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Effect of salinity on water stress, growth and yield of broadbeans

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Abstract

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Broadbeans were grown on clay in tanks and irrigated with water of three different levels of salinity. During the experiment, soil salinity, determined from the salt balance and soil water samples, showed a gradual increase. The water stress of the broadbeans was determined by measuring the predawn leaf water potential, the stomatal conductance and the differences in radiation temperature between the treatments. Growth was measured as leaf area and dry-matter production and, finally, the yield and its components were determined. The three water stress parameters and the two growth parameters showed good coherence, with all parameters indicating systematic differences between the saline treatments and the control. At increasing salinity water potential of the leaf and the stomatal conductance decreased, the difference in

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radiation temperature increased, and the leaf area, dry matter production and yield were reduced.

Introduction

The salinity of irrigation water as a cause of yield reduction has been the subject of many investigations. The salinity effect seems to depend also on other factors such as soil properties, climate, cultural practices and water management. Whereas many data are available with regard to the effect of salinity on crop yield, a great deal less is known about the physiological processes during growth. Studies concerning the effect on crop yield are generally not combined with studies on crop physiology, the first group being conducted in the field and the second mainly in the laboratory. The salinity effect on the water stress of the plant, its gaseous exchanges and its metabolism has been analysed over short periods (see for example Osmond and Greenway, 1972; Longstreth and Strain, 1977; Passera and Albuzio, 1978; Walker et al., 1983; Yeo et al., 1985; West et al., 1986; Bowman and Strain, 1987). This paper presents the results of a study on broadbeans in which the observations of the effect of salinity on the water stress of plants are combined with observations on growth and yield, in order to arrive at a better understanding of their salt tolerance.

Experimental procedure

Set-up

The experiment was conducted at the Mediterranean Agronomic Institute of Bari in southern Italy from December 1989 till June 1990. The set-up consisted of 30 tanks of reinforced fibre glass with a diameter of 1.20 m and a depth of 1. 20 m. A layer of coarse sand and gravel, 0. 10 m thick, was covered by a repacked soil profile of 1 m. At the bottom of the tank a pipe serving as drainage outlet connected the tank with a drainage reservoir (Fig. 1). The set-up was covered at a height of 4 in by a sheet of transparent plastic to protect the assembly against precipitation.

One series of 15 tanks (A) was filled with loam and the second series of 15 tanks (B) with clay. Table 1 presents some properties of the soils.

Crop

Broadbeans (Vicia faba, variety Superaguadulce) were sown with a density of 40 grains per tank and thinned out at the three-leaves stage to 30 plants. A dressing corresponding with 150 kg P_20_5/ha, 100 kg N/ha and 100 kg K_2SO_4/ ha was applied. When 50% of the plants attained a phenological stage, this date was noted, giving the following picture of the growth period: sowing 8 December 1989 (day *t*), emergence *t* + 16, start of flowering *t* + 80, start of fruit setting *t* + 97, milky stage *t* + 107, doughy stage *t* + 123, harvest *t*+ 181. The beans in series A on the loam suffered from broomrape, owing to insufficient disinfection of the soil and leading to a crop failure; their results will not be discussed.

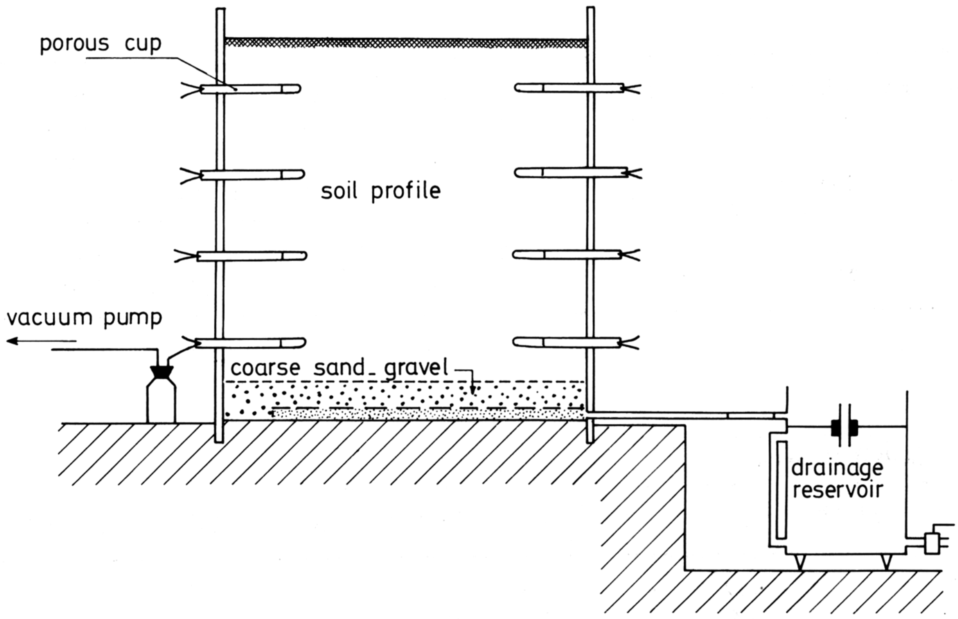

Fig. 1. *Experimental set-up.*

Irrigation

Series B, consisting of 15 tanks filled with clay, was divided into three groups of five tanks and irrigated with water of three different qualities: local fresh water with an EC of 0.9 dS/m as a control (treatment C), and two kinds of saline water (treatments S2 and S4) with EC values of 2.1 and 4 dS/m, obtained by adding NaCl, $CaCl_2$ and $MgSO_4$ to fresh water. Table 2 presents the composition of the water used for irrigation.

At the start of the experiment fresh water was applied to all treatments 2 days after sowing so as to bring the soil water content up to field capacity. Afterwards different kinds of water were applied. At each irrigation surplus water was added in order to provide leaching. The average leaching fraction was about 0.2.

Table 1

Soil properties

Soil	Particle size in % of mineral parts			$CaC0_3$ (%)	% water (v/v)		Bulk density (kg/dm^3)
	$< 2\mu m$	$2-50\mu m$	$> 50\mu m$		pF2.0	pF4.2	
Loam	19	49	32	25	36.3	20.4	1.45
Clay	47	37	16	5	42.0	24.0	1.45

Table2

Composition of irrigation waters (meq/1)

Treatment	Ca^{2+}	Mg^{2+}	Na^+	K^+	Cl^-	HCO_3^-	SO_4^{2-}	EC (dS/m)	SAR
C	6.5	3.5	2.9	0.1	3.8	8.0	1.3	0.9	1.3
S2	10.0	5.0	8.9	0.3	13.8	8.0	2.4	2.1	3.2
S4	18.0	6.0	15.1	0.3	30.0	8.0	1.4	4.0	4.4

Soil salinity

Soil salinity was determined in several ways. By measuring the amounts of irrigation and drainage water and their salt concentrations at each application it is possible to calculate the salt balance of the tanks and, consequently, the increase or decrease in the amount of salt present in the soil. Dividing the amount of salt by the volume of water at field capacity then gives the average salt concentration of the soil water. Since chloride does not react with the absorption complex and does not precipitate at the prevailing concentrations, this ion primarily is used to express soil salinity; it can be converted into electrical conductivity using the correlation of 1 dS/m to 8 meq/l determined in this experiment between the two quantities.

The second method consists of taking soil-water samples after each irrigation from porous ceramic cups which have been installed at depths of 0.125, 0.375, 0.625 and 0.875 m. The data are used to calculate the average concentration in the soil profile. This method yields more variable results than the salt balance method, which is due to the heterogeneity of the salt distribution. Although the porous cups had been installed in four replicates at 4 depths per tank, the differences were such that the average could not be found with great precision. Moreover, due to high retention forces in the soil it was not always possible to obtain samples from each cup.

The third method consists of calculating the salt distribution of the soil profile with a simple model. The model comprises four layers that contribute to the water uptake of the plant according to an extraction pattern of 50, 30, 15 and 5%, respectively. This pattern was derived by determining the soil water content before irrigation. The irrigation water follows a cascade system with complete mixing: all irrigation water mixes with the soil water of the top layer, the excess percolates to the second layer and mixes with the soil water of that layer, and so on. In this experiment it was not possible to make any systematic observations of soil water content or suction during the irrigation interval. Therefore direct water uptake from each layer by the roots was assumed according to the earlier mentioned extraction pattern. Chloride uptake by the roots was neglected. No leaching efficiency coefficient expressing partial mixing and partial bypass of irrigation water was introduced. This way the model was kept as simple as possible.

The calculated salt distribution after irrigation can be compared with the distribution obtained from the soil water samples, and the average salt concentration of the soil profile can be compared with the concentrations obtained from the other two methods.

Water stress of the plant

To characterize the water stress of the plant three parameters were used: the predawn leaf-water potential, the stomatal conductance and the difference in radiation temperature between the saline treatments and the control.

The first parameter is measured when equilibrium between soil and plant is approached, whereas the two other parameters are indicators for the actual water supply of the plant under dynamic conditions of high water stress, e.g., around midday solar time in bright sunshine (Katerji et al., 1987).

The predawn leaf-water potential was determined at dawn before sunrise on leaves of the upper part of the canopy. At each determination, 10 leaves per treatment, equally distributed over the 5 tanks, were taken and the potential was immediately measured in a pressure chamber at the experimental setup.

The stomatal resistance was always determined at midday with a diffusion porometer, also on the 10 leaves for each treatment equally distributed over the 5 tanks.

The difference in radiation temperature between the treatments was determined at midday by 10 measurements equally distributed over 5 tanks of each treatment, using a portable radiation thermometer with direct reading (Mikron[1]). In order to avoid the effect of soil temperature, the angle of incidence of the instrument was about 300 and all measurements were done in the same direction with respect to the sun.

All measurements were made at intervals of about 5 days, from day *t* + 62 until harvest, although not always at the same day.

[1]Trade names are given for the benefit of the reader and do not imply endorsement or preferential treatment of the product by the authors and their institutions.

Growth and yield

The leaf area and dry matter were determined on all treatments at the following phenological stages: 3 leaves, flowering, fruit setting, doughy stage, 27 leaves and drying of pods. For these parameters 10 plants, equally distributed over the 5 tanks of each treatment, were first taken for measuring the leaf area with the apparatus "LAH-Licor 1300" and then for measuring the dry matter by drying at 80°C for 24 hours.

The yield was determined as the average grain production of the 5 tanks. Besides the total yield, the following yield components were measured on 30 plants per treatment: the number and weight of pods per plant and the number and weight of grains per plant.

Statistical treatment

Significant differences in the development of the parameters and the plants between the various treatments were determined from the average values at 0.05 and 0.01 confidence levels.

Experimental results

Soil salinity

Table 3 presents the average chloride concentration of soil water of the layer 0-100 cm found from the three methods described previously. The concentration increases during the irrigation season, as can be expected when a non-saline soil is irrigated with saline water. The three methods yield quite similar results, only the concentration of the soil water samples of treatment S4 from 28 April onwards remained lower than those indicated by the other methods.

The chloride concentration of a solution can be converted into electrical conductivity (EC, dS/m) by dividing the chloride concentration (in meq/l) by 8 and into the electrical conductivity of the saturation extract (EC_e dS/m) by dividing the concentration by 16, assuming that EC of soil water equals $2 \times EC_e$ (Ayers and Westcot, 1985). So the average values of 21.2 and 38.2 meq/l correspond with EC_e values of 1.3 and 2.4 dS/m, respectively.

Table 3

Chloride concentration of soil water of the layer 0-100 cm after irrigation during the growing season (meq/l)

1990	19.2	9.3	26.3	11.4	28.4	8.5	18.5	28.5	Average
S2									
Salt balance	10.7	13.0	14.9	19.0	24.7	27.3	30.3	29.8	21.2
Sampling	11.3	14.7	13.8	18.9	25.6	29.3	31.3	27.2	21.5
Model	10.8	13.1	15.0	19.1	24.3	26.5	29.1	28.9	20.9
S4									
Salt balance	14.5	20.0	24.3	33.7	46.2	51.7	58.1	56.9	38.2
Sampling	14.9	28.0	28.2	35.6	41.9	43.9	47.7	41.0	35.1
Model	14.3	19.6	23.8	33.2	45.0	50.5	57.2	56.6	37.5

Table 4

Distribution of the chloride concentration of soil water after irrigation (meq/l)

Depth	S2				S4			
	28 April 90		28 May 90		28 April 90		28 May 90	
	sampling	model	sampling	model	sampling	model	sampling	model
12.5	21.5	18.2	17.5	19.6	42.8	39.4	37.5	41.2
37.5	26.5	23.8	20.0	27.9	40.8	49.4	37.8	57.4
62.5	26.8	28.2	35.0	34.6	52.5	52.2	41.3	67.7
87.5	27.5	26.9	36.3	33.5	31.3	39.1	47.3	60.2
Average	25.6	24.3	27.2	28.9	41.9	45.0	41.0	56.6

The chloride concentration of the soil water of the control was about 6.0 meq/l, which corresponds with an EC_e value of 0.4 dS/m.

Table 4 shows the distribution of the chloride concentration over the soil profile after irrigation at two dates. It is rather homogeneous with a slight increase with depth. There is a fair correspondence between the values obtained by sampling and the values calculated according to the model.

Water stress of the plant

The predawn leaf-water potential (Fig. 2a) shows an increase after each irrigation, followed by a decrease during the irrigation interval. From day *t* + 90 (8 March 90, at the flowering stage) significant differences appear between the treatments: the higher the salinity, the lower the leaf-water potential and the higher the water stress acting on the plant under near equilibrium conditions. The differences vary and sometimes exceed 0.2 M• Pa (2 bar).

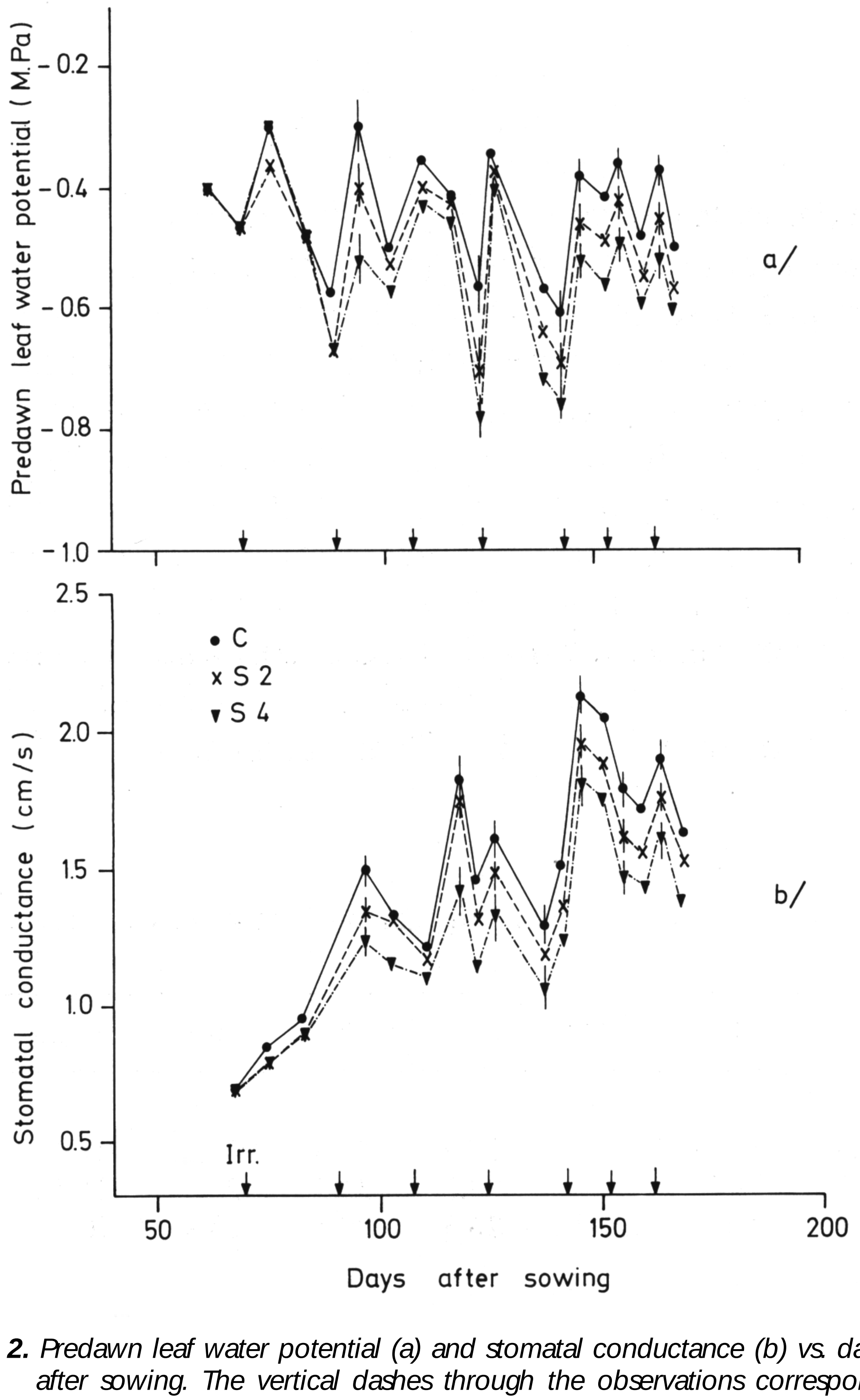

Fig. 2. *Predawn leaf water potential (a) and stomatal conductance (b) vs. days after sowing. The vertical dashes through the observations correspond with 95% confidence interval.*

Table 5

Evapotranspiration during the growing season (mm/day)

	26.12- 19.2	19.2- 9.3	9.3- 26.3	26.3- 11.4	11.4- 28.4	28.4- 8.5	8.5- 18.5	18.5- 28.5
C	1.0	3.7	3.4	8.2	10.5	8.7	13.2	9.3
S2	1.0	3.8	3.3	7.8	10.4	8.7	12.1	7.4
S4	1.0	3.8	3.4	8.0	10.2	8.6	11.9	6.2

The stomatal conductance (Fig. 2b) fluctuates in a similar way as the predawn leaf water potential, although cloud formation during the measurements sometimes disturbs this pattern. From day t+ 97 (15 March 90, at start of fruit setting) significant differences appear between the treatments. The stomatal conductances of the treatments S4 and S2 are on the average, respectively, about 30% and 15% lower than that of the control.

The difference in radiation temperature between the saline treatments and the control (Fig. 3) is always positive but the difference between S4 and the control only becomes significant from day t + 120 (7 April 90) onwards and the difference between S2 and the control from day t + 140 (27 April 90) onwards. Compared with the two other water stress parameters, the difference in radiation temperature seems to be a less suitable criterion for the diagnosis of water stress.

Evapotranspiration

Since at each application surplus water was added to obtain about 20% leaching, the evapotranspiration was calculated for the successive irrigation intervals as the difference between the amounts of irrigation and drainage water (Table 5). Systematic differences between the treatments only appear during the last two irrigation intervals.

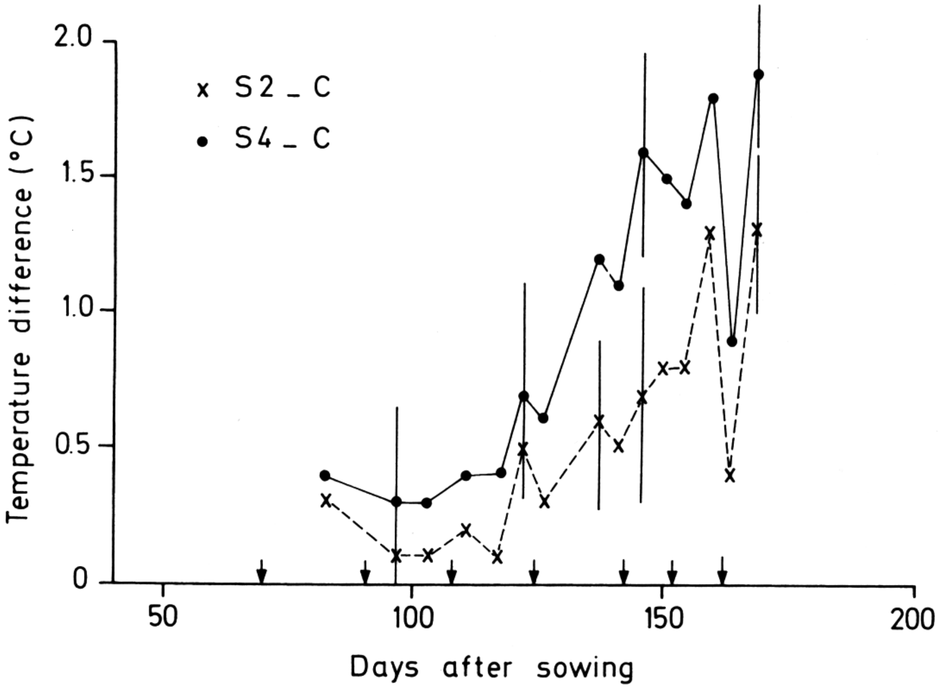

Fig. 3. *Difference in radiation temperature vs. days after sowing.*

Growth and yield

The development of leaf area and dry matter are shown in Fig. 4a and b. The lower the salinity, the better the growth expressed by these parameters. The leaf area seems to be more sensitive to salinity than the dry matter, because significant differences in leaf area appear from day *t* + 110 (28 March 90) onwards and those in dry matter from day *t* + 130 (17 April 90) only.

The yield and its components are presented in Table 6. The yield of the saline treatments is about 28% lower but without a significant difference between the saline treatments. The yield components indicate that the decrease in yield is not due to the effect of salinity on the reproductive stage of the beans because no significant effect is observed on the number of grains per pod and the number of pods per plant. The decrease in yield appears to be caused by the difference in weight of the grains. No difference was observed in the height and number of the plants.

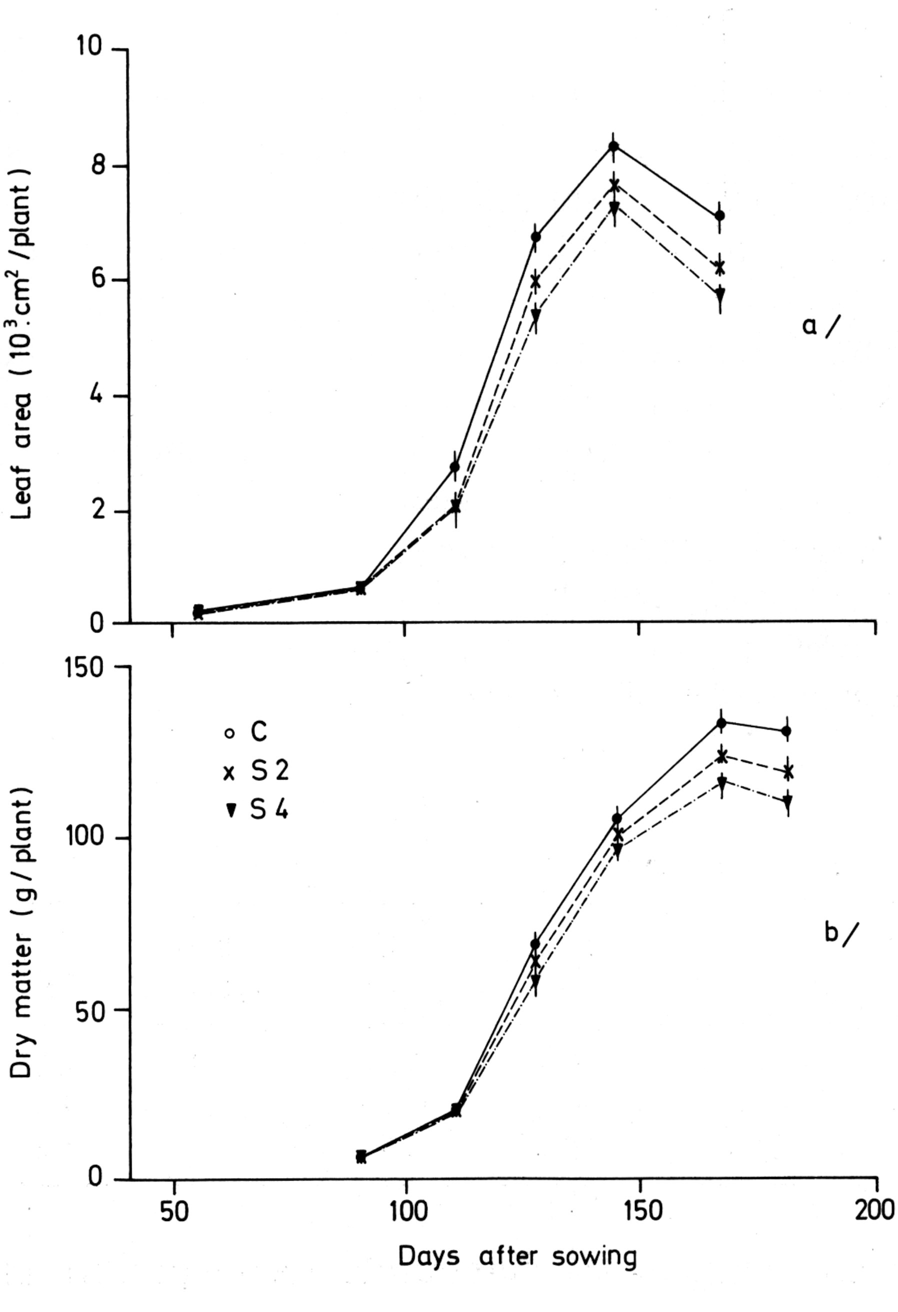

Fig. 4. *Leaf area (a) and dry matter (b) vs. days after sowing.*

Table 6

Yield and yield components

	C	S2	S4
Yield of grain per tank (g)	2776	2017**	1983**
Number of pods per plant	11.0	8.8	8.7
Number of grains per pod	4.2	4.1	4.4
Weight of pods per plant (g)	102.4	85.9*	83.7*
Weight of grains per pod (g)	8.6	7.7*	7.6*

*significant difference at 0.05.
**significant difference at 0.01.

Discussion and conclusion

In the saline treatments soil salinity increased but the concentrations remained rather low due to the initial nearly salt-free stage. Nevertheless, the experiment yields a series of coherent observations which make it possible to identify the effects of salinity on the plant. Salinity affects the water stress of the plant and its gaseous exchanges: from the flowering stage onwards systematic differences were observed between the saline treatments and its control, which lead to a decrease of about 15 to 30% in stomatal conductance, depending on the salinity level. The experiment also showed that the predawn leaf water potential and the stomatal conductance are better indicators for the effect of salinity on the plant than the difference in radiation temperature. Other authors came to similar conclusions (Itier et al., 1990).

The salinity effect on leaf area and dry matter appeared 20 to 40 days later and finally caused a decrease of about 15%. The decrease in yield of grains was about 28%, although the average soil salinity, expressed as EC_e, only equalled 2.4 dS/m for the most saline treatment. The yield depression confirms the low salt tolerance of broad beans (Ayers and Westcot, 1985). The observation that the decrease in yield is mainly caused by a difference in the weight of the grains corresponds with the observation that the water stress was not significantly affected before the stage of flowering and fruit setting. It is possible that the effect of salinity would have been more pronounced if the soil salinity had been different from the start of the experiment (Van Hoorn, 1991).

If saline water is used in agriculture, the salt tolerance of the crop must be known. This experiment suggests that this knowledge should be supported by a description of the physiological behaviour of the plants in a saline environment, since this behaviour implies other variables, such as physical and chemical soil properties, climate and phenological stage, which may modify the reaction of the plant to salinity. In this way the relation between physiological behaviour and yield allows a better and more reliable analysis of the salinity effect on crop yield. Not only do crops differ in their salt tolerance, but also cultivars of the same species are known to vary in their responses. Thus, physiological testing may be helpful in assessing such differences.

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