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Response of cowpea (*Vigna unguiculata*) to salinity and irrigation regimes

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Abstract The effects of salinity and irrigation regimes on yield, growth, and water consumption of cowpea (*Vigna unguiculata*) were determined in two different experiments. The first experiment focused on cowpea responses to irrigation water with six different levels of salinity (0.7, 2.0, 3.0, 4.0, 5.0, and 7.0 dS m^{-1}). In the second experiment four different amounts of water (1.43, 1.0, 0.75, and 0.50 times of depleted water) were applied to cowpea plants. Seed and pod yields of cowpea decreased significantly for the soil salinity values higher than 9.0 dS m^{-1}. As soil salinity increased, water consumption of cowpea decreased. Therefore, the effect of salinity in lowering evapotranspiration should be considered in irrigation planning and scheduling of cowpea. Either excessive or limited water applications caused decreases in seed and pod yields of cowpea. Yield response factor (K_y), from the relationships between relative evapotranspiration and relative yield decrease, were 0.98 and 0.92 for pod and seed yields, respectively. It is concluded that cowpea is tolerant to water stress in terms of seed and pod yields.

Keywords salinity effects; cowpea; yield; plant water consumption; irrigation regime

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INTRODUCTION

Cowpea (*Vigna unguiculata* (L.) Walp.), also known as blackeye pea, southern pea, and crowder pea, is a legume of African origin. Its drought tolerance makes it valuable for rainfed agriculture or for non-irrigated fallow fields (Valenzuela & Smith 2002). Worldwide, 700 million people consume leguminous crops, among which the common bean is the leading (Dölekoğlu & Keskin 2004) legume. Cowpea is a legume and an important source of protein (Ehlers & Hall 1997). Cowpea is generally cultivated in rainfed areas rather than irrigated fields (Duke 1981). It is more tolerant to water stress than soybean (McLeod 1982).

Cowpea is ranked third among legumes in world production, and was grown on 10.7 million ha in 2004. Cowpea is mostly grown in Africa, followed by Asia (FAO 2008). According to the 2006 statistics, in Turkey, cowpea was cultivated on 2925 ha with a total production of 2937 t and an average yield of 1004 kg ha^{-1} (TUIK 2008).

Soil salinity and sodicity problems are present in nearly all irrigated area of the world and also occur on rangelands and non-irrigated croplands. Therefore, strategies to reduce these problems and new ways to use these extensive sodic and saline soils and water resources are vitally important (Pessarakli & Szabolcs 1999). To grow a crop on saline soils and/or with saline water, more information about salinity effects on both plant and soil are required.

This study was aimed at determining the effects of salinity in irrigation water and irrigation regime on vegetative growth, seed, and pod yields and water consumption of cowpea.

MATERIALS AND METHODS

Site description

Two experiments comprising irrigation water salinity and irrigation regime were carried out in two pot studies at the experimental field of Gaziosmanpaşa University, Turkey. The geographic coordinates of the experimental area are lat. 40°20′07″N and long. 36°28′26″E. To protect plants from rainfall, the pots were located in the experimental area under a polyethylene cover which was c. 1.8 m height from the surface.

Experimental design

In the salinity experiment, we used six different saline water treatments: 0.7 (S_0), 2.0 (S_1), 3.0 (S_2), 4.0 (S_3), 5.0 (S_4), and 7.0 dS m^{-1} (S_5). During the preparation of saline waters, sodium adsorption ratios (SAR) were maintained c. 5.0 to eliminate the effects of SAR for the salinity experiment. This was accomplished by mixing calculated amounts of $CaCl_2$, $MgSO_4$, and NaCl with water to produce the desired salinity level for each treatment. Electrical conductivity (EC_i) of saline waters was checked in the laboratory and then saline irrigation waters were used to irrigate treatments. Saline water for treatments was stored in 100-litre closed plastic containers.

For the irrigation regime experiment, there were four treatments including 1.43 (I_1), 1.0 (I_2), 0.75 (I_3), and 0.50 (I_4) of the water required to bring the pot soil to its field capacity. Only tap water (EC_i = 0.70 dS m^{-1}) was used to irrigate plants for this experiment. The I_1 treatment consisted of excess water application, I_2 complete water application, and I_3 and I_4 treatments limited water applications. The control treatment (S_0) for the salinity experiment was also used as an excess water treatment for irrigation regime experiment (I_1). Both experiments were conducted as randomised plot designs with five replications.

The pots used in the experiments were 27 cm in height, and 29 and 25 cm in top and bottom diameter, respectively. Soil depth in each pot was 21 cm. The soil used for both experiments was collected from a nearby field and sieved through a 4 mm screen to remove large particles. An 18.4 kg of air-dried soil was placed in each pot. The sandy loam textured soil used for the experiments had various physical and chemical properties (Table 1).

Seeds of cowpea (*Vigna unguiculata*) (Turgutlu local population) were sown in each pot on 10 June and harvested on 16 September. Fertilising needs were decided as 20, 50, and 30 kg ha^{-1} for nitrogen (N), phosphorus (P), and potassium (K), respectively (Akcin 1988). Therefore, at the beginning of the experiments, 2 g diammonium phosphates (DAP) was applied to each pot.

The field capacity weight of each pot was determined before the experiments started by saturating soil in pots with tap water, after which the soil surface was covered to prevent evaporation. After the drainage stopped, the weight of each pot was assumed as the field capacity weight (W_{FC}) of that pot. The amounts of irrigation water (IW) that should be applied were calculated using Equation 1 and Equation 2 for irrigation water salinity and irrigation regime experiments, respectively:

$$IW = \frac{\frac{W_{FC} - W}{\rho}}{1 - LF} \quad (1)$$

$$IW = \frac{(W_{FC} - W)}{\rho} \times C_A, \quad (2)$$

where LF is leaching fraction (Ayers & Westcott 1989) (0.30 for LF was aimed for in this experiment); W_{FC} is the pot weight (kg) at field capacity; W is the pot weight (kg) just before irrigation; ρ is water bulk density (1 kg litre^{-1}); and C_{AW} is water application coefficient.

Table 1 Some physical and chemical properties of the experimental soil.

Particle size distribution	
Sand (%)	64.3
Silt (%)	20.0
Clay (%)	15.7
Soil water contents (dry weight basis)	
Saturation (%)	38.6
Field capacity (%)	21.8
Wilting point (%)	5.1
Bulk density (g cm^{-3})	1.49
Electrical conductivity (EC_e) (dS m^{-1})	0.63
pHe (paste)	7.34

A drain pan was placed underneath each pot and volume of drainage water collected was measured. Throughout the experiment, the plants were irrigated at 3–6-day intervals.

Considering the water budget equation, total evapotranspiration for each pot was calculated using the following equation:

$$ET = \frac{(W_b - W_s)}{\rho} + (\sum IW - \sum R) \quad (3)$$

where W_b and W_s are the pot weights (kg) at the beginning and end of the experiments, respectively; ρ is water bulk density (1 kg litre^{-1}); IW and R are amounts of applied and drainage water (litres).

After the experiments ended, soil samples were taken from the entire depth of each pot and sieved using a 2-mm screen after drying under open air conditions. Saturated soil pastes were prepared for soil samples to determine soil salinity (EC_e).

Statistical analysis

Experimental data were analysed by using SPSS statistical analysis software (SPSS 2002). General linear models (GLM) were used to perform analysis of variance and to obtain regression coefficients (R^2) to measure the goodness of fit of linear models for the data. Unless otherwise noted, all statistical tests were performed at 0.01 levels of significance. The strengths of the linear correlations between variables were evaluated according to Devore & Peck (1993) who suggested that the relationship is strong if $R^2 \geq 64\%$, moderate if $25\% < R^2 < 64\%$, and weak if $R^2 \leq 25\%$. Duncan's multiple range test was used where appropriate for mean separations.

RESULTS

Effects of salinity and irrigation water rates on soil salinity

In the salinity experiment, soil salinities (EC_i) significantly increased with increasing electrical conductivities of applied irrigation water (EC_e) (Table 2). The lowest EC_e (0.74 dS m^{-1}) was obtained from control treatment whereas the highest (14.9 dS m^{-1}) from S_5 treatment. Considering EC_e values, S_3 and S_4 treatments were not different from each other. Leaching fraction (LF) values ranged from 0.27 (S_0) to 0.33 (S_5) with an average of 0.30. In addition, significant differences among LF values of treatments were observed (Table 2).

In the irrigation regime experiment, the highest EC_e (1.36 dS m^{-1}) was obtained from I_2 (control) treatment which was statistically different from that of I_1 treatment with the lowest EC_e (0.74 dS m^{-1}) value (Table 3). The low soil salinity value for I_1 treatment is expected since much more water was applied than needed. Thus, excess water leached some salts from soil. Compared to electrical conductivity of tap water (0.70 dS m^{-1}), EC_e values were 1.1, 1.9, 1.3, and 1.5 times higher for I_1, I_2, I_3, and I_4 treatments, respectively. Limited water applications (I_3 and I_4 treatments) caused lower salinities than full water application because less salt was added to soil in parallel to the amount of total water application.

Effects of salinity and irrigation water rates on growth and yield of cowpea

Dry pod and seed yields of cowpea among treatments were significantly different in the salinity experiment. The highest pod (9.17 g) and seed yields (6.75 g)

Table 2 Effect of irrigation water salinity on soil and selected parameters of cowpea (*Vigna unguiculata*). (EC, electrical conductivity; LF, leaching fraction; ET, evapotranspiration.)

	Treatments (dS m^{-1})						
Analysis	S_0(0.70)	S_1(2.0)	S_2(3.0)	S_3(4.0)	S_4(5.0)	S_5(7.0)	*P>F*
Soil EC_e (dS m^{-1})	0.74e	3.57d	6.19c	9.06b	9.52b	14.9a	0.01
LF	0.27e	0.30bc	0.29de	0.30bc	0.33a	0.32ab	0.01
Pod yield (g)	9.17a	7.75a	7.58a	9.15a	3.83b	4.59b	0.01
Seed yield (g)	6.75a	5.90a	5.74a	7.02a	2.80b	3.59b	0.01
Amount of pods	10.2ab	10.2ab	10.8ab	11.4a	7.4bc	5.8c	0.05
Amount of seeds	44.8a	37.8a	39.2a	47.2a	22.2b	18b	0.01
ET (litre)	33.3a	27.8b	25.8c	25.5c	23.2d	22.4d	0.01
100-seed weight (g)	15.42b	15.80ab	15.12b	14.98b	12.96b	19.58a	0.05
Veg. dry weight (g)	9.87a	7.70bc	8.22ab	6.93bcd	5.26d	6.22cd	0.01
Pod length (cm)	9.9a	8.8abc	8.8abc	9.4ab	8.0c	8.6bc	0.05
Leaf yellow colour value	27.2ab	27.8ab	30.6a	28.6ab	26.3bc	23.0c	0.05

were obtained from S_0 which was not significantly different from those of S_1, S_2, and S_3 treatments. Significantly lower yields were observed for S_4 and S_5 treatments (Table 2). Compared with the control treatment, relatively lower yields were obtained from S_4 and S_5 treatments, which were 58% and 50% for pod and 59% and 47% for seed yields, respectively.

In the irrigation regime experiment, there were significant differences among treatments in pod and seed yields of cowpea at the 0.05 probability level. The highest pod (12.0 g) and seed yields (9.40 g) were obtained from the I_2 treatment, whereas the lowest from I_4 treatment were 7.43 g and 6.14 g, respectively. For pod yield, I_2 treatment was not significantly different from those of I_1 and I_3 treatments, whereas seed yield from I_2 treatment was significantly different from those of the other treatments (Table 3). Compared with I_2 treatment, relative pod yield was lower for I_4 treatment (38%). Similarly, relative seed yield was lower for I_1, I_3, and I_4 treatments (28%, 32%, and 35%, respectively).

The number of pods and seeds of cowpea showed similar results to those of pod and seeds yields from both experiments (Tables 2 and 3). For the salinity experiment, significant differences among treatments for number of pods ($P < 0.05$) and for number of seeds ($P < 0.01$) were obtained (Table 2). Distinctive differences were obtained in the number of pods and seeds at EC_i values greater than 3.0 dS m^{-1} or EC_e values greater than 9.0 dS m^{-1}. Similarly, the number of pods and seeds of cowpea showed significant differences among treatments of irrigation regime ($P < 0.05$). The highest values were obtained from I_2 treatment which was significantly different from those of the limited water applications of I_3 and I_4 treatments (Table 3). Considering these results it can be concluded that limited water applications can cause important decreases in number of pods and seeds of cowpea.

Weights of 100-cowpea seeds were significantly different among treatments of each experiment ($P < 0.05$) (Tables 2 and 3). The highest 100-seed weight, 19.58 g, was obtained from S_5 which was significantly different from those of other treatments except S_1 treatment of salinity experiment. S_4 treatment which produced the lowest 100-seed weight was similar to S_0, S_1, S_2, and S_3 (Table 2). In the irrigation experiment, the highest 100-seed weight was obtained from the I_4 treatment (21.65 g) which was significantly different only from that of I_1 treatment, 15.42 g (Table 3). Thus, an increase in water stress seems to cause formation of bigger seeds.

Although vegetative dry weights among treatments showed significant differences for salinity experiment, there was no significant differences among irrigation regime experiment (Tables 2 and 3). Increase in salt concentration of irrigation water or soil salinity caused slight decreases in vegetative weights of cowpea. The highest value was obtained from control treatment (9.87 g) which was significantly different from those of the other treatments except S_2 treatment (8.22 g) (Table 2). Compared with the control treatment, the relative vegetative weights were 22%, 30%, 47%, and 37% lower for S_1, S_3, S_4, and S_5 treatments, respectively.

Pod length values from the salinity experiment showed significant differences among treatments ($P < 0.05$) whereas no significant difference was found for pod length from the irrigation regime experiment (Tables 2 and 3). The highest pod length was observed

Table 3 Effect of irrigation regime on soil and selected parameters of cowpea (*Vigna unguiculata*). (EC, electrical conductivity; LF, leaching fraction; ET, evapotranspiration; NS, not significant.)

Treatments:	I_1 (1.43)	I_2 (1.00)	I_3 (0.75)	I_4 (0.50)	*P*>*F*
Soil EC_e (dS m^{-1})	0.74c	1.36a	0.92ab	1.06ab	0.01
LF	0.27a	0.06b	0.00c	0.00c	0.01
Pod yield (g)	9.17ab	12.0a	9.52ab	7.43b	0.05
Seed yield (g)	6.75b	9.40a	6.41b	6.14b	0.05
Amount of pods	10.2ab	12.8a	8.8b	7.5b	0.05
Amount of seeds	44.8ab	54.3a	36bc	29c	0.05
ET (litre)	33.3a	32b	25.9c	19.3d	0.01
100-seed weight (g)	15.42b	17.43ab	20.68a	21.65a	0.05
Veg. dry weight (g)	9.94	10.10	9.98	7.88	NS
Pod length (cm)	9.9	9.6	9.4	8.9	NS
Leaf brightness	49.9a	50.1a	45.1b	45.8b	0.01
Leaf green colour value	−15.6b	−16.6b	−12.8a	−13.8a	0.01

in the S_0 treatment (9.9 cm) followed by S_3 (9.4 cm), and S_1 and S_2 (8.8 cm) treatments, and the lowest pod length was from the S_4 (8.0 cm) treatment. Again, distinctive differences for pod length of cowpea start at EC_i values greater than 3.0 dS m^{-1}.

Effects of salinity and irrigation water rates on evapotranspiration of cowpea

Effect of irrigation water and/or soil salinity on ET was found to be significantly different (Table 2). Increase in salt concentration of irrigation water or soil salinity caused decreases in ET. The highest ET value (33.3 litre) was obtained from control treatment which was significantly different from those of the other treatments, whereas the lowest (22.4 litre) was from S_5 treatment which was not significantly different from that of S_4 treatment (23.2 litre). Compared with the control treatment, cowpea in S_1, S_2, S_3, S_4, and S_5 treatments consumed relatively less water (17%, 23%, 24%, 30%, and 33%, respectively).

Owing to the nature of the irrigation regime experiment, excess water was applied to I_1, full amount, and I_2, and limited water to I_3 and I_4 treatments. Thus, different amounts of water applications affected water consumptions of cowpea (Table 3).

Effects of salinity and irrigation water rates on leaf colour of cowpea

During the study period, colour changes in leaves were easily differentiated visually in both experiments. One month before the harvest, colours of three leaves of plants were measured by using Minolta CR-300 equipment for each treatment of both experiments. According to variance analysis results, yellow colour (+b) variation for salinity experiment ($P < 0.05$), brightness (L), and green colour (–a) variation for irrigation regime ($P < 0.01$) showed significant differences. In the salinity experiment, the highest yellow colour value (30.6) was observed for S_2 treatment which was significantly different from those of S_4 (26.3) and S_5 (23.0) treatments. High level of irrigation water or soil salinities resulted in decreases in yellow colour value of leaves. Similarly, limited water applications caused decreases in brightness of leaves but increases in green colour value of leaves.

Relationships between observed parameters

Linear relationships (R^2) between selected parameters of both experiments are presented in Table 4. In the irrigation regime experiment, there were significant strong positive or negative (–) relationships between seed yield and dry pod yield (98%), number of seeds (78%), and number of pods (69%); leaching fraction and applied water (92%) and ET (73%); ET versus applied water (94%); applied water versus weight of 100-seed (–67%); number of pods versus number of seeds (78%) and dry pod yield (69%); and number of seeds versus dry pod yield (84%). Significant moderate positive relationships were found between leaching fraction versus pod length (47% at $P < 0.05$); ET versus number of seeds (62%), number of pods (54% at $P < 0.05$), pod length (53% at $P < 0.05$), and dry pod yield (47% at $P < 0.05$); applied water versus pod length (53% at $P < 0.05$), number of seeds (52% at $P < 0.05$), and number of pods (42% at $P < 0.05$). There were significant moderate negative relationships between soil salinity versus leaching fraction (–51% at $P < 0.05$); leaching fraction versus weight of 100-seed (–62%); applied water versus weight of 100-seed (–67%); number of pods versus weight of 100-seed (–44% at $P < 0.05$); and number of seeds versus weight of 100-seed (–58%). The rests of the linear relationships between other parameters from irrigation regime experiment were weak or not significant.

In the irrigation water salinity experiment, significant strong positive or negative (–) relationships between seed yield versus dry pod yield (99%), number of seeds (92%), and number of pods (76%); soil salinity versus ET (–87%) and applied water (–86%); leaching fraction versus ET (–73%); ET versus applied water (98%); number of pods versus dry pod yield (79%) and number of seeds (76%); and number of seeds versus dry pod yield (92%) were obtained. There were significant moderate positive relationships between seed yield versus ET (57%), applied water (54%) and pod length (37% at $P < 0.05$); soil salinity versus leaching fraction (58%); ET versus dry pod yield (62%), number of seeds (54%), and number of pods (39% at $P < 0.05$); applied water versus dry pod yield (59%), number of seeds (51%), pod length (47%), and number of pods (38% at $P < 0.05$); and dry pod yield versus pod length (39% at $P < 0.05$). Significant moderate negative relationships were found between seed yield versus soil salinity (–56%) and leaching fraction (–50%); soil salinity versus dry pod yield (–61%), number of seeds (–56%), and number of pods (–52%); leaching fraction versus applied water (–58%), dry pod yield (–54%), pod length (–51%), and number of seeds (–47%); ET versus pod length (–51%) and number of seeds versus weight of 100-seed (–33% at $P < 0.05$). The remainder of the linear relationships between other parameters from salinity experiment were not significant.

Table 4 Linear relationships (R^2) between selected parameters of experiments. (ET, evapotranspiration; AW, applied water; APOD, amount of pods; ASEE, amount of seeds; DPY, dry pod yield; PLE, pod length; WHS, 100-seed weight; SY, seed yield; SS, soil salinity; LF, leaching fraction.)

Parameters	SY	SS	LF	ET	AW	APOD	ASEED	DPY	PLE
Irrigation regime experiment									
SY	1.00								
SS	0.35	1.00							
LF	–0.11	–0.51 <0.05	1.00						
ET	0.32	–0.09	0.73 <0.01	1.00					
AW	0.14	–0.31	0.92 <0.01	0.94 <0.01	1.00				
APOD	0.69 <0.01	0.21	0.19	0.54 <0.05	0.42 <0.05	1.00			
ASEED	0.78 <0.01	0.11	0.31	0.62 <0.01	0.52 <0.05	0.78 <0.01	1.00		
DPY	0.98 <0.01	0.26	0.02	0.47 <0.05	0.29	0.69 <0.01	0.84 <0.01	1.00	
PLE	0.23	–0.29	0.47 <0.05	0.53 <0.05	0.53 <0.05	0.18	0.25	0.32	1.00
WHS	0.02	0.29	–0.62 <0.01	–0.62 <0.01	–0.67 <0.01	–0.44 <0.05	–0.58 <0.01	–0.12	–0.12
Salinity experiment									
SY	1.00								
SS	–0.56 <0.01	1.00							
LF	–0.50 <0.01	0.58 <0.01	1.00						
ET	0.57 <0.01	–0.87 <0.01	–0.73 <0.01	1.00					
AW	0.54 <0.01	–0.86 < 0.01	–0.58 <0.01	0.98 <0.01	1.00				
APOD	0.76 <0.01	–0.52 < 0.01	–0.27	0.39 <0.05	0.38 <0.05	1.00			
ASEED	0.92 <0.01	–0.56 < 0.01	–0.47 <0.01	0.54 <0.01	0.51 <0.01	0.76 <0.01	1.00		
DPY	0.99 <0.01	–0.61 <0.01	–0.54 <0.01	0.62 <0.01	0.59 <0.01	0.79 <0.01	0.92 <0.01	1.00	
PLE	0.37 <0.05	–0.23	–0.51 <0.01	–0.51 <0.01	0.47 <0.01	–0.08	0.38	0.39 <0.05	1.00
WHS	0.03	0.20	0.06	–0.09	–0.09	–0.15	–0.33 <0.05	0.01	–0.11

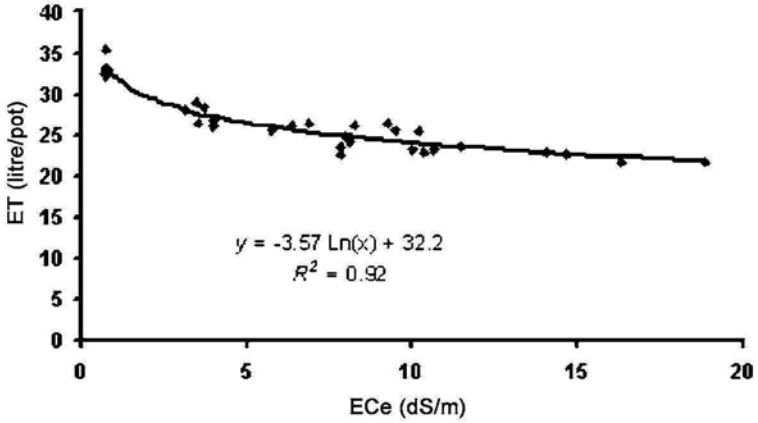


Fig. 1 Relationship between evapotranspiration (ET) and salinity for cowpea (*Vigna unguiculata*). (K_s, stress coefficient; EC, electrical conductivity.)

DISCUSSION

Effects of irrigation water salinity and irrigation regimes on growth parameters of cowpea were investigated in this study. In general, the numbers of pods and seeds, pod length, pod and seed yields are considered as growth parameters for cowpea (Aryeetey & Laing 1972; Umaharan et al 1997). In addition to these parameters, dry pod weight and 100-seed weight were taken into consideration.

Soil salinities showed significant increases depending on the salinity level of applied irrigation water. For S_0, S_1, S_2, S_3, S_4, and S_5 treatments, the ratios of EC_e/EC_i were 1.1, 1.8, 2.1, 2.3, 1.9, and 2.1 respectively. Since salt concentration of the control treatment and soil salinity at the beginning of the experiments were low, this treatment did not cause an important change in soil salinity value at the end of the experiment. Applied water to soil is lost from the soil surface via evaporation and transpiration by plants, and salts added to soil with water stays in the soil. In irrigation regime experiment, soil salinities increased with increased amount of applied irrigation water except excess water application with the I_1 treatment that caused some leaching of salts from the soil. Even though the soil salinity level of the I_2 was the highest among treatments of the irrigation regime experiment, the highest yields was also obtained from this treatment. In this treatment, dominant stress effects on plants were a result of limited water which surpassed the effects of other stresses. Compared with I_2 treatment, lower yield in I_1 treatment might have been owing to removal of nutrients with drainage water and/or exposure to anaerobic conditions of plant roots for a long time period. In the I_2 treatment, however, it was possible that a good equilibrium existed between water and air in the root zone, and the plants used plant nutrients more effectively.

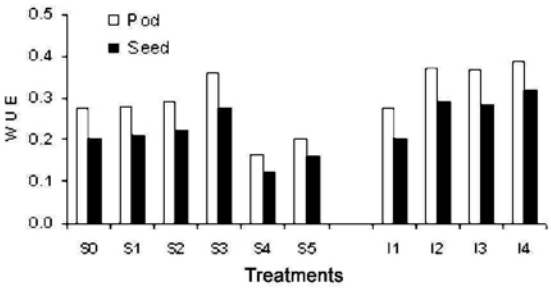


Fig. 2 Effects of salinity and irrigation regime on water use efficiency (WUE) of cowpea (*Vigna unguiculata*).

Salinity clearly caused lower pod and seed yields of cowpea, especially for soil salinity values higher than 9 dS m^{-1}. However, West & Francois (1982) stated that cowpea yield was lower by 12% per unit increase in soil salinity after 4.9 dS m^{-1}, which is the threshold value of cowpea. It seems that our results contradict those of West & Francois (1982). Maas (1990) stated that the threshold value of a plant is not definite. Tolerance to salinity depends on many factors, limitations, and conditions. Salt types, growth conditions, age of plant, and growth period are among these

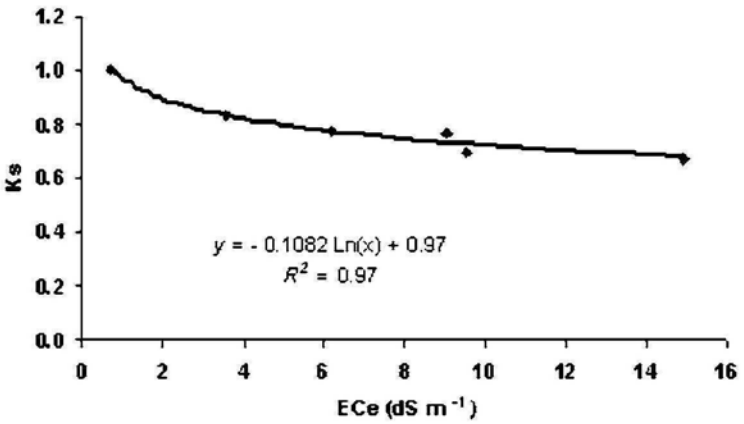


Fig. 3 Relationship between soil salinity and salinity stress coefficient for cowpea (*Vigna unguiculata*). (EC, electrical conductivity.)

factors. Dadson et al. (2005) conducted a 2-year study on 10 different genotypes of cowpea and stated that there were important differences in seed yield among genotypes. For the first and second year of the study, the lowest (1515 and 2560 kg ha^{-1}, respectively) and the highest (4467 and 4588 kg ha^{-1}, respectively) seed yields were obtained from different genotypes. Therefore, it is possible for cowpea to give different responses either owing to difference in environmental factors and/or difference among genotypes. Murillo-Amador et al. (2006) conducted an experiment to evaluate the effect of salinity on the early vegetative growth of 25 cowpea genotypes. The cowpea genotypes were exposed to 0, 85, and 170 m*M* NaCl saline treatments. They found that eight genotypes were salt-tolerant, five genotypes moderately salt-tolerant, nine genotypes moderately salt-sensitive, and three genotypes salt-sensitive. These results showed that there are large differences in responses to salinity among the cowpea genotypes.

Increase in soil salinity caused a logarithmic decrease in ET (Fig. 1). Rhoades et al. (1992) stated that excess salinity within the plant root zone has a deleterious effect on plant growth which is manifested as nearly equivalent reductions in the transpiration and growth rates (including cell enlargement and the synthesis of metabolites and structural compounds). In this study, pod and seed yields of cowpea were negatively affected from salinity which also caused decrease in ET. This situation also caused differences in water use efficiency (Fig. 2). Even though yields up to S_3 treatment were not significantly lower, decreased ET caused increases in water use efficiencies. However, in extreme salinity levels, water use efficiencies considerably decreased in important degrees. In the irrigation regime experiment, water use efficiency showed a clear difference in excess water application treatment.

Effect of salinity in lowering evapotranspiration should be considered in irrigation planning and scheduling, especially by an adjustment under salinity conditions with a constant value which depends on soil salinity. The excess application of saline irrigation water that makes the drainage system work at low capacity can be prevented by this adjustment. Decreasing the amount of drainage water that is saline and rich in plant nutrients means decreasing its harmful effect on the environment. The adjustment for evapotranspiration in cowpea from salinity is estimated by the following equation by Allen et al. (1998):

$$ET_{adj} = K_s \times K_c \times ET_c = K_s \times ET_m \quad (4)$$

in which $K_c \times Et_c$ is the evapotranspiration observed for the control treatment (ET_m) and K_s is stress coefficient. The K_s coefficient, ET_{adj}/ET_m for saline treatments were calculated and plotted against soil salinity values (Fig. 3). A logarithmic relationship was obtained between ET_{adj}/ET_m and EC_e. From this relationship, the following equation for K_s coefficient can be used for cowpea:

$$K_s = -0.1082 \text{ Ln } (EC_e) + 0.97 \quad (5)$$

For the situation where optimum water is provided, plants are not exposed to water stress and evapotranspiration reaches to its maximum level, thus, maximum yield is obtained. Otherwise, if irrigation practices are not done in time and at the

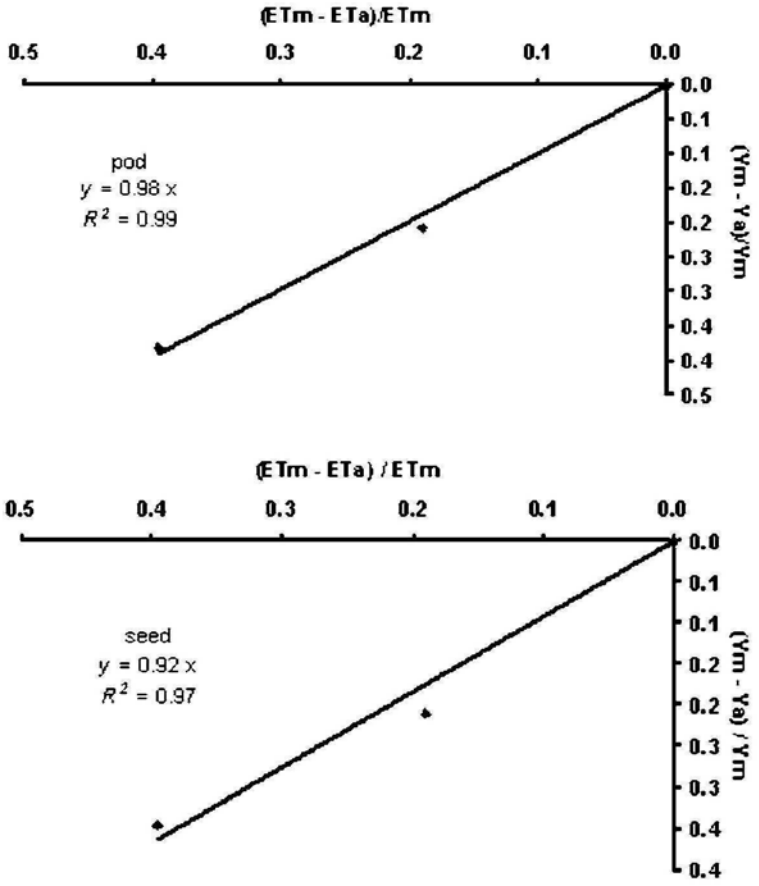


Fig. 4 Relationship between relative evapotranspiration (ET) and relative yield loss. (K_s, stress coefficient.)

required level, plants show water stress effects which cause a decrease in evapotranspiration and yield. Steward & Hagan (1973) formulated yield decrease for per unit decrease in ET as yield response factor:

$$\frac{Y_m - Y_a}{Y_m} = K_y \frac{ET_m - ET_a}{ET_m}; \frac{\Delta Y}{Y_m} = K_y \frac{\Delta ET}{ET_m} \qquad (6)$$

in which, Y_a and ET_a are actual crop yield and evapotranspiration, respectively, under deficit irrigation conditions; Y_m and ET_m are maximum crop yield and evapotranspiration under non-deficit water conditions; and K_y is the crop yield response coefficient.

The yield response factor (K_y) has been used to evaluate plant tolerance to water stress (Doorenbos & Kassam 1986). For $K_y \leq 1$, the plant is tolerant; for $K_y \geq 1$, the plant is sensitive to water stress. From I_2 treatment of the irrigation regime experiment, if the yield value as Y_m and evapotranspiration as ET_m is used in Equation 6, yield response factors for seed and pod yield can be obtained as 0.92 and 0.98, respectively (Fig. 4). According to these results, cowpea is very slightly tolerant to water stress in terms of seed and pod yields.

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