academicJournals

Vol. 11(23), pp. 1999-2006, 9 June, 2016
DOI: 10.5897/AJAR2016.10955
Article Number: 572DEB258888
ISSN 1991-637X

http://www.academicjournals.org/AJAR

**African Journal of Agricultural Research**

*Full Length Research Paper*

# Productivity and economic analysis of sunflower/maize crop rotation under different levels of salinity and nitrogen

**Hernandes de Oliveira Feitosa[1], Claudivan Feitosa de Lacerda[2]*, Albanise Barbosa Marinho[3], Raimundo Nonato Távora Costa[2], Clayton Moura de Carvalho[1] and Hans Raj Gheyi[4]**

[1]Technological Education Center Institute, Juazeiro do Norte, Fortaleza, Ceará, Brazil.
[2]Agricultural Engineering Department / Federal University of Ceará, Campus do Pici, CEP: 60.055-460, Fortaleza, Ceará, Brazil.
[3]Rural Development Institute / University of International Integration Lusophone African-Brazilian, Redenção, Ceará, Brazil.
[4]Nucleus of Soil and Water Engineering, Federal University of Recôncavo of Bahia, Cruz das Almas, Bahia, Brazil.

Received 2 March, 2016; Accepted 23 April, 2016

**This study aimed to assess the effect of salinity of irrigation water and nitrogen fertilization on yield and oil production of sunflower, cv. BRS 324, and yield of maize hybrid AG1051, as well as economic analysis of crop rotation (sunflower/maize). The experimental was laid out in a randomized complete block design in split plot with five replications, the plots were formed by five levels of electrical conductivity of the irrigation water (0.8, 2.2, 3.6, 5.0 and 6.4 dS $m^{-1}$) and the subplots by four rates of nitrogen (0, 25, 50 and 75 kg $ha^{-1}$), in sunflower crop. For maize crop the same design was used, studying on the same plots the residual effects of salts and four nitrogen rates (0, 108.5, 217 and 325.5 kg $ha^{-1}$). Sunflower was grown in dry seasons (2011 and 2012), while maize was grown in the rainy seasons (2012 and 2013). For the sunflower crop, the productivity and potential oil production showed the highest values when the plants were not salt-stressed and subjected to the maximum dose of nitrogen. But yield was decreased with increasing salinity, even with increasing the rate of nitrogen. For the maize crop, productivity was strongly influenced by increasing the rate of nitrogen; the leaching of salts, caused by rainfall, virtually eliminated any residual effect of the salts on this crop. A soil management system employing sunflower-maize crop rotation was found to be economically viable, being more attractive when using low saline water and the highest application rate of nitrogen.**

**Key words:** *Helianthus annuus* L., *Zea mays* L., salt stress, nitrogen fertilization, economic viability.

## INTRODUCTION

In Brazil and around the world, the demand for energy sources that meet the goals set by the Kyoto Protocol has generated the need to replace fossil fuels (the greatest generator of greenhouse gasses), by energy

*Corresponding author. E-mail: cfeitosa@ufc.br.

**Table 1.** Physical and chemical attributes of the soil in the experimental area.

| Attribute | Depth (m) | |
|---|---|---|
| | 0 - 0.30 | 0.30 - 0.60 |
| **Textural class** | **Sandy loam** | **Sandy clay loam** |
| Soil Density (kg $dm^{-3}$) | 1.39 | 1.42 |
| $Ca^{2+}$ ($cmol_c$ $dm^{-3}$) | 0.83 | 1.2 |
| $Mg^{2+}$($cmol_c$ $dm^{-3}$) | 0.82 | 0.80 |
| $Na^{+}$ ($cmol_c$ $dm^{-3}$) | 0.25 | 0.33 |
| $K^{+}$ ($cmol_c$ $dm^{-3}$) | 0.12 | 0.12 |
| ESP (%) | 5 | 7 |
| $H^{+}$+$Al^{3+}$ ($cmol_c$ $dm^{-3}$) | 2.0 | 2.4 |
| $Al^{3+}$ ($cmol_c$ $dm^{-3}$) | 0.30 | 0.45 |
| pH in water (1:2.5) | 5.6 | 5.4 |
| ECse (dS $m^{-1}$) | 0.20 | 0.28 |

$EC_{se}$, Electrical conductivity of saturation extract; ESP, exchangeable sodium percentage.

derived from biomass or other alternative sources (wind, solar radiation, etc.). As it is a renewable resource, and due to its sustainable use considerably reducing damage to the environment, there has been much research into the use of biodiesel in programs of renewable energy. Projections indicate Brazil as the country with the greatest potential in the production of vegetable oil for biodiesel, especially of oilseed crops such as castor bean, palm oil, sunflower and cotton, among others.

The European Union currently leads the market in the global production of biodiesel, despite the relative scarcity of arable land, designing its market for the addition of 8% biofuel by 2020, and with a focus on the environment. In Brazil, and around the world, competitiveness of the biodiesel market depends closely on tax exemption of the product, since production costs are higher compared to diesel.

In addition to economic problems, the productivity of oilseed crops is also hampered by such abiotic factors as water deficit, salinity and nutrient deficiency. Salinity is a common problem mainly in the soils and sources of water of semi-arid regions, and leads to reduced productivity in most crops due to the direct and indirect effects of a high concentration of salts on plant physiology and metabolism. This limits the expansion of irrigated agriculture, an extremely important factor in the development of these regions (Chen et al., 2009).

Mineral nutrition is another aspect that is directly linked to agricultural production, due to the high demand for nutrients such as nitrogen for obtaining high productivity. This problem becomes more complex under saline conditions, considering that the excess of certain ions in the root zone can affect the absorption of some essential elements; for example, an excess of Cl can limit the uptake of nitrates. On the other hand, the restrictions on growth caused by salinity also reduce the need for nutrients (Neves et al., 2009; Lacerda et al., 2016). This may increase nutrient loss, which is already quite high in non-saline environments.

Medium and long-term studies have demonstrated the need to work simultaneously with different management strategies under saline conditions, and particularly when using brackish water for irrigation. Among these strategies can be highlighted the use of tolerant or moderately tolerant crops, the use of crop rotation and the use of organic and mineral inputs. For example, the use of high doses of nitrogen has been suggested as a way to minimise the harmful effects of salinity (Gengmao et al., 2014), although this has not often been demonstrated by results (Lacerda et al., 2016).

The aim of present study was to evaluate the productivity and economic viability of sunflower/maize crop rotation, as a function of the salinity of the irrigation water used during the dry season. The survey also sought to evaluate whether an increase in the rate of nitrogen overcomes the effects of salinity under this cropping system.

## MATERIALS AND METHODS

The study was carried out in the Experimental area of the Department of Agricultural Engineering at the Federal University of Ceará, in Fortaleza (3°45' S, 38°33' W, at an altitude of 20 m), Ceará, Brazil, during a period of 24 months (06/2011 to 06/2013). A sunflower and maize crop rotation system was used, with cultivation of sunflower during the dry seasons of 2011 and 2012, and maize in the rainy seasons of 2012 and 2013.

According to the Köppen classification (Köppen, 1948), the local climate is of type Aw', that is, rainy tropical, very hot, with a predominance of rainfall in the summer and autumn, and an average annual temperature of 27.1°C. Table 1 shows the physical and chemical properties of the soil, obtained before starting the experiment.

Information on the weather variables obtained during the dry season (sunflower crop) and the rainy season (maize) are shown in Table 2. The sunflower (*Helianthus annuus* L.) cultivar BRS 324 was used. This is an open-pollinated, early variety, displaying, on average, high oil content, around 47%, with a productivity

**Table 2.** Climatic parameters of the experimental area and irrigation depths (ID) applied during each cultivation.

| Month | Maximum temp. (°C) | Minimum temp. (°C) | RH (%) | Insolation (h month$^{-1}$) | ETo (mm) | Rainfall (mm) | ID (mm) |
|---|---|---|---|---|---|---|---|
| **First cycle (sunflower) – 2011** | | | | | | | |
| Sept | 31.6 | 22.8 | 59 | 168.4 | 159.4 | 0.0 | 76.87 |
| Oct | 31.0 | 23.6 | 66 | 288.5 | 258.6 | 23.8 | 166.24 |
| Nov | 31.1 | 24.0 | 68 | 296.5 | 242.4 | 7.3 | 133.53 |
| Dec | 31.2 | 24.3 | 65 | 202.9 | 163.7 | 2.8 | 45.61 |
| Mean/sum | **31.2** | **23.7** | **64.5** | **956.3** | **824.1** | **33.9** | **422.25** |
| **Second cycle (maize) – 2012** | | | | | | | |
| Feb | 30.2 | 22.8 | 81 | 95.8 | 108.8 | 237.6 | 9.2 |
| Mar | 30.5 | 23.1 | 78 | 216.3 | 194.4 | 488.6 | 75.1 |
| Apr | 30.6 | 23.7 | 77 | 240.6 | 201.4 | 170.3 | 75.4 |
| May | 30.7 | 23.6 | 72 | 284.2 | 208.7 | 101.3 | 94.5 |
| Mean/sum | **30.5** | **23.3** | **77** | **836.9** | **713.3** | **997.8** | **254.2** |
| **Third cycle (sunflower) – 2012** | | | | | | | |
| Sept | 31.0 | 23.4 | 61 | 203.2 | 194.3 | 0.0 | 75.53 |
| Oct | 30.9 | 23.4 | 63 | 294.9 | 276.4 | 10.0 | 198.78 |
| Nov | 31.3 | 24.0 | 63 | 308.9 | 263.7 | 0.9 | 155.58 |
| Dec | 31.4 | 24.5 | 67 | 187.9 | 163.0 | 2.0 | 46.58 |
| Mean/sum | **31.1** | **23.8** | **63.5** | **994.9** | **897.4** | **12.9** | **475.94** |
| **Fourth cycle (maize)- 2013** | | | | | | | |
| Apr | 31.1 | 23.7 | 78 | 143.6 | 116.4 | 111.1 | 68.4 |
| May | 31.2 | 23.4 | 73 | 234.6 | 173.7 | 155.6 | 129.5 |
| Jun | 30.7 | 22.6 | 77 | 216.2 | 164.1 | 168 | 125.2 |
| Jul | 30.3 | 22.5 | 69 | 266.1 | 190.1 | 91.0 | 53.2 |
| Mean/sum | **30.8** | **23.0** | **74.2** | **860.5** | **488.3** | **525.7** | **373.3** |

RH, Relative humidity; ETo, Evapotranspiration of reference.

of 1,600 kg ha$^{-1}$ as a rainfed crop. The other crop used was maize (*Zea mays* L), double cross hybrid AG1051. This has a semi-early cycle, high ear insertion, a cycle from 90 to 120 days, with a productivity of 4,500 kg ha$^{-1}$ under rainfed conditions.

The experimental design was a randomized block in a split plot. The plots (40 m$^2$) consisted of five levels of irrigation water salinity , and the subplots (10 m$^2$) of four doses of nitrogen fertilizer, with five repetitions. Irrigation with different salinity water was only used in sunflower cultivation during the dry season.

For sunflower crop, the treatments with saline water were S1 = 0.8 (well water), S2 = 2.2, S3 = 3.6, S4 = 5.0 and S5 = 6.4 dS m$^{-1}$; nitrogen doses were N1 = no fertilizer, N2 = 25, N3 =50 and N4 = 75 kg N ha$^{-1}$, with the dose of 50 kg N ha$^{-1}$ being recommended. Urea was used as the source of N. To prepare the saline water treatments, the salts NaCl, $CaCl_2.2H_2O$ and $MgCl_2.6H_2O$ were added to the well water, using an equivalent ratio of 7:2:1, complying with a relationship between EC and salt concentration (mmol$_c$ L$^{-1}$ = EC x 10), as per Rhoades et al. (1992). The characteristics of the well water were: EC= 0.8 dS m$^{-1}$, pH = 6.9, and Ca, Mg, Na, $HCO_3^-$ and $Cl^{-1}$ equal to 1.1, 1.2, 4.0, 2.7, and 3.7 mmol$_c$ L$^{-1}$, respectively.

The same plots with sizes of 50 m$^2$ and subplots with an area of 12.5 m$^2$ previously cultivated with sunflower were used for the purpose of evaluating the residual effect of saline water on maize plants. However, supplementary irrigation with well water (EC = 0.8 dS m$^{-1}$) was used for this crop, with the following levels of nitrogen: N1 = no fertilizer, N2 = 108.5, N3 = 217 and N4 = 325.5 kg N ha$^{-1}$; with the rate N3 (217 kg N ha$^{-1}$) being the dose recommended for maize according to technical recommendation. Urea was used as a source of nitrogen.

Sixty-five days before sowing the sunflower, liming based on soil analysis was carried out using dolomitic limestone (1.8 Mg ha$^{-1}$), and incorporated by ploughing followed by a single harrowing. Five days before sowing, the soil was ploughed and then cross-harrowed twice.

Water depths applied in irrigation were calculated using data for reference evapotranspiration, as determined by the Class A tank method, and the crop coefficients of the sunflower and maize (Doorenbos and Kassam, 1994), in the latter case, only for supplementary irrigation. A pressurised drip-irrigation system was used for both crops.

The sunflower was sown with four seeds per hole, at a spacing of 0.8 × 0.3 m, and a density of 41,666 plants ha$^{-1}$. Ten days after sowing (DAS), thinning was carried out leaving only one plant per hole. Fertilization was performed in the furrows, and was based on soil analysis and the recommendations: 80 kg ha$^{-1}$ of $P_2O_5$, 70 kg ha$^{-1}$of $K_2O$, and 10 kg ha$^{-1}$ of FTE BR12. The single superphosphate and the FTE were applied as basal dose of sowing, while the urea and potassium chloride were divided up, with 1/3 being applied as basal dressing and 2/3 as top dressing at 31 DAS. To meet boron

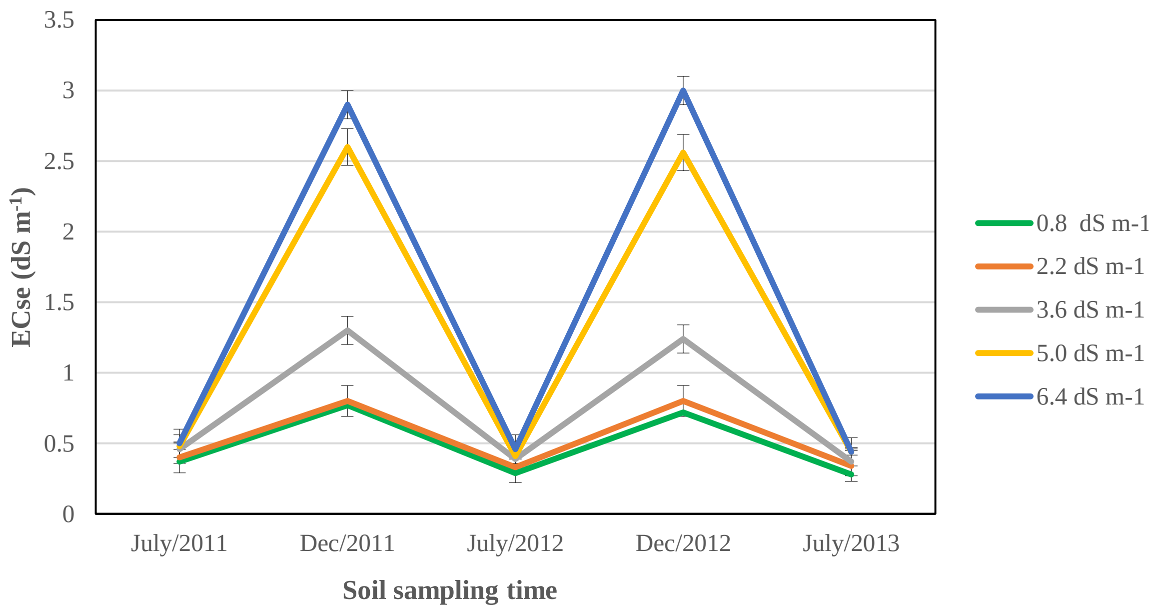


**Figure 1.** Variations in electrical conductivity of the saturation extract of the soil before and after each crop of sunflower and maize.

needs 4.0 kg ha$^{-1}$ of boric acid were applied, as recommended by Castro et al. (2006).

After each crop, the plant residue was mown once, and all remaining biomass was maintained in the respective plots. At the beginning of the rainy seasons of 2012 and 2013, after sunflower crop, the maize was sown, using three seeds of the cultivar AG1051 per hole, following the same order of treatment, and following the same spacing, as the previous crop. On the tenth day after germination, the plants were thinned, leaving only one plant per hole.

Fertilization of the maize crop was also carried out in the furrows, using 42 kg ha$^{-1}$ of $P_2O_5$, 157 kg ha$^{-1}$ of $K_2O$ and 40 kg ha$^{-1}$ of FTE-BR12. The superphosphate and the FTE were applied as basal dressing in a single application, while the potassium chloride and the rates of nitrogen were divided, with 1/3 being applied as basal dose and 2/3 as top dressing at 31 DAS.

At the end of each sunflower cycle (at 78 and 80 DAS) and maize cycle (at 95 and 90 DAS), ten plants from each sub-plot were collected to evaluate productivity of the crops under study. The productivity of both crops in kg ha$^{-1}$ was taken as the product of the average mass of achenes per plant (sunflower) and grains (maize) of the two crop cycles and plant density of 41,666 plants ha$^{-1}$. The potential for oil production in kg ha$^{-1}$ was estimated for each treatment according to its achene productivity and the respective percentages of oil.

The data were submitted to analysis of variance by F-test at 0.01 and 0.05 probability, using the statistical software ASSISTAT 7.6 (Silva and Azevedo, 2009). When significant effects of the interaction were observed, the response surfaces were plotted, using the Table Curve3D v.4.0 software.

Based on the productivity of the crops (sunflower and maize), the effects of the treatments were analysed by investment analysis, using profitability indicators (benefit to cost ratio, net present value and internal rate of return) for a planning horizon of eight years, as per Costa et al. (2005). All prices used in the economic analysis were obtained at the local market, taking the average prices over recent years, so as to represent the real economic potential of the alternatives tested in this study.

## RESULTS AND DISCUSSION

The variations in electrical conductivity of the soil saturation extract (ECse) before and at the end of each crop cycle are shown in Figure 1. It can be seen that during the dry season, that is, the period in which the sunflower was grown using water of different salt concentrations, increases in soil salinity were observed, especially at the highest salinity levels. Whereas, in the rainy season, the period when maize was cultivated using well water for supplementary irrigation, ECse decreased, showing that the rainfall helped to reduce the soil salinity regardless of the level of water salinity used previously. It is noteworthy that the sunflower crop was always cultivated in periods (July/2011 and July/2012) and the corn crop in periods (Feb/2012 and Feb / 2013).

A quadratic mathematical model was the best fit for the average productivity values for the sunflower cultivar BRS 324, as a function of water salinity and rates of nitrogen, with a coefficient of determination ($R^2$) of 0.92. The maximum yield was 4,050 kg ha$^{-1}$ was obtained with the treatments S1N4 (0.8 dS m$^{-1}$ and 75 kg N ha$^{-1}$) (Figure 2). The lowest estimated yield (1,480 kg ha$^{-1}$) was obtained under the highest concentration of saline water (EC = 6.4 dS m$^{-1}$) and no nitrogen fertilization. Furthermore, it can be seen that response to the nitrogen was more significant in the non-stressed plants, indicating that salt stress reduces the efficiency of nitrogen fertilization (Semiz et al., 2014; Lacerda et al., 2016). Similar results were observed for oil yield (Figure 3). The maximal potential for oil production (2000 kg ha$^{-1}$) was obtained with the treatments S1N4 (0.8 dS m$^{-1}$ and

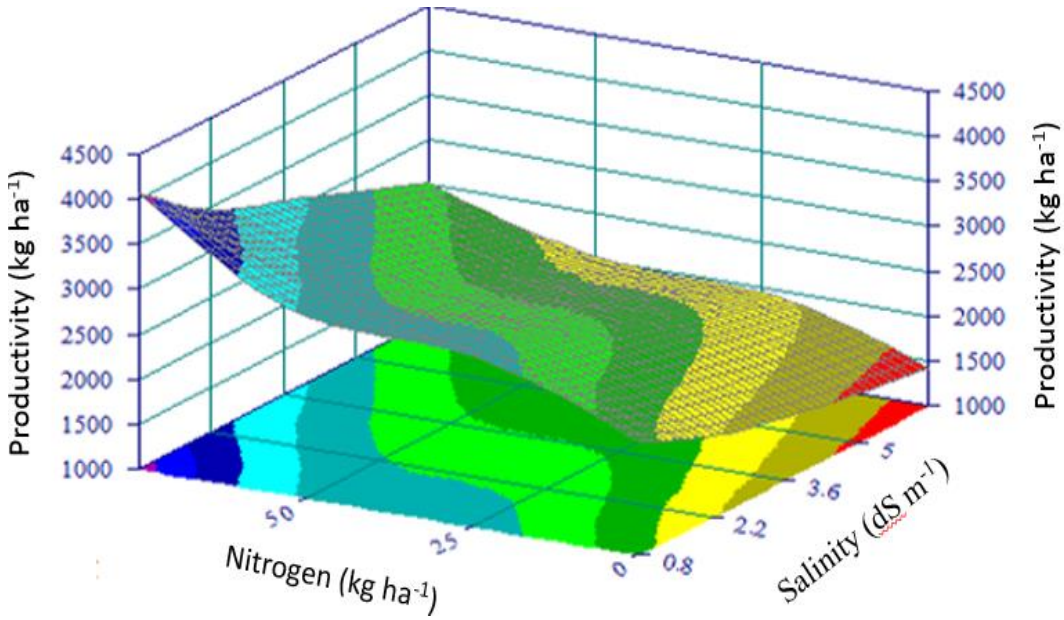


**Figure 2.** Response surface for the mean yield of two cycles of the sunflower cultivar BRS 324, as a function of salinity of irrigation water and levels of nitrogen fertilizer. Z= 2589.57 - 259.84 × salinity + 9.73 × $(salinity)^2$ + 17.64 × nitrogen; $R^2$ = 0.92

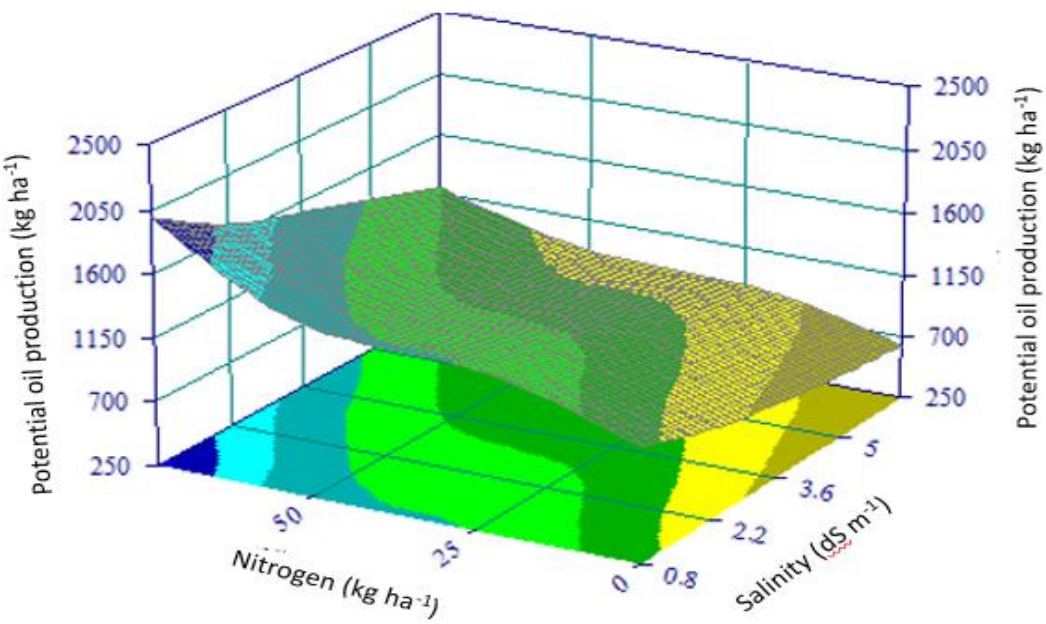


**Figure 3.** Response surface for potential oil production from two cycles of the sunflower cultivar BRS 324, as a function of salinity irrigation water and rates of nitrogen fertilizer. Z = 122.13 - 139.32 × salinity + 5.57 × $(salinity)^2$ + 9.17 × nitrogen; $R^2$ = 0.94.

75 kg N $ha^{-1}$), while the lowest value (590 kg $ha^{-1}$) was observed in plants under S5N1 treatment (6.4 dS $m^{-1}$ and without nitrogen fertilization).

Reductions in plant yield under saline stress conditions (Figures 2 and 3) are associated with the osmotic, toxic and nutritional effects resulting from the accumulation of salts in the root zone (Figure 1), which affects $CO_2$ assimilation, inhibits leaf expansion and accelerates the senescence of mature leaves. These effects reduce the area reserved for the photosynthetic process and the total production of photoassimilates, causing a reduction in crop yields (Munns, 2002; Wilson et al., 2006). Salinity

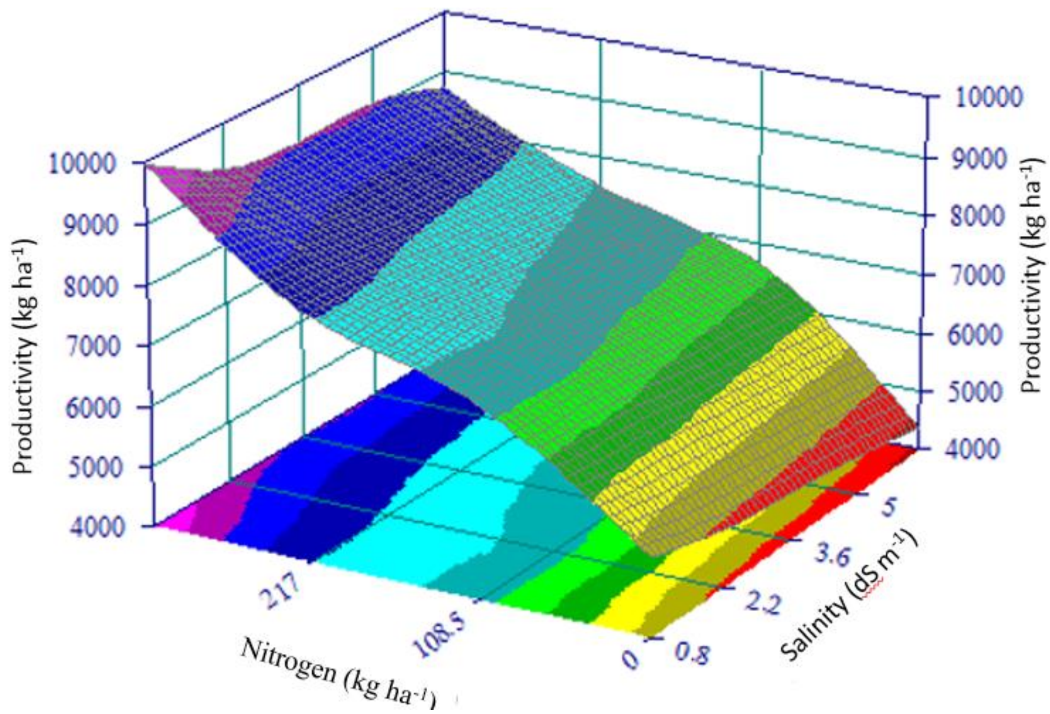


**Figure 4.** Response surface for the mean yield of maize cultivar AG 1051 from two cycles as a function of salinity of irrigation water and levels of nitrogen fertilizer. Z = 5394.28 - 137.40 × salinity + 17.93 x $(salinity)^2$ - 0.0153 x nitrogen; $R^2$ = 0.97.

affect both quantity and quality of the seeds of many different oilseed crops, with negative impacts on oil production (Travassos et al., 2011; Sezen et al., 2011; Nobre et al., 2013).

Increasing rates of nitrogen caused considerable effect on maize productivity (Figure 4). When maize was grown without nitrogen fertilization, the yields were very low at different salinity levels previously used during the dry-season crop (sunflower). Increasing the rate of N resulted in significant increases in maize yield, and these effects were not influenced by residual soil salinity. The absence of a residual effect of salinity on maize plants can be related to leaching of salts (Figure 1) caused by rainfall and by the supplementary irrigation (Table 2) performed during the cultivation in the rainy seasons. The surplus irrigation and / or rainwater leaches the excess salts from the soil profile, resulting in a less detrimental effect from salinity on the rooting medium, which favours the growth and development of the crop (Murtaza et al., 2006; Assis Junior et al., 2007; Bezerra et al., 2010; Lacerda et al., 2011; Neves et al., 2015).

The benefit to cost ratio (BCR) shows values greater than one for the majority of treatments or scenarios (Table 3), that is, the expected benefits are greater than the costs, indicating the economic feasibility of such arrangements. However, for some of these arrangements the BCR was less than unity, such as S2N1 (0.91), S3N1 (0.87), S4N1 (0.83) and S5N1 (0.78), that is, all the treatments with saline water greater than 2.2 dS $m^{-1}$ and with no nitrogen fertilization have a BCR of less than one.

The arrangements S1N4, S2N4, S3N4, S4N4 and S5N4 showed the highest BCR values, with 1.4, 1.29, 1.25, 1.24 and 1.19, respectively (Table 3). All of these treatments represent the lowest to the highest levels of salinity at the maximum rates of nitrogen, and it is clear that BCR was decreased with increasing water salinity. Despite these reductions in BCR, it can be seen that the results are always greater than 1.0, which is due in large part to the greater influence of the maize crop, whose productivity was not affected by the residual effect of the salts (Figure 2).

Only the arrangements S2N1, S3N1, S4N1 and S5N1 show a negative net present value (NPV), thereby indicating economic unviability (Table 3). Conversely, the other treatments had positive NPVs, particularly S1N4, S2N4, S3N4, S4N4 and S5N4, indicating that investment in these systems would be possible without loss to the investor. It is important to emphasize that saline water was used in these treatments only for irrigation of the sunflower, and practically no residual effect of salinity was observed on the maize crop. On the other hand, increasing rates of N caused significant yield responses for both crops, which contributed to the positive impact on the economic indicators. This is confirmed by the negative NPV values for those treatments where there was no nitrogen fertilization, even under low salinity water for irrigating the crops during the dry season.

The internal rate of return (IRR) of the present study

**Table 3.** Benefit to cost ratio (BCR), net present value (NPV) and internal rate of return (IRR) for the treatments under analysis, submitted to sunflower-maize crop rotation using saline water and rates of nitrogen.

| Salinity (dS $m^{-1}$) | Nitrogen (%)* | BCR | NPV (R$) | IRR (%) |
|---|---|---|---|---|
| S1 - 0.8 | N1 - 0 | 1.03 | 1667.88 | 3.05 |
| | N2 - 50 | 1.17 | 10516.13 | 17.44 |
| | N3 - 100 | 1.22 | 14110.48 | 21.75 |
| | N4 - 150 | 1.40 | 28267.90 | 40.14 |
| S2 - 2.2 | N1 - 0 | 0.91 | -5020.21 | -9.17 |
| | N2 - 50 | 1.16 | 9505.06 | 15.76 |
| | N3 - 100 | 1.20 | 12789.12 | 19.72 |
| | N4 - 150 | 1.29 | 20363.17 | 28.91 |
| S3 - 3.6 | N1 - 0 | 0.87 | -6863.74 | -12.54 |
| | N2 - 50 | 1.12 | 7424.70 | 12.31 |
| | N3 - 100 | 1.17 | 10732.70 | 16.55 |
| | N4 - 150 | 1.25 | 17921.03 | 25.45 |
| S4 - 5.0 | N1 - 0 | 0.83 | -9139.74 | -16.70 |
| | N2 - 50 | 1.09 | 5656.87 | 9.38 |
| | N3 - 100 | 1.14 | 8938.68 | 13.78 |
| | N4 - 150 | 1.24 | 17128.20 | 24.32 |
| S5 - 6.4 | N1 - 0 | 0.78 | -12009.77 | -21.94 |
| | N2 - 50 | 1.06 | 3746.43 | 6.21 |
| | N3 - 100 | 1.10 | 6697.98 | 10.33 |
| | N4 - 150 | 1.19 | 13126.57 | 18.64 |
| | **Mean** | **1.112** | **7777.971** | **11.170** |

-12.54, -16.70 and -21.94% for the treatments S2N1, S3N1, S4N1 and S5N1, respectively. When the IRR is equal to the minimum attractive rate (MAR), the NPV is equal to zero; but when the IRR is greater than the MAR, it means that the project yielded a higher return than the expected minimum rate, that is, the project should be accepted. The results obtained with the above treatments show the project can not be attractive. It can also be seen that the other scenarios showed a positive IRR, that is, greater than the MAR of 2% per annum, showing that these arrangements yielded a financial return to the investor. It was also found that scenarios that used the maximum levels of nitrogen, even with saline water, such as S1N4, S2N4, S3N4, S4N4 and S5N4, obtained a higher IRR respectively of 40.14, 28.91, 25.45, 24.32 and 18.64%, compared to the other scenarios, decreasing with the increase in salinity. For those scenarios in which nitrogen fertilizer was not used, it appears that increasing salinity also substantially reduced gains, making the BCR less than 1.0, and the values of NPV and IRR increasingly more negative.

## Conclusion

The highest productivity and potential oil production of sunflower were observed in unstressed plants and subjected to the maximum rate of nitrogen. But yield decreased with increase in salinity, even with increase in the rate of nitrogen. The productivity of maize was strongly influenced by increases in the rate of nitrogen and the leaching of salts, caused by rainfall, virtually eliminating any residual effect of the salts on this crop. A soil management system employing sunflower/maize crop rotation is economically viable, being more attractive when using low salinity water and the highest application rate of nitrogen (75 kg $ha^{-1}$ for the sunflower and 325 kg $ha^{-1}$ for the maize).

## Conflict of Interests

The authors have not declared any conflict of interests.

## ACKNOWLEDGMENTS

Acknowledgments are due to the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Instituto Nacional de Ciência e Tecnologia em Salinidade (INCTSal), and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), Brazil, for financial support and scholarship provided to the first author.

**REFERENCES**


Assis Junior JO, Lacerda CF, Silva FB, Silva FLB, Bezerra MA, Gheyi HR (2007). Cowpea yield and soil salt accumulation as a function of leaching fraction and irrigation water salinity. Engenharia Agrícola 27:702-713..

Bezerra AKP, Lacerda CF, Hernandez FFF, Silva FB, Gheyi HR (2010). Cowpea/corn crop rotation utilizing waters of different salinities. Ciênc. Rural 40(5):1075-1082.

Castro C, Moreira A, Oliveira RF, Dechen AR (2006). Boron and water stress on yield of sunflower. Ciênc. Agrotecnologia 30:214-220.

Chen M, Kang Y, Wan S, Liu S (2009). Drip irrigation with saline water for oleic sunflower (*Helianthus annuus* L.). Agric. Water Manag. 96:1766-1772.

Costa RNT, Saunders LCU, Oliveira JNM, Biserra JV (2005). Economic indicators for soil sodic reclamation using a underground drainage system in Curu Valley, CE. Irriga 10:272-278.

Doorenbos J, Kassam AH (1979). Efectos del agua sobre el rendimento de los cultivos. Rome: FAO, 212p..

Gengmao Z, Quanmei S, Yu H, Shihui L, Changhai W (2014). The physiological and biochemical responses of a medicinal plant (Salvia miltiorrhiza L.) to stress caused by various concentrations of NaCl. PLOS ONE 9 (2):e89624.

Köppen NW (1948). Climatologia: Com um estúdio de lós climas de la tierra. Fondo de Cultura Economica, 478 p.

Lacerda CF, Sousa GG, Silva FLB, Guimarães FVA, Silva GL, Cavalcante LF (2011). Soil salinization and maize and cowpea yield in the crop rotation system using saline waters. Engenharia Agrícola 31(4):15-28.

Lacerda CF, Ferreira JFS, Liu X, Suarez DL (2016). Evapotranspiration as a criterion to estimate nitrogen requirement of maize under salt stress. J. Agron. Crop Sci. 202(3):192-202.

Munns R (2002). Comparative physiology of salt and water stress. Plant Cell Environ. 25(2):239-250.

Murtaza G, Ghafoor A, Qadir M (2006). Irrigation and soil management strategies for using saline-sodic water in a cotton-wheat rotation. Agric. Water Manag. 81:98-114.

Neves ALR, Lacerda CF, Guimarães FVA, Hernandez FFF, Silva FB, Prisco JT, Gheyi HR (2009). Biomass accumulation and nutrient extraction by cowpea plants irrigated with saline water at different growth stage. Ciênc. Rural 39(3):758-765.

Neves ALR, Lacerda CF, Sousa CHC, Silva FLB, Gheyi HR, Ferreira FJ, Andrade Filho FL (2015). Growth and yield of cowpea/sunflower crop rotation under different irrigation management strategies with saline water. Cienc. Rural 45(5):814-820.

Nobre RG, Lima GS, Gheyi HR, Soares LA, Silva SS, Silva AO, Lourenço GS (2013). Growth and production of castor bean under different levels of irrigation water salinity and nitrogen doses. Semina: Ciênc. Agrárias 34(3):961-974.

Rhoades JD, Kandiah A, Mashali AM (1992). Use of saline water for crop production. FAO: Irrigation and Dreinage Paper 48, 145 p.

Semiz GD, Suarez DL,Ünlükara A, Yurtseven E (2014). Interactive effects of salinity and N on pepper (*Capsicum annuum* L.) yield, water use efficiency and root zone and drainage salinity. J. Plant Nutr. 37:595-610.

Sezen SM, Yazar A. Tekin S, Eker S, Kapur B (2011). Yield and quality response of drip-irrigated pepper under Mediterranean climatic conditions to various water regimes. Afr. J. Biotechnol. 10(8):1329-1339.

Silva FAS, Azevedo CAV (2009). Principal components analysis in the software assistat-statistical attendance. In: WORLD CONGRESS ON COMPUTERS IN AGRICULTURE, 7, Reno-NV-USA: American Society of Agricultural and Biological Engineers.

Travassos KD, Soares AL, Gheyi HR, Silva DRS, Nascimento AKS, Dias NS (2011). Achene production of the sunflower irrigated with brackish water. Rev. Bras. Engenharia Agrícola Ambient 15(4):371-376.

Wilson C, Liu S, Lesch SM, Suarez DL (2006). Growth response of major USA cowpea cultivars II. Effect of salinity on leaf gas exchange. Plant Sci. 170(6):1095-1101.