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Effect of salinity on emergence and on water stress and early seedling growth of sunflower and maize

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Abstract

To study the effect of salinity on the emergence and early seedling growth of sunflower and maize, experiments were conducted in pots filled with sandy clay and sandy loam. The experiments consisted of a control and four saline water qualities with chloride concentrations of 15, 30, 45, and 60 meq/l. The emergence of sunflower and maize were affected by salinity. Soil texture did not affect the emergence. During early seedling growth, salinity and soil texture affected the development of the seedlings that showed symptoms of water stress in the form of lower leaf water potential, stomatal conductance, and evapotranspiration. The higher the salinity, the lower the leaf area and the dry matter production. Leaf, stem, and root showed an almost similar growth reduction due to salinity. Seedlings on sandy loam were more affected by water stress than those on sandy clay.

Keywords: Soil salinity; Early seedling growth; Leaf water potential; Stomatal conductance; Maize; Sunflower

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1. Introduction

Salt tolerance of plants varies during their successive growth stages (Bernstein and Hayward, 1958). The first stage, during which the crop is established, is regarded as particularly difficult, even for tolerant crops (Bernstein and Fireman, 1957; Maas and Hoffman, 1977). Seeds and young seedlings are exposed to much higher salt concentrations than later on; their environment is still limited to a top layer, the salt concentration of which is increased through the loss of water by evapotranspiration and the increase of salt by capillary rise from underlying layers (Bernstein, 1974; van Hoorn, 1991).

The establishment stage of the crop consists of three parts: germination, emergence, and early seedling growth. When seeds are placed in the soil, germination can only be observed as emergence, which may be affected by the water content and structure of the top soil. Much information is available in literature about the effects of water quality, soil texture and soil salinity on germination and emergence (Grillot, 1957; Maas, 1986). Much less information is available about their effect on water stress and growth of leaf area and dry matter during early seedling growth, because young seedlings are rather delicate material for such measurements.

In a previous paper (van Hoorn, 1991), the salinity effect during early seedling growth was shown as a reduction in evapotranspiration and in relative growth rate. This paper intends to illustrate the salinity effect on water stress and early seedling growth by also presenting leaf water potential, stomatal conductance, leaf area, and dry matter production. The methodology used in this study has been described in previous papers (Katerji et al., 1992; van Hoorn et al., 1993). Two crops were used: sunflower and maize. Sunflower, which belongs to the plants with C_3 metabolism, is classified as moderately salt sensitive (Ayers and Westcot, 1985) but, during early seedling growth, is not less tolerant than safflower, sorghum, and wheat (van Hoorn, 1991). Maize, which belongs to the plants with C_4 metabolism, is also classified as moderately sensitive.

2. Experimental procedure

2.1 Set-up

The experiment was conducted at the Mediterranean Agronomic Institute of Bari in southern Italy from March till June 1993 in a greenhouse, where temperature, relative humidity, and evaporation of a Class A pan were measured daily. The set-up consisted of 150 plastic pots with a diameter increasing from 15 to 22 cm, and a depth of 22 cm, half of which were filled with sandy clay and the other half with sandy loam. Table 1 presents some physical soil properties. Sunflower (*Helianthus annuus*), variety hybrid ISA, was sown on 21 March and maize (*Zea mays*), variety hybrid 188, on 4 May, each crop at a density of 20 seeds per pot. After the emergence percentage had been determined, the seedlings were thinned out to a number of 6 per pot.

Table 1

Physical soil properties

Soil	Particle size in % of mineral parts			Bulk density kg/dm ³	% water by volume	
	< 2 μ m	2–50 μ m	> 50 μ m		field cap.	wilt. point
Sandy clay	42	16	42	1.13	36.7	30.7
Sandyloam	12	6	82	1.28	9.0	7.0

The pots were irrigated with water of five different qualities: the control treatment with fresh water, containing 3.7 meq Cl/l and an EC of 0.9 dS/m, and four saline treatments, containing 15, 30, 45 and 60 meq Cl/l with EC values of 2.3, 3.8, 5.3, and 6.8 dS/m, respectively, obtained by adding equivalent amounts of NaCl and CaCl₂ to fresh water. The irrigation interval was 10 days for sunflower and 8 days for maize.

Since the set-up consisted of 150 pots, 15 replicates were available for each treatment.

2.2. Soil salinity

In the absence of drainage, soil salinity could be determined without sampling simply by measuring the amount of irrigation water and

calculating the amount of chloride added to the soil. As the pots were weighed after the first irrigation and before each of the following irrigations, the amount of water lost by evapotranspiration and the amount of remaining soil water could be calculated, and so too could the chloride concentration before and after irrigation as an average value for the pot.

The equation $\ln EC = 0.824 \ln Cl - 1.42$, established for these types of irrigation waters on similar soils (van Hoorn et al., 1993) was used to convert Cl - into EC of soil water at field capacity, which value was divided by 2 for the conversion into EC_e .

2.3. Water stress of the plant

Three parameters were used to characterize the water stress of the plant: the pre-dawn leaf water potential, the hourly leaf water potential, and the stomatal conductance. These parameters were measured on both soils for the control, 30 and 60 meq Cl/l.

The pre-dawn leaf water potential and the hourly leaf water potential of sunflower were measured by taking the whole plant and incorporated in that way all leaves. The predawn leaf water potential of maize was measured by taking the whole plant only the first three times. Afterwards, because its growth was much faster and the plants became too big for the pressure chamber, the pre-dawn and the hourly leaf water potential were measured on the young top leaves, which were not affected by senescence and more homogeneous than the old leaves.

The pre-dawn leaf water potential was measured every 3 days. A complete cycle of the hourly leaf water potential was measured on the day when the final dry matter yield was determined, for sunflower 37 days after sowing and for maize 30 days after sowing. The leaf water potential was measured with a pressure chamber on six plants or leaves taken at random from the 15 replicates of each treatment. During the maize experiment, the stomatal conductance was measured with an automatic porometer (Li1600), also on six leaves taken at random from the 15 replicates.

2.4. Evapotranspiration

Evapotranspiration was determined by weighing the pots after the first irrigation, when water had been added to obtain field capacity, and before each of the following irrigations. As the amount of irrigation water corresponded with the water loss during the previous irrigation interval, the difference between the weight after the first irrigation and the weight before the following irrigations corresponded with the evapotranspiration, since the correction for the weight increase due to plant growth was negligible.

2.5. Growth of leaf area and dry matter

The growth of leaf area and dry matter of leaf, stem, and root were determined twice on all treatments: for sunflower 22 and 37 days after sowing and for maize 10 and 30 days after sowing. The seedlings were first used to measure the leaf area with the apparatus AM-Licor 1300, and then to measure the dry matter by drying at 85°C for 48 h.

3. Results and discussion

3. 1. Soil salinity

Table 2 shows the development of the chloride concentration of soil water during germination, emergence, and early seedling growth of sunflower as the average for both soils, between which the difference was negligible. The chloride concentration increased between two irrigations because of water loss. The lower the salinity of the irrigation water, the higher the water loss. Before the third irrigation the soil water content attained the wilting point and was even below it for the control treatment. Before the fourth irrigation the soil water content was below the wilting point for all treatments. Moreover, the chloride concentration increased with each irrigation because irrigation water was added till field capacity without any leaching and drainage taking place.

Table 3 presents soil salinity during the early seedling growth of sunflower and maize, expressed as Cl-concentration and EC_e and calculated as the average for both soils after the second, third, and

fourth irrigation. During the maize experiment, soil salinity was somewhat higher owing to the higher evapotranspiration and consequently larger water applications.

3.2. Emergence of sunflower and maize

Table 4 shows the emergence percentage of sunflower and maize. For sunflower, emergence started 4 days after sowing and was completed 6 days later, 10 days after sowing.

Table 2

Chloride concentration of soil water (meq/l) during germination, emergence and early seedling growth of sunflower. Average for both soils

Treatment	1st irrigation	2nd irrigation		3rd irrigation		4th irrigation	
	after	before	after	before	after	before	after
Control	3.7	7.2	5.5	40	8.6	108	12
15 meq Cl/l	15	25	21	103	33	274	46
30	30	50	41	175	64	400	89
45	45	70	61	260	95	600	133
60	60	98	79	320	124	775	166

Table 3

Soil salinity during early seedling growth of sunflower and maize, expressed as chloride concentration of soil water (meq/l) and as EC_e (dS/m). Average for both soils after second, third and fourth irrigation

Treatment	Sunflower		Maize	
	Cl-concentration	EC_e	Cl-concentration	EC_e
Control	9	0.1	10	0.1
15 meq Cl/l	33	2.1	40	2.1
30	65	3.1	78	4.1
45	96	5.1	115	6.1
60	123	6.1	151	7.1

For maize, emergence started 3 days after sowing and was completed after 6 days. The difference between the two crops can be ascribed to the difference in temperature: for sunflower the average maximum and minimum temperature was 15 and 6.4°C, and for maize, 21.5 and 11.9°C.

Both soils with approximately the same salinity showed the same development: at the start, a delay in emergence with increasing salinity and, at the end, a lower emergence percentage, slightly lower for sunflower than for maize.

Table 4

Development of emergence percentage of sunflower and maize after sowing

Crop	Time (days)	Cl ⁻¹ concentration of irrigation water (meq/l)									
		3.7	15	30	45	60	3.7	15	30	45	60
		Sandy clay					Sandy loam				
Sunflower	4	55	53	47	45	43	64	63	61	57	38
	7	78	72	69	63	61	76	75	73	70	61
	10	95	90	85	79	74	93	91	86	81	76
Maize	3	56	60	48	49	42	68	68	50	42	39
	4	78	72	69	70	64	84	84	65	60	56
	6	95	92	89	87	82	95	95	87	85	81

3.3. Water stress of the seedlings

The pre-dawn leaf water potential (Fig. 1) of sunflower seedlings differed with the three water qualities and their corresponding soil salinities: the higher the salinity, the lower the leaf water potential. Soil texture also had a slight effect: the values measured on sandy loam were systematically lower than those on sandy clay, although the differences were not always significant.

The pre-dawn leaf water potential (Fig. 2) of maize seedlings showed the same differences caused by salinity and soil texture as sunflower. The first three measurements were made by taking the whole plant and incorporated all leaves, whereas afterwards the measurements were only made on green leaves, not affected by senescence, and showed higher values, the effect of salinity and soil texture remaining the same.

Fig. 3 presents the hourly values of the leaf water potential and the stomatal conductance of maize seedlings. The leaf water potential decreased after dawn, attained a minimum around solar noon, and afterwards increased again. Sunflower seedlings showed a similar daily trend. The stomatal conductance increased during the morning, attained a maximum value also around solar noon, and afterwards decreased to

attain its minimum value again around 18 h. All treatments showed the same development of the stomatal conductance, but the saline treatments less clearly than the control treatment. Leaf water potential and stomatal conductance were affected in the same way by salinity and texture. The higher the salinity, the lower the leaf water potential and the lower the stomatal conductance. Sandy loam showed lower values than sandy clay.

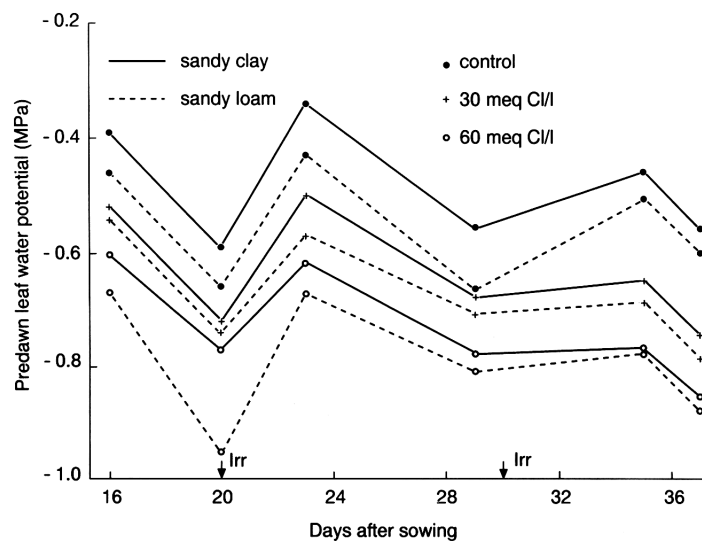


Fig. 1. Pre-dawn leaf water potential of sunflower seedlings vs. days after sowing.

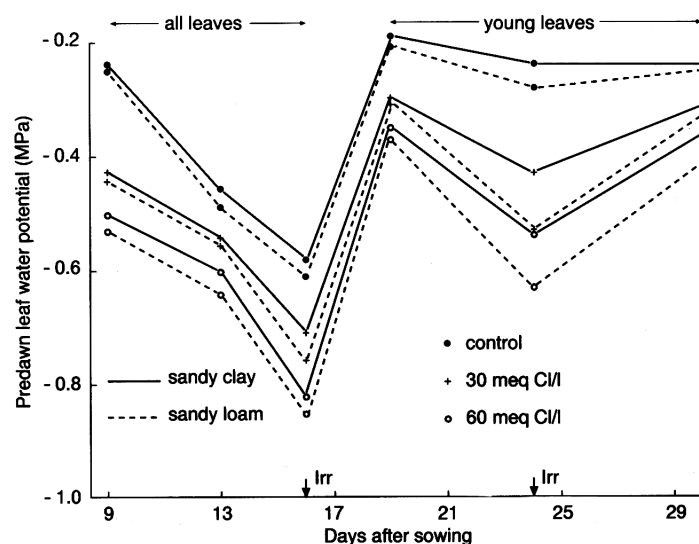


Fig. 2. Pre-dawn leaf water potential of maize seedlings vs. days after sowing.

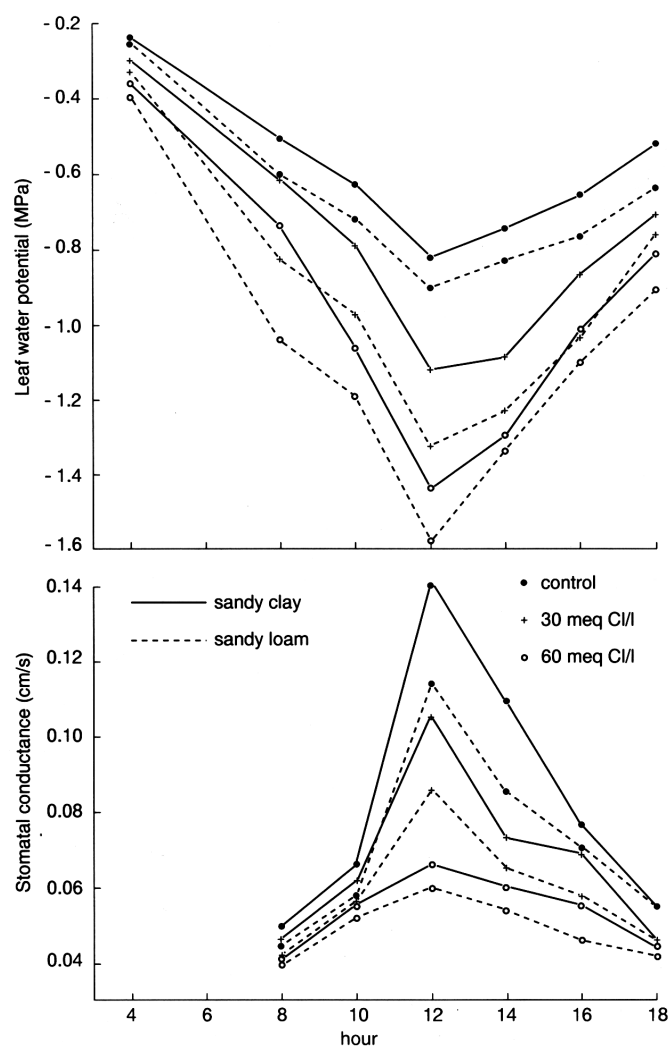


Fig. 3. Daily course of leaf water potential and stomatal conductance of maize.

3.4. Evapotranspiration

Table 5 presents the average evapotranspiration of sunflower during 37 days after sowing and of maize during 30 days after sowing. Salinity and soil texture both affect the evapotranspiration, corresponding with their effect on leaf water potential and stomatal conductance. The effect is rather small because, during early seedling growth, evaporation of the soil is still large compared to transpiration of the plant.

Table 5

Average evapotranspiration after sowing (mm/day)

Treatment	Sunflower		Maize	
	Sandy clay	Sandy loam	Sandy clay	Sandy loam
Control	3.4	3.2	4.3	3.9
15 meq C1/1	3.1	3.0	4.0	3.7
30	3.0	2.8	3.9	3.6
45	2.9	2.8	3.7	3.5
60	2.8	2.7	3.6	3.4

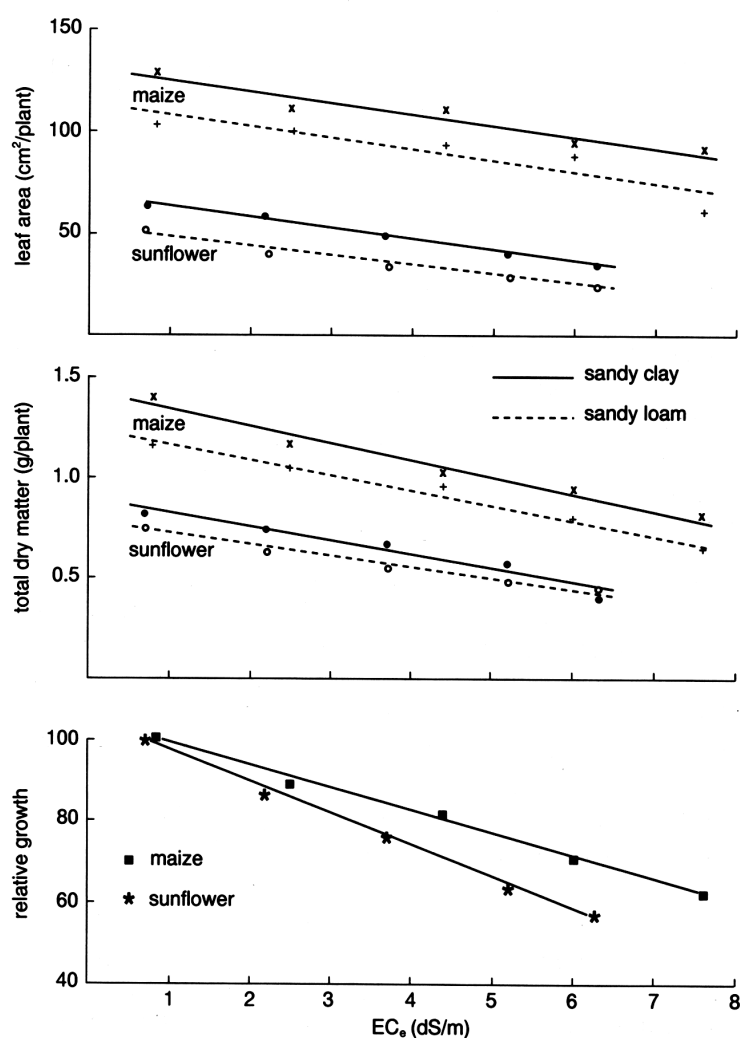


Fig. 4. Leaf area, total dry matter, and relative growth vs soil salinity.

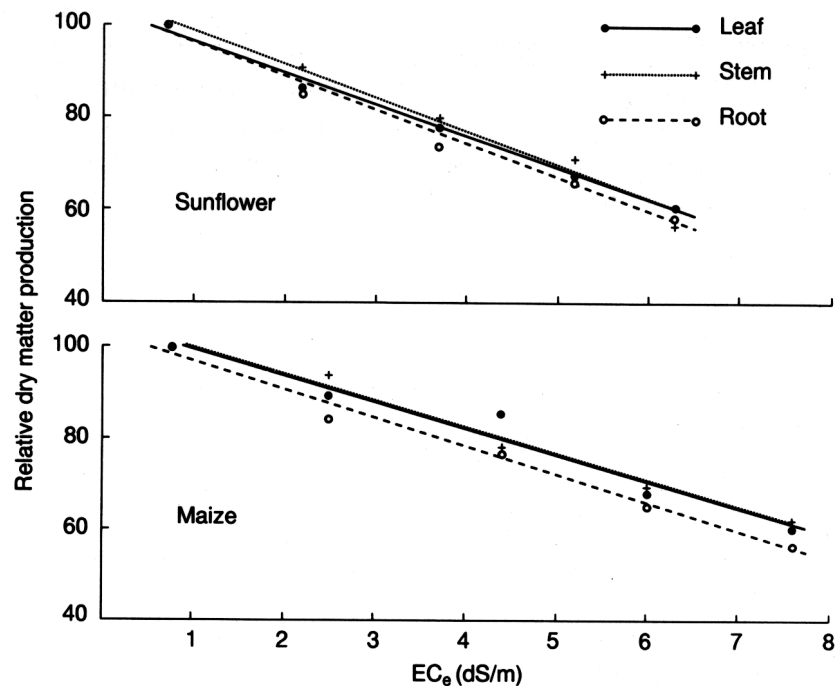


Fig. 5. Relative dry matter production of leaf, stem, and root vs soil salinity.

3.5. Growth of leaf area and dry matter

Fig. 4 shows the effect of soil salinity, expressed by the EC_e-values of Table 3, on leaf area and total dry matter from leaf, stem, and root, determined 37 days after the sowing of sunflower and 30 days after the sowing of maize on the same day as hourly leaf water potential and stomatal conductance were measured. Leaf area and dry matter were higher for maize (a plant with C₄ metabolism) than for sunflower (a plant with C₃ metabolism). The total dry matter production of sunflower was approximately 60% of that of maize, corresponding quite well with field observations of both crops (Blanchet et al., 1982). Another difference between sunflower and maize concerns the distribution of dry matter, the ratio between the roots and the total dry matter being approximately 0.5 for maize against 0.2 for sunflower. Salinity and soil texture both affect leaf area and dry matter production in the same way as they affect leaf water potential, stomatal conductance, and evapotranspiration. The dry matter production on sandy loam was about 12% lower than on sandy clay.

Relative growth values were calculated as average values of 4 observations of leaf area and 4 observations of dry matter, obtained from both soils on the 22nd and 37th day after the sowing of sunflower and on the 10th and 30th day after the sowing of maize. During early seedling growth, maize showed growth reductions of 10 and 25% at EC_e values of 2.5 and 5.4 dS/m against similar grain yield reductions at harvest time at EC_e values of 2.5 and 3.8 dS/m according to Ayers and Westcot (1985). Thus, maize does not appear to be more salt sensitive during early seedling growth than during the later growth stage. Sunflower appears to be somewhat more sensitive than maize during early seedling growth.

Fig. 5 presents the relative dry matter production separately for leaf, stem, and root versus soil salinity, calculated as an average for both soils. The three parts of the plant showed an almost similar growth reduction, the reduction of root growth being slightly more severe for both crops.

4. Conclusion

The emergence of sunflower and maize showed a reduction of the emergence percentage between the control and the most saline treatment of respectively 21 and 14% whereas the growth reduction during early seedling growth was about 40% for both crops. Soil texture did not affect the emergence. An increase in seed density could counterbalance the emergence reduction in practice.

During early seedling growth, salinity and soil texture affected the development of the seedlings that showed symptoms of water stress. These symptoms could be observed in the form of leaf water potential, stomatal conductance, and evapotranspiration. The consequence of water stress could already be observed some days after emergence as a reduction in leaf area and dry matter growth. The higher the soil salinity, the higher the water stress, expressed by lower leaf water potential, stomatal conductance, and evapotranspiration, and the lower the leaf area and dry matter production. Seedlings on sandy loam were more affected by water stress than those on sandy clay, showing lower leaf water potential, stomatal conductance, and evapotranspiration, and a dry matter reduction of about 12%.

The classical explanation of water stress in plants growing in a saline environment is the reduced availability of soil water due to its osmotic potential. The reduction in root growth may provide a supplementary explanation. It is also possible that the reduction in root development and a delay in the exploration of soil at greater depth causes less water and fewer nutrients to be available for the plant.

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