Monitoring soil coverage and yield of cowpea furrow irrigated with saline water[1]

Monitoramento da cobertura do solo e produtividade do feijão-de-corda irrigado por sulcos com água salina

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Abstract - Cowpea crop is of great importance for northeast Brazil. The objective of this work was to evaluate the application of saline water in different developing stages on plant growth and changes in soil characteristics, measured by soil coverage, and on yield of cowpea plants. The experiment was conducted under field conditions, during the dry season in a completely randomized block design with five treatments and five replications. Each experimental unit consisted of 4 lines of plants with 5.0 m long. The treatments evaluated were: 1. irrigation with groundwater with electrical conductivity (ECw) of 0.8 dS m^{-1} during the whole crop cycle; 2. saline water (5.0 dS m^{-1}) during the whole crop cycle; 3, 4 and 5. saline water (5.0 dS m^{-1}) up to 22nd, during 23rd to 42nd and from the 43rd to 62nd days after sowing, respectively, and groundwater in the remaining period. Soil coverage was evaluated by digital images using the software ENVI for image processing and classification. It was found that the continuous use of saline water inhibits plant growth, while irrigation with saline water during germination and initial growth stages caused retardation in plant development, but in this last case a recovery was observed in the final part of the experimental period. For treatments 2 and 3, a reduction was verified in the number of pods and in seed production, as compared to other treatments. Irrigation with saline water during 23 to 42 and 43 to 62 days after sowing did not affect reproductive and vegetative growth, but the saline water application in the pre-flowering (treatment 4) caused anticipation of the reproductive cycle.

Key words - *Vigna unguiculata.* Image classification. Salinity of the water. Salt tolerance.

Resumo - Feijão-de-corda é uma cultura de grande importância socioeconômica no Nordeste brasileiro. O objetivo deste trabalho foi avaliar a aplicação de água salina em diferentes estádios de desenvolvimento e no rendimento do feijão-de-corda (caupi) e alterações em características do solo. O experimento foi conduzido no campo, durante a estação seca em um delineamento em blocos casualizados com cinco tratamentos e cinco repetições. Cada unidade experimental constou de 4 linhas de plantio com 5,0 m de comprimento. Os tratamentos avaliados foram: 1. irrigação com água subterrânea com a condutividade elétrica (CEa) de 0,8 dS m^{-1} durante todo o ciclo da cultura; 2. água salina (5,0 dS m^{-1}) durante todo o ciclo; 3, 4 e 5. irrigação com água salina até 22, de 23 a 42 e de 43 a 62 dias após o plantio, respectivamente, e no resto do ciclo irrigada com água subterrânea. A cobertura do solo foi avaliada por imagens digitais e utilizou-se o software ENVI para processamento e classificação. Verificou-se que o uso contínuo de água salina inibiu o crescimento das plantas, enquanto a irrigação com água salina durante a germinação e o crescimento inicial retardou o desenvolvimento, mas no último caso, a recuperação foi observada na parte final do período experimental. Para os tratamentos 2 e 3, foi verificada redução no número de vagens e na produção de sementes, em comparação com outros tratamentos. A irrigação com água salina durante 20 a 40 e 40 a 60 dias após a germinação não afetou o crescimento vegetativo e reprodutivo, sendo que a aplicação de água salina na pré-floração (tratamento 4) causou antecipação do ciclo reprodutivo.

Palavras-chave - *Vigna unguiculata.* Classificação por imagem. Salinização da água. Tolerância à salinidade.

Introduction

The use of irrigation has contributed significantly to increased agricultural production, especially in the semi arid regions, where the total rainfall limits the plant yield (RHOADES et al., 2000). However, there are some areas, including the Northeast of Brazil, where availability of freshwater resources increases or decreases according to rainfall changes, and there is competition for freshwater among different water-users, causing a decreased allocation of freshwater to agriculture (MURTAZA et al., 2006). In addition, in these regions, existence of sources of water containing high amounts of soluble salts is common, causing problems in plant growth and crop yield.

The use of saline water in agriculture depends on some factors, such as salt tolerance of crops, physical properties of soil, drainage conditions, and the total rainfall of the region. The evaluation of these factors allows the formulation of long term strategies, which contribute to obtain economical harvests without soil degradation. Among these strategies, one can find: cultivation of salt tolerant species, the use of alternative soil management techniques, the crop rotation, the use of blended water, the application of soil amendments, and the use of saline water during salt tolerant growth stages (GLENN et al., 1998; MALASH et al., 2005; MURTAZA et al., 2006; NEVES et al., 2008; SHARMA; RAO, 1998).

The sensitivity of crops to soil salinity often changes from one growth stage to the next (MAAS; POSS, 1989), and some efforts have been made with different crops to develop appropriate management practices for irrigation with saline water, with respect to the timing of its application, to reduce yield losses and soil salinization (BOTIA et al., 2005). These studies aim at determining the sensitivities of the crop at different growth stages, which is one of the major issues in the utilization of saline water for crop production. With the identification of salt-sensitive or salt-tolerant growth stages, management options may be developed to ameliorate yield reduction under salt stress, while reducing the consumption of good quality water (CHARTZOULAKIS; KLAPAKI, 2000; ZENG et al., 2001).

Cowpea [*Vigna unguiculata* (*L.*) Walp.] is an important crop cultivated in different regions of the world, being an important source of vegetal protein for human consumption in semi arid regions. This crop is extensively cultivated in the Northeast of Brazil, and presents great social and economical importance, especially for the poorest portion of its population (CARDOSO et al., 2005). Cowpea has been cultivated under both irrigated and non-irrigated regimes, and it is considered a moderately sensitive crop to salinity (MAAS; GRATTAN 1999), with a higher tolerance than corn, but lower than wheat, barley, sugar beet, and cotton (AMADOR et al., 2006).

Although there are many studies related to salt tolerance of cowpea under greenhouse conditions (COSTA et al., 2003; DANTAS et al., 2002; MAAS; POSS, 1989), there is little information about its tolerance in different growth stages, especially under field conditions. Therefore, in this study the effect of the application of saline water at different stages of crop on plant growth and yield was evaluated, with the objective to identify the response of cowpea at different development stages to application of saline water, as well as the impacts of these treatments on the soil properties.

Material e methods

The experiment was carried out during the last three months of the dry season, between October and December, 2006, in an area of Red Yellow Argisol (chemical and physical characteristics were previously described by Assis Junior et al. (2007), in Fortaleza (3°45'S; 38°33'W), Ceará, Brazil where cowpea [*Vigna unguiculata* (L) Walp.] cv. Epace 10 was sown. The weather conditions during the experimental period (October to December, 2006) and during rainy season (January to April, 2007) after cultivation of cowpea are characterized in Table 1.

Table 1 - Values of the meteorological data obtained during dry season (along cowpea cultivation) and during rainy season

Months	T (°C)	RU (%)	v (m s^{-1})	Insolation (hours)	Rainfall (mm)	ETP (mm)
Out/2006	27.7	68	4.5	327	3.2	196.3
Nov/2006	27.5	70	4.3	297	2.7	183.4
Dec/2006	28.1	72	3.7	341	11.7	164.7
Jan/2007	28.3	73	3.7	259	36.5	159.5
Feb/2007	27.1	81	2.8	148	279.8	83.2
Mar/2007	27.2	80	2.7	179	340.0	115.7
April/2007	27.4	79	2.5	168	236.9	113.7

T – mean temperature, RU – relative humidity, v – wind velocity, ETP – potential evapotranspiration

A completely randomized block design, with five replications, was adopted. Each experimental unit consisted of four lines of plants, each 5.0 m long. The distance between lines and plants were 0.8 and 0.3 m, respectively, with two plants per hole.

The plants were subjected to the following treatments of irrigation: 1). Irrigation with groundwater of 0.8 dS m^{-1} electrical conductivity (ECw) during the whole crop cycle; 2). Irrigation with saline water (ECw=5.0 dS m^{-1}) during the whole crop cycle, starting after germination; the value of 5.0 dS m^{-1} was chosen on the basis of study of Dantas et al. (2002) and Assis Júnior et al. (2007). This concentration of salts in irrigation water causes nearly 40% reduction in yield and is superior than the threshold limit for the crop which according to Ayers e Westcot (1999), is of 3.3 dS m^{-1}; 3). Irrigation with saline water (ECw=5.0 dS m^{-1}) from sowing until 22nd day after seedling emergence (germination and initial growth) and groundwater in remaining stages of the crop cycle; 4). Irrigation with saline water (ECw=5.0 dS m^{-1}) from 23rd to 42nd day after germination (intense growth and pre-flowering), and irrigation with groundwater for the remaining growth stages and 5). Irrigation with groundwater (ECw=0.8 dS m^{-1}) from sowing to the 43rd day after germination and irrigation with saline water (ECw=5.0 dS m^{-1}) during flowering and pod-filling stages. For the preparation of the saline waters, NaCl, CaCl$_2$.2H$_2$O and MgCl$_2$.6H$_2$O were used maintaining the equivalent ratio 7:2:1 for Na:Ca:Mg (proportion commonly observed in waters of northeast Brazil), and following the ECw - salt concentration relationship (mmol$_c$ L^{-1}=CE x 10) reported by Rhoades et al. (2000). The main characteristics of the groundwater and saline water used in irrigation are presented in Table 2.

Irrigation schedule adopted was according to crop water requirements based on reference evapotranspiration, ETo (estimated from a Class A pan according to Doorenbos e Pruit (1997) and the values of the crop coefficients (K$_c$) according to the growth stage, as follows: 0.70 (0 to 10 days after sowing, DAS), 0.81 (11 to 30 DAS), 1.12 (31 to 53 DAS) and 0.77 (54 to 60 DAS), following recommendation presented by Souza et al. (2005). An additional 15% leaching fraction was added to the net water requirement to prevent excessive salt accumulation. A dead-end leveled furrow irrigation system was used for the experiment. The total water applied during the irrigation cycle was 352 mm in all treatments.

The fertilization followed the recommendation of Fernandes (1993), and consisted of applying 1.1 g of urea, 8.0 g of simple superphosphate, and 1.5 g of potassium chloride for each plant. During the crop development, two manual weedings were carried out and the application of agricultural defensives was performed in accordance with the necessities.

Plant canopy coverage was assessed by digital images taken at weekly intervals from a 2 m high platform and using a 5.1 megapixels digital camera and an 80 by 80 cm grid as backgound. In order to avoid any distortion due to shade, images were taken at noon time. The raw images were edited using Adobe Photoshop software to produce a net covered area of 6400 cm^2 (Figure 1). Software ENVI 4.3 RSI was used to quantify the area of crop coverage applying the supervised classification algoritm known as Maximum Likelihood-Maxver. It considers the balance of distances between means of the digital levels of the classes and pixel, using statistical parameters, considering the distribution of normal probability for each class.

At the end of the crop cycle, the following parameters were measured: dry mass of vegetative (stems, petioles and leaf blades) and reproductive (pods and seeds) plant parts, number of pods per plant, number of seeds per pod, size of the pod, and dry biomass of 1000 seeds. Dry biomass partitioning between vegetative and reproductive parts was also evaluated.

Soil samples from three layers (0-0.3; 0.3-0.6 and 0.6-0.9 m) were collected during the dry season (before and after cowpea cultivation) and after the rainy season, to determine electrical conductivity in 1:1 soil water extract

Table 2 - Characteristics of groundwater (from well) and saline water used in irrigation

Characteristics	Unit	Groundwater	Saline water
EC	(dS m^{-1})	0.8	5.0
pH		7.1	7.1
Ca^{2+}	mmol$_c$ L^{-1}	1.0	10.0
Mg^{2+}	mmol$_c$ L^{-1}	1.0	5.0
Na$^+$	mmol$_c$ L^{-1}	3.9	35.0
HCO$_{3-}$	mmol$_c$ L^{-1}	2.8	2.8
Cl$^-$	mmol$_c$ L^{-1}	3.6	65.0
SAR	(mmol L^{-1})$^{1/2}$	3.9	12.8

Figure 1 - (A) image obtained in the field; (B) edited image in the computer; (C) classified image by ENVI method

($EC_{1:1}$) and exchangeable sodium percentage (ESP), according to methods recommended in Silva (1999).

The data were subjected to analysis of variance, and the means were compared by Tukey's test at 0.05 level of probability.

Results and discussion

Salt accumulation in soil

Soil profile salinity ($EC_{1:1}$) and sodicity (ESP) at the start of the experiment (October, 2006) ranged from 0.29 to 0.60 dS m^{-1} and from 3 to 6%, respectively

(Table 3). The irrigation with combination of groundwater and saline water, during the last three months of the dry season, caused an increase in electrical conductivity and exchangeable sodium levels in the soil profile (Table 3) due to accumulation of salts. However, the response to the treatment varied according to the duration of the exposure to saline water at a given growth stage and was dependant upon the soil layer. The continuous use of saline water (treatment 2) caused larger increases in $EC_{1:1}$ and in ESP for the three layers studied, although higher values were observed for the 0.3 to 0.6 m layer. When saline water was used only during germination and initial growth stages (treatment 3), higher values of $EC_{1:1}$ and ESP were observed in the layers between 0.3 and 0.9 m, and the values in the superficial layer were quite similar to those

Table 3 - Values of electrical conductivity obtained in 1:1 soil/water extracts ($EC_{1:1}$) and of exchangeable sodium percentage (ESP) at different soil depths

Treatment	$CE_{1:1}$ (dS m^{-1})			ESP (%)		
	0-0.3 m	0.3-0.6 m	0.6-0.9 m	0-0.3 m	0.3-0.6 m	0.6-0.9 m
	September of 2006 (before sowing of cowpea)					
	0.29	0.36	0.60	3	6	9
	January of 2007 (after harvest of cowpea)					
T1	0.43	0.58	0.30	12	12	11
T2	1.15	1.39	1.15	19	23	19
T3	0.57	0.99	0.94	13	15	16
T4	0.66	1.17	0.74	13	15	15
T5	0.91	0.72	0.42	15	11	10
	April of 2007 (after rainy season)					
T1	0.17	0.16	0.24	5	9	10
T2	0.14	0.17	0.28	7	11	9
T3	0.16	0.13	0.15	7	7	9
T4	0.19	0.15	0.17	3	8	8
T5	0.10	0.11	0.17	6	8	9

observed in treatment 1 (groundwater). This could be due to the use of groundwater during the remaining stages of the crop cycle, causing salts to leach from the surface layer. On the other hand, application of the saline water at the end of the crop cycle (treatment 5) caused higher salt accumulation in the superficial layer, suggesting that the time was insufficient to promote salt distribution/ leaching in the soil profile. Soil analysis after the rainy season revealed a decrease in soil salinity and sodicity in all treatments probably because of leaching caused by rainwater during the months of January to April. However the decrease in the electrical conductivity was more evident than for exchangeable sodium because of solubility of accumulated salts in water.

Soil coverage

Allen et al. (1998) classified crop coefficients on the basis of development stages (initial stage - up to 10% of soil coverage; stage of development of the crop - approximately 70-80% of soil coverage; intermediate stage - total soil coverage until the beginning of the maturation; and final stage - beginning of the maturation until total senescence). Table 4 presents the evolution of the cowpea cv. EPACE 10 with 10% and 80% of soil covering submitted to irrigation with saline water in different stages of the cycle. Saline water application during the whole cycle reduced soil cover (Figure 2), and the plants under this treatment 2 did not fill 80% of the crop spacing (Table 4). The plants irrigated with saline water since sowing up to 20th DAS (treatment 3) showed a reduction in the growth rate, and did not differ from plants of treatment 2, in terms of soil coverage, until about 45 DAS. The plants under treatment 3, however, showed an intensive growth up to 45 DAS, and reached 80% of the soil coverage 57 DAS (Table 4), similar values were observed in other treatments. On the other hand, the plants of treatments 1 (irrigated with groundwater), 4 and 5, showed higher growth along the cycle in relation to the plants of the treatments 2 and 3, indicating that saline water application before flowering and during the flowering and pod-filling stages did not affect vegetative growth of the
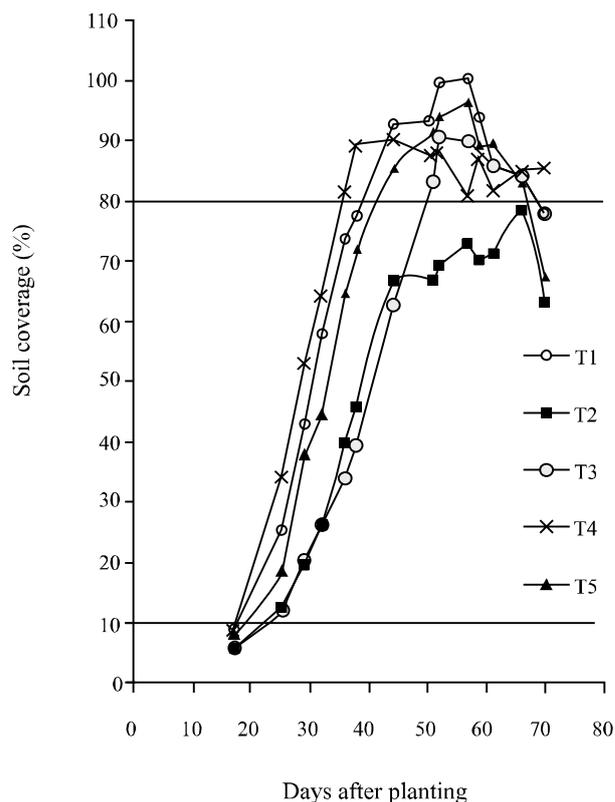

Figure 2 - Evolution of the soil coverage by cowpea plants irrigated with saline water at different stages of plant development

crop. The plants of treatments 1 and 4 reached 80% of soil cover by the 40th day after germination, but the plants of treatment 4 showed a tendency to stabilize after this period, suggesting an acceleration of plant senescence.

Dry biomass production

Continuous saline water application reduced the production of dry biomass of shoot, in relation to the plants irrigated with groundwater, and the reductions reached up to 40 and 46%, respectively, for stems plus leaves and pods (Figure 3). Observed reductions may be due to osmotic, toxic and nutritional effects related

Table 4 - Limit values in days after sowing for changes in growth stages, according to Allen et al. (1998)

Treatment	Soil coverage	
	10%	80%
T1. Well water	19-20	39-40
T2. Saline water during the complete crop cycle	22-23	Did not reach
T3. Saline water during seedling germination and initial growth	23-24	56-57
T4. Saline water during the stage of intense growth and pre-flowering	16-17	39-40
T5. Saline water during flowering and fruit development	20-21	43-44

to salt accumulation in the root zone (Table 3) (due to NaCl principally), which might have affected carbon assimilation, inhibiting leaf expansion and enhancing leaf senescence, thereby reducing the area used for photosynthetic process and photosynthate production (LACERDA et al., 2006; MUNNS, 2002; WILSON et al., 2006). The plants irrigated with saline water during the germination and initial growth stages showed a 33% reduction in the reproductive growth. However, vegetative growth (leaves plus stems) was not affected, since a recovery in the vegetative development of the plant was observed along the crop cycle, as demonstrated in the measurement of the soil cover (Figure 2), and this effect could be related to reduction in salt accumulation in the root zone (Table 3). These results indicate that the salinity applied in the initial crop stage delayed plant development. This effect was observed in another study with this species during the seedling phase (SOUSA et al., 2003). In addition, alteration in the development pattern of the crop and in photosynthate partitioning was observed, causing reduction in the pod production in detriment of the vegetative growth (Table 5). Salt-induced changes in morphophysiology of cowpea plants have also been observed in other studies (LACERDA et al., 2006).

The saline water application in the periods of intense growth and in the flowering and pod-filling stages did not affect the vegetative growth and pod production per plant (Figure 3), which indicates that germination and seedling establishment stages are more sensitive to salt accumulation in the root zone (AMADOR et al., 2006). Maas e Poss (1989) observed reduction in the vegetative growth in cowpea under
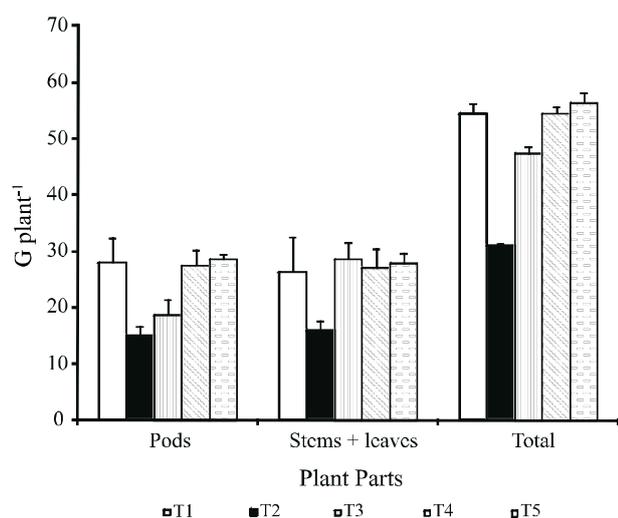
Table 5 - Dry biomass partitioning in cowpea plants irrigated with saline water at different stages of plant development

Treatments	Vegetative Parts	Reproductive parts
T1	47.2 b	52.8 a
T2	51.0 b	49.0 a
T3	60.0 a	40.0 b
T4	49.0 b	51.0 a
T5	49.5 b	50.5 a

[1]Means followed by the same letter in columns do not differ significantly (Tukey's test, $P \le 0.05$); $n = 5$

greenhouse condition, both when saline water was applied during the growth and during flowering and pod-filling stages, but the highest reduction was verified when the crop was irrigated with saline water during the initial stage of plant growth. According to Maas (1993), most crops show higher sensitivity to salt injury during seedling emergence and early juvenile development. Once established, plants generally become increasingly tolerant until the final stage. On the other hand, it was observed that the saline water application in the pre-flowering stage caused acceleration in the reproductive development, while the saline water application in the initial growth stage caused retardation in the pod filling. On the 58th day after germination, when the first harvest was carried out, it was verified that the plants of treatment 4 had, on average, about 3 mature pods, while practically no mature pods were observed in the plants of treatment 3 (Figure 4). It was also observed that the
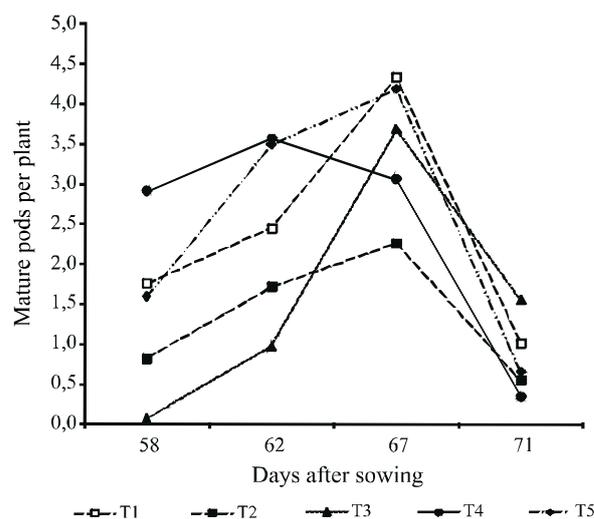

Figure 3 - Dry biomass of reproductive (pods) and vegetative parts (stems plus leaves) of cowpea plants irrigated with saline water at different stages of plant development. Bars represent SE (n = 5)

Figure 4 - Number of mature pods per plant, along the harvest period, of cowpea plants irrigated with saline water at different stages of plant development

Table 6 - Number of pods per plant (NP), number of seeds per pod (NSP), size of the pod (SP), dry biomass of 1000 seeds (DM1000), and total dry biomass of seeds per plant (DMS) of cowpea plants irrigated with saline water at different stages of plant development

Treatments	NP	NSP	SP (cm)	DM1000 (g)	DMS (g plant^{-1})
T1	8.7 a	14.3 ab	19.7 a	184.1 a	22.4 a
T2	5.1 b	12.8 b	18.8 a	198.3 a	11.8 b
T3	5.9 b	14.3 ab	19.2 a	198.7 a	14.9 b
T4	9.3 a	14.2 ab	19.6 a	203.9 a	21.9 a
T5	9.2 a	14.7 a	20.1 a	198.8 a	22.5 a

[1]Means followed by the same letter in columns do not differ significantly (Tukey's test, $P \leq 0.05$); $n = 5$

maximum production of the treatment 4 occurred at the 62nd day after the germination, while in the other treatments this peak only occurred at the 67th days.

The seed production of cowpea results from the number of pods (NP) per unit area, the numbers of seeds per pod (NSP) and from the weight of 1000 seeds (DM1000) (CARDOSO et al., 2005). In the present work it was verified that the continuous application of saline water, as well as application during germination and initial growth stages, reduced dry biomass of pods and seeds, but no reduction in the pod size and in the mean weight of the seeds was observed (Table 6), similar results was also obtained by Maas e Poss (1989). However, a reduction in the number of pods per plant and in the number of seeds per pod were verified, demonstrating that the salinity affected the emission of reproductive branches, this being an important component for the reduction in the cowpea yield under salt stress conditions. These results are partially in accordance to those obtained by Maas e Poss (1989) under greenhouse conditions, which showed that cowpea is most sensitive to salinity during early vegetative growth but exhibits higher tolerance during flowering and pod-filling stages.

Conclusions

1. Saline water application during whole cycle increased salinity in the soil profile and reduced the growth and yield of cowpea.

2. The saline water application during germination and initial growth stages caused retardation in plant development and reduced the final crop yield mainly due to reduction in number of pods per plant.

3. The saline water use in the periods from 23 to 42 and 43 to 62 days after sowing did not affect the cowpea growth and yield, however the application in former case caused an acceleration in the formation and filling of pods.

4. Use of saline water during 43 to 62 days after sowing permit to obtain economic harvests without soil degradation reducing the consumption of good quality water.

5. No appreciable increase in soil salinity due to application of saline water was observed after the rainy season.

Acknowledgments

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