to water stress, reductions in stomatal conductance are observed. According to the authors, such occurrences often impair photosynthesis and transpiration, causing, among undesirable consequences, reductions in leaf expansion, biomass accumulation, and changes in biomass partitioning patterns among the different plant parts.

The responses to dry biomass production of coconut crop under the interactive conditions of abiotic stressors salinity and water deficiency, also show the sensitivity of the culture to these stresses and confirm the hypothesis also proposed by Syvertsen and Garcia-Sanchez (2014) that the responses of plants to simultaneous stresses may have the effect of increasing the susceptibility to salinity and / or water deficit. For the authors, drought and salinity are often considered as stress factors for plants.

This inference is consistent and better justified relying on inductions of Srivastava and Singh (2009), who reported that restricted water availability in saline soil increases the toxicity to salts, which can severely restrict the acquisition of ground water and therefore, the resistance capacity of plants to water stress. According to the authors, the implications of salinity on plant growth directly reflect in biomass production and are not restricted only to aspects related to effects of osmotic nature.

In addition, reductions in growth and / or biomass production may also be related to a gradual accumulation of toxic  $\text{Cl}^-$  ions and  $\text{Na}^+$  levels in leaves. In this organ, salts may accumulate in the apoplast and dehydrate cells, and may also be retained in the cytoplasm and chloroplasts, inhibiting the activity of enzymes involved in photosynthetic processes, directly affecting carbohydrate metabolism. In short, these changes will reflect in the biomass production by the species (MUNNS, TESTER, 2008).

Figure 1e and Table 4 show the response surface and its mathematical model adjusted for variable root and shoot dry biomass ( $\text{BSR BSPA}^{-1}$ ),

as a function of the levels of ETpc and EC factors evaluated.

The mathematical model that best fits data of this variable proposed linear decreases and increases of approximately 0.0020 and 0.0012 units for each increase in ETpc and EC, respectively; and parameter related to the ETpc x EC association, decreases of  $-5.76 \times 10^{-5}$  units were estimated for each respective simultaneous increase in the levels of the study factors (Table 4; Figure 1e).

It was estimated that the highest value (0.3711) was obtained by the association between 60% ETpc and  $EC = 25.8 \text{ dS m}^{-1}$ . In contrast, the lowest values (0.1118), lower by approximately 70%, was obtained under optimal water supply conditions (100% ETpc) in the lowest salinity level ( $1.72 \text{ dS m}^{-1}$ ).

These results support the inferences of Reis et al. (2006), who reported that the root shoot<sup>-1</sup> ratio may increase with increasing water stress, given that it is expected that plants have more developed root system when grown under severe water deficits. Thus, according to the estimated mathematical model, the water favoring represented by the increment in ETpc tends to reduce the of the root dry biomass shoot<sup>-1</sup> ratio value (Table 4; Figure 1e).

Additionally, Scalón et al. (2011) reported that in water stress conditions, root growth is prioritized, which reflects the higher allocation of photoassimilates to the roots in order to facilitate the water absorption and minimize water loss through transpiration, and the high root shoot<sup>-1</sup> ratio is a major feature able to give plants greater survivability under water stress.

Contrary to the behavior of this variable for the water favoring, the root dry biomass shoot<sup>-1</sup> ratio was positively related to soil salinity levels, indicating a probable change in the allocation of dry biomass in favor of roots at the expense of shoots, before increasing EC levels (Figure 1e; Table 4).

Cruz et al. (2003) reported that the importance of maintaining high root shoot<sup>-1</sup> ratio in plants grown under saline conditions has been the subject of discussions in literature. For some authors, greater investment in biomass in the root system can benefit plant growth, given the possibility that this strategy gives plants the ability to explore a larger soil volume, providing access to water and essential mineral elements. This is particularly important in soils with limited ability to supply nutrients, such as in soil with high salt concentration (SOUSA et al., 2009).

Under adverse soil salinity conditions; however, the greater root growth can induce

increased absorption of  $\text{Na}^+$  and  $\text{Cl}^-$  ions, reaching even toxic levels to plant species, coupled with the fact that the consequent transport to shoots may impair the growth of all other plant parts (Coelho et al., 2014).

As for the simultaneous action of factors under study, there is an increase in the root dry biomass shoot<sup>-1</sup> ratio, as the soil salinity levels increased. In contrast, with the highest percentages of replacement of water loss through evapotranspiration, the ratio was reduced even at low salt concentration, and this effect is increased as the salt content in the soil is high, which confirms the antagonism between water availability and soil salinity on the expression of the variable responses (Figure 1e; Table 4).

Table 5 shows the relative reduction in dry biomass production - RP, expressed as percentage, and the classification of the salt tolerance of young plants of coconut “Green Dwarf” cultivar in response to combinations of different levels of water stress and soil salinity levels, according to Gheyi et al. (2010).

According to results, it could be inferred that, in general, young coconut plants seem to be moderately tolerant to the salinity effects on total dry biomass production, with average percent reduction of 35% compared to the association of control treatments (100% ETpc,  $1.72 \text{ dS m}^{-1}$ ). However, the analyses of values obtained in the reduction of total dry biomass in various combinations of treatments allow concluding that, of the total, in 25% of interactions among treatments, coconut seedlings were classified as tolerant to salinity, 30% as moderately tolerant and 45% as moderately susceptible.

Table 5 shows that the degree of water stress is able to enhance the susceptibility to salinity because when comparing the production values that determine the classification of salinity tolerance to extreme water deficit (20 and 100% ETpc), it appears that plants grown in the most severe water stress level (20% ETpc) showed moderate susceptibility to salinity, with reductions in total dry biomass production between 41 and 60 %, regardless of the salinity level. Under ideal water supply conditions (100% ETpc), plants only began to show moderate susceptibility to salinity from electrical conductivity level of  $25.80 \text{ dS m}^{-1}$ .

Similarly, the interaction between water deficit and salinity levels that resulted in tolerance to salinity coincided precisely with the lowest soil salinity levels ( $1.72$ ;  $6.25 \text{ dS m}^{-1}$ ) associated to meeting at least 60% of the crop water requirements.

On the other hand, young coconut plants show moderate salinity tolerance at electric conductivity

level of 40.70 dS m<sup>-1</sup>, where the water requirements (% ET<sub>pc</sub>) were partially met with values between 60 and 80%, whereas full compliance with water requirements (100% ET<sub>pc</sub>) characterizes the species as moderately susceptible to excess salts.

Lima (2014) classified coconut as tolerance to salinity of irrigation water up to electrical conductivity value of 5 dS m<sup>-1</sup>, whereas at 10 dS m<sup>-1</sup>, the crop exhibited percentage reductions of total

dry matter production that qualifies it as moderately tolerant. Such differences, when compared to results obtained here, may be attributed to the fact that salinity imposed on plants comes from irrigation water, whereas, in the present survey, soil salinity may have increased the adverse effects that this abiotic stress gives the plant species, resulting as response, in greater restrictions to dry biomass production.

**TABLE 1-** Hydro-physical attributes of soils used as substrates for the cultivation of coconut seedlings “Green Dwarf” cultivar in the experiment. Fortaleza, Ceará, 2013/2014.

Salinity	Granulometric composition			Textural class	Density		Humidity	
	Sand	Silt	Clay		Soil	Particles	33 kPa	1.500 kPa
	(----- g kg <sup>-1</sup> -----)				(-)	(--- kg dm <sup>-3</sup> ---)		(--- m <sup>3</sup> m <sup>-3</sup> ---)
S1	608	231	239	Sandy clay loam	1.23	2.52	19.59	12.10
S2	532	285	332	Sandy clay loam	1.33	2.56	19.63	11.55
S3	605	272	225	Sandy clay loam	1.38	2.60	16.41	9.11
S4	459	368	219	Loam	1.27	2.59	23.43	12.78

**TABLE 2-** Chemical attributes of soils used as substrates for the cultivation of coconut seedlings “Green Dwarf” cultivar in the experiment. Fortaleza, Ceará, 2013/2014.

Salinity	pH	CE (dS m <sup>-1</sup> )	Sorption complex					
	(Water)		Ca <sup>2+</sup>	Mg <sup>2+</sup>	K <sup>+</sup>	Na <sup>+</sup>	H <sup>+</sup> + Al <sup>3+</sup>	Al <sup>3+</sup>
	(-)		(----- cmol <sub>c</sub> kg <sup>-1</sup> -----)					
S1	6.8	1.72	6.58	4.34	0.06	4.32	2.56	0.00
S2	7.5	6.25	7.80	5.24	0.08	7.23	0.00	0.00
S3	7.4	25.80	7.51	5.69	0.05	15.78	0.00	0.00
S4	7.0	40.70	14.91	4.58	0.07	22.46	0.00	0.00

Salinity	S	T	V	PST	C	M.O.	P <sub>Assimilable</sub>	Classification
	(--- cmol <sub>c</sub> kg <sup>-1</sup> ---)	(--- % ---)	(--- g kg <sup>-1</sup> ---)	(mg kg <sup>-1</sup> )				
S1	15.30	17.86	86	24	12.26	21.13	30	Sodic
S2	20.35	20.35	100	36	16.64	28.66	30	Saline - sodic
S3	29.03	29.03	100	54	9.22	34.88	69	Saline - sodic
S4	42.02	42.02	100	53	20.23	34.88	82	Saline - sodic

<sup>1</sup>pH - hydrogenionic potential; EC - Electrical conductivity of soil saturation extract; S - sum of bases; T - cation exchange capacity; V - base saturation; PST - exchangeable sodium percentage; C - organic carbon; O.M. - organic matter; P<sub>Assimilable</sub> - Assimilable phosphorus; Classification - According to Gheyi et al., 2010.



**TABLE 3-** Summary of analyses of variance for leaf area data - LA (m<sup>2</sup> plant<sup>-1</sup>); root dry biomass - BSR (g plant<sup>-1</sup>); shoot dry biomass - BSPA (g plant<sup>-1</sup>); total dry biomass - BST (g plant<sup>-1</sup>); root dry biomass shoot<sup>-1</sup> ratio (BSR BSPA<sup>-1</sup>) of coconut seedlings “Green Dwarf” cultivar grown under different water stress and salinity levels 120 days after transplanting. Fortaleza, Ceará, 2013/2014<sup>1</sup>.

FV	GL	Average Squares				
		LA	BSR	BSPA	BST	BSR BSPA <sup>-1</sup>
Blocks	5	0.00122 <sup>ns</sup>	7.58 <sup>ns</sup>	64.8 <sup>3ns</sup>	45.40 <sup>ns</sup>	0.00432 <sup>ns</sup>
Water deficit (D)	4	0.05875 <sup>**</sup>	8.21 <sup>ns</sup>	5.736.23 <sup>**</sup>	5.871.76 <sup>**</sup>	0.02694 <sup>**</sup>
Residue - D	20	0.00064	4.57	49.51	47.41	0.00205
Plots	29					
Soil salinity (S)	3	0.01476 <sup>**</sup>	9.31 <sup>*</sup>	9.336.17 <sup>**</sup>	9.161.10 <sup>**</sup>	0.05071 <sup>**</sup>
D x S Interaction	12	0.00591 <sup>**</sup>	6.67 <sup>*</sup>	3.103.35 <sup>**</sup>	2.973.22 <sup>**</sup>	0.02818 <sup>**</sup>
Residue - S	75	0.00061	3.16	66.97	61.47	0.00254
Total	119					
V.C. - D (%)		11.96	13.43	8.70	12.23	20.43
V.C. - E (%)		11.73	11.16	10.12	11.90	22.73

<sup>1</sup> (\*\*) significant at 1% probability; (<sup>ns</sup>) not significant by the “F” test

**TABLE 4-** Regression equations corresponding to the response surfaces for the following variables: leaf area - LA (m<sup>2</sup> plant<sup>-1</sup>); root dry biomass - BSR (g plant<sup>-1</sup>); shoot dry biomass - BSPA (g planta<sup>-1</sup>); total dry biomass - BST (g plant<sup>-1</sup>), root dry biomass shoot<sup>-1</sup> ratio (BSR BSPA<sup>-1</sup>) (dimensionless) of coconut seedlings “Green Dwarf” cultivar in response to combinations of different water deficit - ETpc (%) and soil salinity levels - EC (dS m<sup>-1</sup>), 120 days after transplanting of seedlings. Fortaleza, Ceará, 2013/2014<sup>1</sup>.

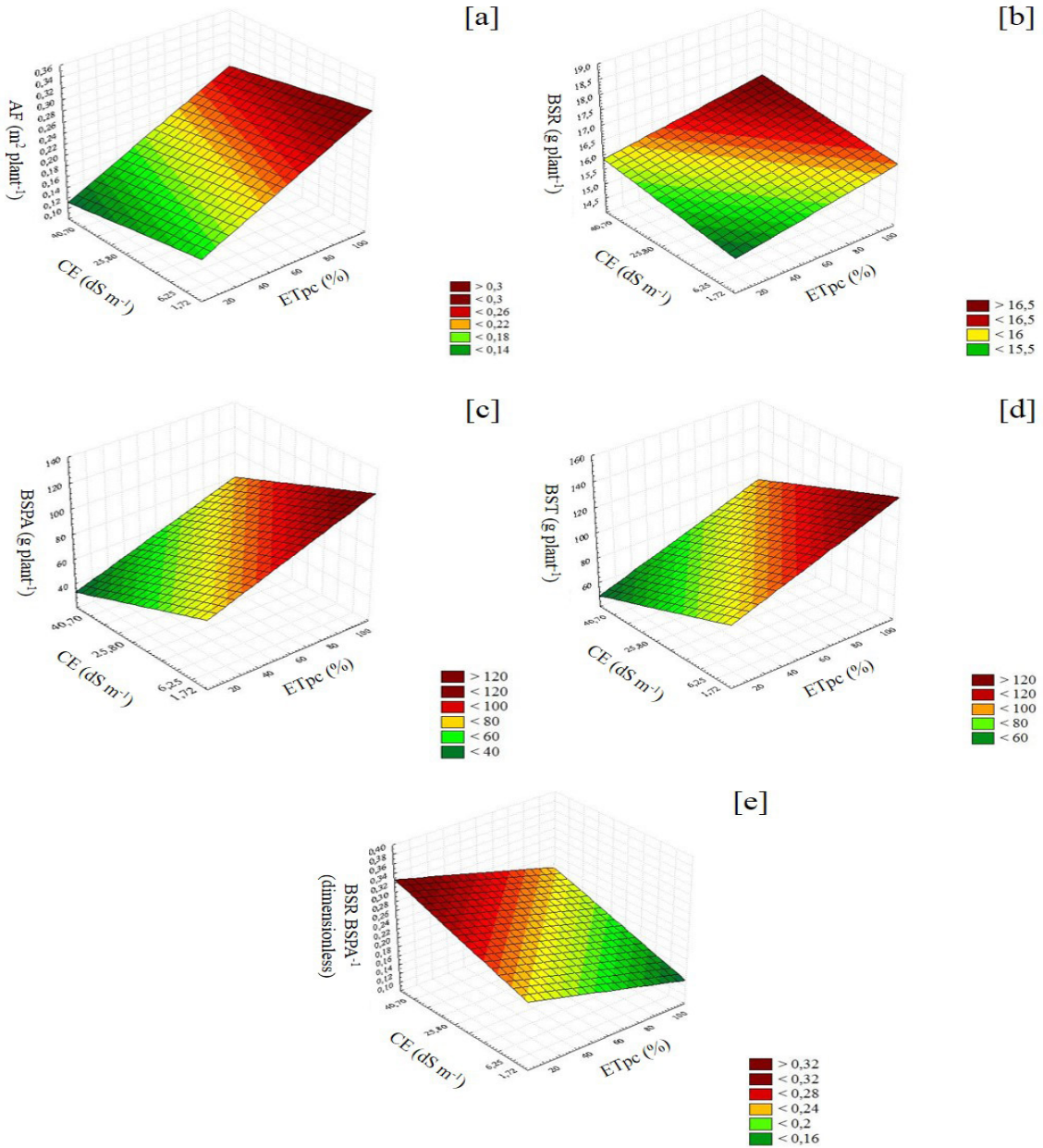
Regression equations	R <sup>2</sup>
AF = 0.1173* + 0.0019* ETpc - 0.0004*EC - 2.35 . 10 <sup>-5</sup> *ETpc . EC	0.7023
BSR = 14.8602* + 0.0186* ETpc + 0.0102*EC + 0.0008*ETpc . EC	0.3283
BSPA = 45.4378* + 0.8782* ETpc - 0.3984*EC - 0.0221*ETpc . EC	0.6528
BST = 61.4320* + 0.8723* ETpc - 0.3649*EC - 0.0213*ETpc . EC	0.6550
BSR BSPA <sup>-1</sup> = 0.3022* - 0.0020* ETpc + 0.0012*EC - 5.76 . 10 <sup>-5</sup> *ETpc . EC	0.5153

R<sup>2</sup> - Determination coefficient; \* - Significant at 5% probability by the “t” test.

**TABLE 5-** Reduction of total dry biomass production - RP (%) and classification of tolerance to salinity saplings of coconut seedlings “Green Dwarf” cultivar in response to combinations of different water stress and soil salinity levels 120 days after transplanting. Fortaleza, Ceará, 2013/2014<sup>1</sup>.

Water stress (% ETpc)	Soil salinity (dS m <sup>-1</sup> )				Averages
	1,72	6,25	25,80	40,70	
20	41 (MS)	48 (MS)	50 (MS)	54 (MS)	48 (MS)
40	37 (MT)	39 (MT)	42 (MS)	43 (MS)	40 (MT)
60	5 (T)	38 (MT)	40 (MT)	31 (MT)	29 (MT)
80	0 (T)	8 (T)	43 (MS)	34 (MT)	21 (MT)
100	Control	3 (T)	54 (MS)	57 (MS)	28 (MT)
Averages	21 (MT)	27 (MT)	46 (MS)	44 (MS)	35 (MT)

<sup>1</sup> Classification of tolerance to salinity according to Gheyi et al. (2010): (T) = tolerant [0% to ≥ 20% ≤ RP]; (MT) = Moderately tolerant [21% ≥ RP ≤ 40%]; (MS) = Moderately susceptible [41% ≥ RP ≤ 60%]; (S) = Susceptible [PR ≥ 61%].



**FIGURE 1-** Response surfaces for the following variables: leaf area - LA (m<sup>2</sup> plant<sup>-1</sup>); root dry biomass - BSR (g plant<sup>-1</sup>); shoot dry biomass - BSPA (g planta<sup>-1</sup>); total dry biomass - BST (g plant<sup>-1</sup>), root dry biomass shoot<sup>-1</sup> ratio (BSR BSPA<sup>-1</sup>) (dimensionless) of coconut seedlings “Green Dwarf” cultivar in response to combinations of different water stress (ETpc) and soil salinity levels (EC) 120 days after transplanting. Fortaleza, Ceará, 2013/2014.

## CONCLUSIONS

Leaf area and biomass production of coconut seedlings are sharply reduced by water restriction and high soil salinity conditions, apparently being more critical to the crop the condition of water restriction in detriment of the soil salinity.

The degree of water stress is able to increase the susceptibility to salinity and coconut plants are classified, in general terms, as moderately tolerant to the salinity effects when combined with water deficiency.

Coconut plants show full capacity of establishment in saline soils of PIMN up to electrical conductivity level corresponding to 6.50 dS m<sup>-1</sup>, but only when the water supply remains adequate. For higher salinity levels, the plants survive, but their size reduced around 50%, even when fully irrigated.

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