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ON THE DEPENDENCE OF SALT TOLERANCE OF BEANS (*PHASEOLUS VULGARIS* L.) ON SOIL WATER MATRIC POTENTIALS

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KEY WORDS

Beans Leaf extension rate Salt tolerance Soil water osmotic potential Transpiration rate

SUMMARY

Bean plants (Kora cv) were grown in potted soil artificially salinized by adding NaCl and $CaCl_2$ to the irrigation water to obtain an electrical conductivity of the soil saturation extract (EC_e) thirty days after emergence of 0.1, 0.3, 0.5 and 0.7 S/m at 25°C and a sodium adsorption ratio (SAR) of 4 $(mmol/l)^{\frac{1}{2}}$. Thereafter, plants were irrigated when soil water matric potential (Ψ_M) was in the range of -20 to -30 kPa (wet treatment) and when Ψ_M was in the range of -40 to -60 kPa (dry treatment).

Transpiration rates (Tr) and leaf extension rates (LER) per plant or per unit of leaf area were decreased by increasing soil salinity and by decreasing soil moisture. However, a given decrement of Ψ_M produced a considerable larger decrement in Tr of LER than an equivalent decrement of soil water osmotic potential (Ψ_0). Absolute yields of green pods under wet treatments were from twice to one and a half time as large under the wet than under the dry treatment at equivalent values of Ψ_0. Relative yields were reduced by 25% when EC_e were about 0.5 S/m and 0.7 S/m in the dry and wet treatment respectively. Salt tolerance data of crops may not have a quantitative interest when soil irrigation regimes under which they were obtained are not specified.

INTRODUCTION

Crop salt tolerance has usually been established as the yield decrease produced by a given level of soluble salts in the root medium as compared with yields under non-saline conditions[1,4,16]. In western countries soluble salts in the soil are often expressed as the electrical conductivity of the soil saturation extract (EC_e). Soil water osmotic potential (Ψ_0, in kilopascals) at a given volumetric water content (θ_s) is empirically related[16] to EC_e (siemens/metre at 25°C) by

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$$\Psi_0 = -355\,\mathrm{EC_e}\frac{\theta_e}{\theta_s} \qquad (1)$$

where θ_e is the pore volume of the soil.

When $\mathrm{EC_e}$ figures are used to estimate relative crop yields the following assumptions are implied: 1) yield depression of crops due to soil salinity is a function of Ψ_0 and independent of the nature of the solutes; 2) relationship (1) holds for the range of θ_s occurring in the field. Both assumptions seem reasonably valid under conditions where ionic specific effects on plants or soils are absent and when salt solution and precipitation in the soil upon changes in moisture are negligible. However, most crop salt tolerance figures available are still of relative value since they were obtained under some unspecified cultural conditions which affect crop yields. When θ_s or Ψ_M range at which crops are grown are not specified one of the parameter of Equation (1) is ignored. Furthermore, regardless of the influence of soil moisture of Ψ_0, reduced growth rate of beans at decreasing Ψ_M even within a relative high range of Ψ_M have been reported[10]. With the expanding use of high frequency irrigation systems[14] and the claim[6, 15] of increasing salt tolerance of crops under such management, it seems most appropriate to reasses salt tolerance of crops under different irrigation regimes.

This study reports the results of a pot experiment designed to evaluate salt tolerance of green beans under two irrigation regimes.

MATERIAL AND METHODS

Plants of bean (Kora cultivar) were grown in a polyethylene-covered enclosure in 61 plastic pots filled with 4.8 kg of the fine fraction of a calcareous alluvial sandy loam soil. After emergence (day 0) plants were thinned to one per pot and 1 kg of siliceous sand (diameter between 3 and 6 mm) was spread on each pot in order to minimize evaporation.

Four salinity levels, including the check, and two irrigation regimes were combined in a 4 × 2 factorial design that was replicated 22 times. Saline irrigation waters were prepared by adding increasing amounts of NaCl and $\mathrm{CaCl_2}$ to tap water (check) to obtain waters with EC of 0.3, 0.5 and 0.7 S/m at 25°C and SAR = 4 $(\mathrm{mmol/l})^{\frac{1}{2}}$. The tap water had an EC = 0.09 S/m, a SAR = 0.7 $(\mathrm{mmol/l})^{\frac{1}{2}}$ and an average composition in mmoles/l: Ca = 2.25, Mg = 1.7, Na = 1.5, K = 0.5, $\mathrm{CO_3H^-} = 7$, $\mathrm{SO_4^=} = 1.0$, $\mathrm{Cl^-} = 0.9$. Soil salinization was started on day 20 and was completed on day 30 by applying 500 and 1000 ml of saline water per pot at the indicated dates. From the latter date two differential irrigation schedules were imposed. Under the 'wet' treatment Ψ_M was kept between −20 and −30 kPa and under the 'dry' treatment between −40 and −60 kPa. Water lost by evapotranspiration was added to each pot on a daily basis, except on days 52, 55 and 58 when irrigations were unduly postponed two days. Evapotranspiration (EVT) was obtained by difference in weight of each pot in consecutive days and transpiration was estimated substracting from the EVT value the average water lost from four pots without plants that were kept within the soil moisture range of cultivated pots.

Soil Ψ_M was indirectly estimated from the soil water characteristic curve and daily estimation of soil moisture. In three pots per treatment tensiometers were installed at 8 cm depth. Electrical conductivity of the soil solution (EC_s) was directly determined with salinity sensors placed at 8 cm depth in two pots per treatment and indirectly by determining EC_e and soil moisture.

Every ten days three pots per treatment were eliminated in order to determine EC_e, leaf area (LA) and dry matter of leaves and stems. Every other day, LA of four plants per treatment was estimated from the average length of central leaflet by using Equation:

$$A = 1.03\,L^2 + 1.82\,L - 8.3 \qquad (2)$$

where A (cm^2) and L (cm) are the area of a composed leaf and the length of the central leaflet, respectively. Equation (2) was adjusted ($r^2 = 0.920$) to data of over one hundred leaves.

On day 62 the harvest of 12 pots per treatment, which had not been eliminated, was made.

RESULTS AND DISCUSSION

Soil water potential

Fig. 1 shows the evolution with time of the estimated values of Ψ_M in the check and high salinity treatments under the 'wet' and 'dry' irrigation regimes. From

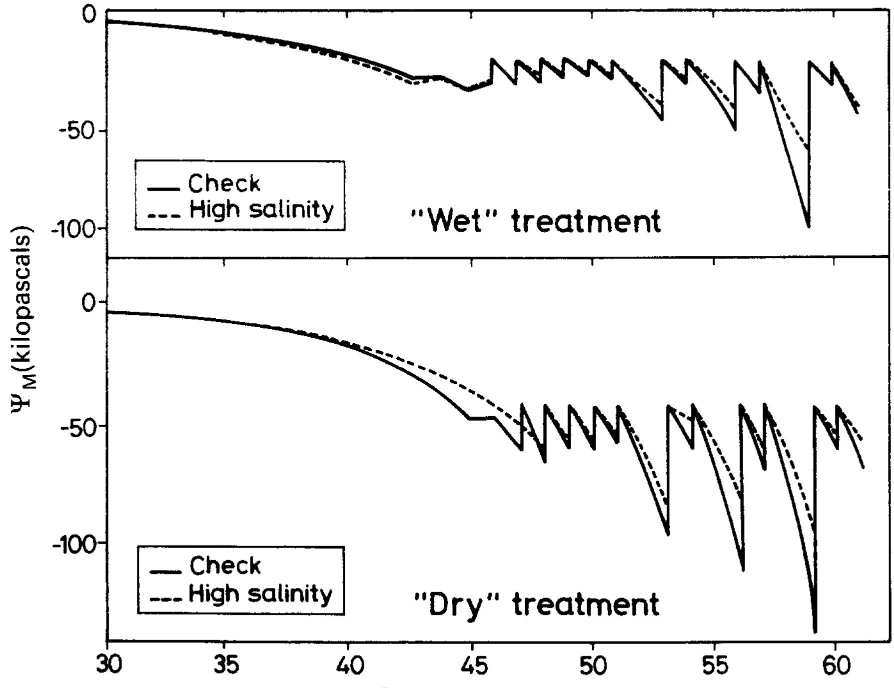

Fig. 1. Daily changes of soil water matric potential in the check and high salinity treatments under 'dry' and 'wet' irrigation regimes.

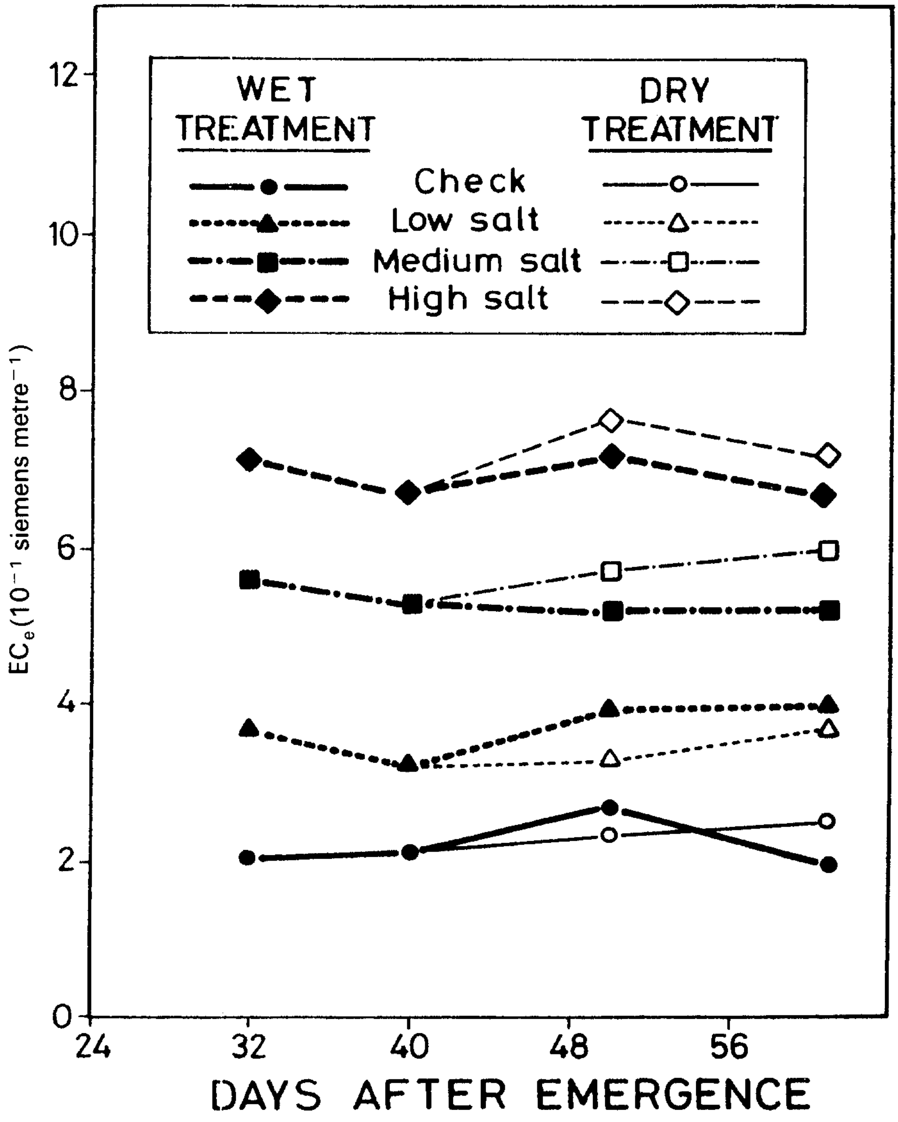

Fig. 2. Evolution with time of the electrical conductivity of the soil saturation extract (EC_e).

Table 1. Average soil water matric and osmotic potentials (kilopascals) during the indicated dates

Treatments		Days 30–43		Days 43–61	
Irrigation regime	Salinity level	Ψ_M	Ψ_0	Ψ_M	Ψ_0
Wet	Check	−15	−136	−38	−183
	Low	−16	−218	−33	−301
	Medium	−15	−339	−30	−388
	High	−13	−420	−27	−507
Dry	Check			−76	−218
	Low	The same as in the wet		−72	−374
	Medium			−62	−624
	High			−63	−796

day 43 on, when the two differential irrigation regimes became effective, Ψ_M oscillated within the aimed ranges except for the periods when irrigations were delayed and Ψ_M reached values below − 100 kPa in the dry check. Otherwise, whenever Ψ_M values were within the tensiometer range there was good agreement between the estimated and measured Ψ_M values. Fig. 2 shows the evolution with time of the measured values of EC_e from the day the soil salinization was accomplished. EC_e under 'dry' and 'wet' treatments were roughly stable around 0.2, 0.35, 0.55, and 0.7 S/cm for the check, low, medium and high salinity treatments respectively.

Table 1 summarizes data from Figs. 1 and 2 for the two distinct periods of the experiment: days 30–43 (differential effects due to salinity) and days 43–61 (differential effects due to salinity and irrigation regimes). The values of Ψ_0 in Table 1 were estimated from EC_e (Equation 1) rather than from the EC_s measured with salinity sensors. EC_s in the wet treatments were higher than in the dry ones (data not given), showing an opposite trend to the one that should be expected. It has been unequivocally demonstrated[2] how current salinity sensors fail to measure EC_s when the Ψ_M drops below −40 or −50 kPa, partly due to sensor desaturation and partly due to limited ion diffusion produced by reduced contact between the ceramic cup and the soil when it dries, particularly under situations of changing salinity. Therefore, the use of current salinity sensors is restricted to a soil moisture range narrower than the one it has been previously reported[7,13].

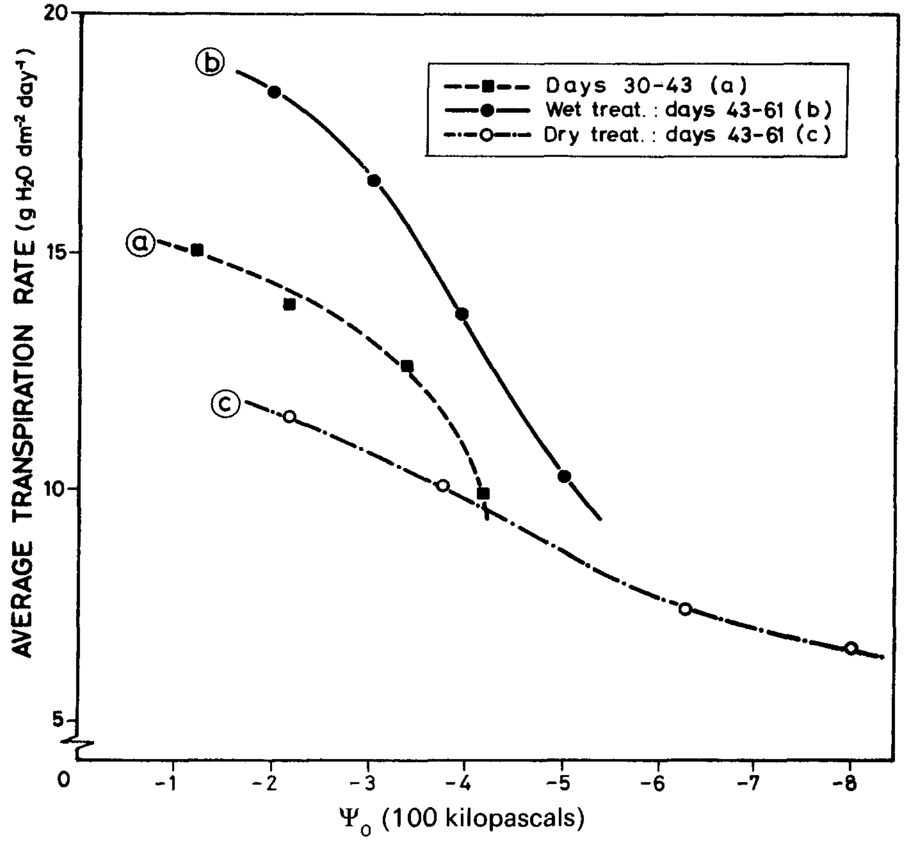

Fig. 3. Average transpiration rates as a function of soil water osmotic potential (Ψ_0).

Transpiration and growth

Fig. 3 shows the transpiration rate (Tr) before (curve a) and after (curves b and c) implanting the irrigation regimes as a function of Ψ_0. The average values of Ψ_M in a), b) and c) were -15, -32 and -70 kPa, respectively. Tr decreased as Ψ_0 decreased in agreement with results of other authors[8,9,11,12]. However, with a salt tolerant plant such as cotton grown in solution culture with Ψ_0 between -50 and -1250 kPa no Tr reduction was observed[5]. Differences in Tr between a) and b) are due to changing atmospheric evaporative demand. If transpiration rates are expressed as percentage of the check (Fig. 4), the effect of Ψ_0 on relative transpiration rates (RTr) are practically the same for the two periods considered

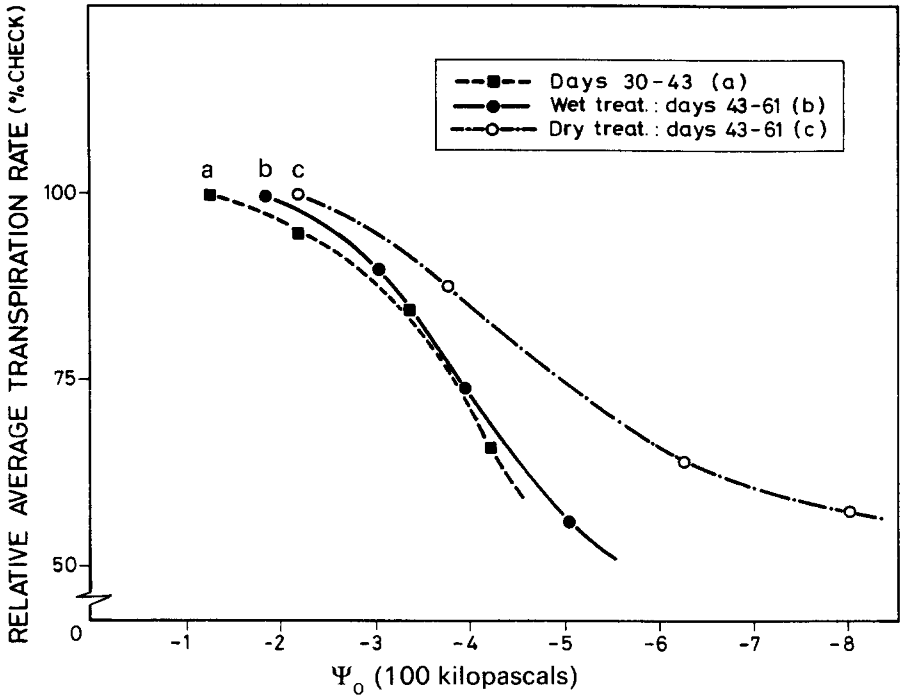

Fig. 4. Relative average transpiration rates as a function of soil water osmotic potential (Ψ_0).

(*a* and *b*). Furthermore, a decrement in Ψ_0 produced a larger decrease in RTr in the 'wet' treatment (Curves *a* and *b*) than in the 'dry' one (Curve *c*). We suggest that in the wet treatment ($-15 > \Psi_M > -32$ kPa) Tr was independent of Ψ_M and was largely controlled by Ψ_0 and other environmental factors, while in the 'dry' treatment ($\Psi_M = -70$ kPa) Tr was primarily controlled by Ψ_M. It has been reported[3] that when $\Psi_M > -20$ kPa soybean Tr was determined by atmospheric conditions, while at $\Psi_M < -40$ kPa Tr was practically independent of atmospheric conditions. At $\Psi_0 = -200$ kPa, Tr of the dry check ($\Psi_M = -76$ kPa) was 60% of Tr of the wet check ($\Psi_M = -38$ kPa). Other authors[10] found that Tr of bean under non-saline conditions was reduced by 60% when Ψ_M decreased from -25 to -40 kPa. The significant reduction of transpiration found with decreasing soil moisture are relevant since they occur even within the moisture range found in soil where crops are irrigated by conventional methods (surface or sprinklers).

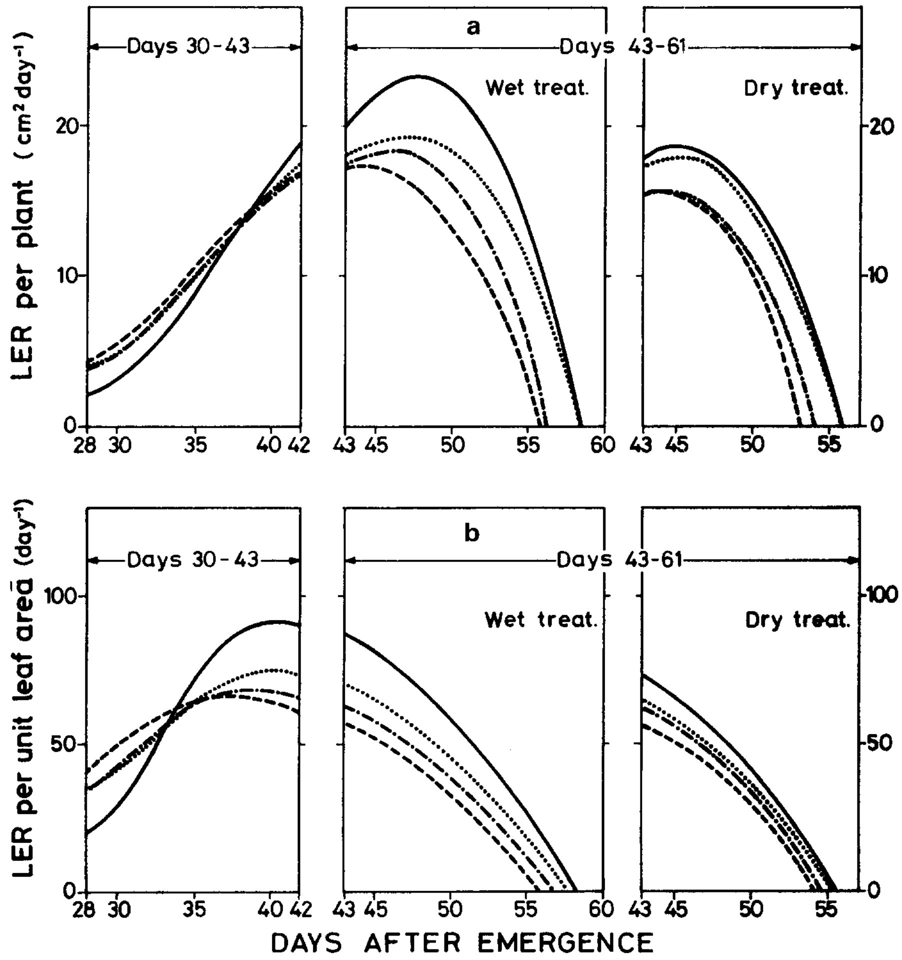

Fig. 5. Evolution with time of leaf extension rate (LER) per plant (a) and per unit of leaf area (b). (For curve types see legend in Fig. 2).

Due to initial differences in leaf area of plants when soil salinization was started, it was decided that treatment effects on plant growth would be better evaluated by leaf expansion rate (LER) per plant or per unit of leaf area rather than by absolute LA. Fig. 5 a-b shows that LER per plant (*a*) or per unit leaf area (*b*) were decreased by increasing soil salinity about one week after soil salinization was completed. The higher the soil salinity and the lower the soil moisture the sooner LER starts decreasing to become zero when leaf abcission period set in (day 53 for

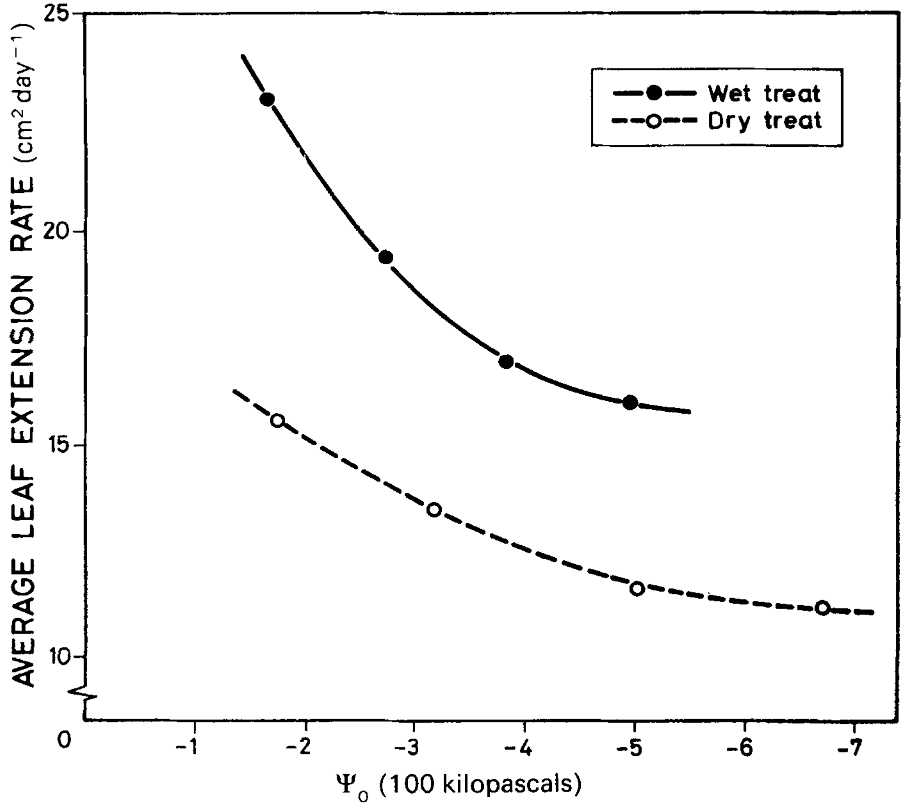

Fig. 6. Average leaf extension rate ($\overline{\text{LER}}$) as a function of soil water osmotic potential (Ψ_0).

the most stressed treatment to day 58 for the check of the wet treatment). Leaf abcission was enhanced by delay in irrigations. Therefore, changes in LA after the first occurance abcission are not considered.

Average LER ($\overline{\text{LER}}$) under the two irrigation regimes are plotted as a function of Ψ_0 in Fig. 6. $\overline{\text{LER}}$ was reduced at decreasing Ψ_0 under both irrigation regimes. When relative $\overline{\text{LER}}$ ($\overline{\text{RLER}}$) is plotted against Ψ_0 (Fig. 7) a given decrement of Ψ_0 produced a larger decrement of $\overline{\text{RLER}}$ under the wet than under the dry treatment. This result could be interpreted as an increase of salt tolerance of beans at reduced soil water matric potential. However, this is only so when soil salinity is evaluated by Ψ_0 of soil water. When soil salinity is expressed by EC_e, $\overline{\text{RLER}}$ was independent of irrigation regimes.

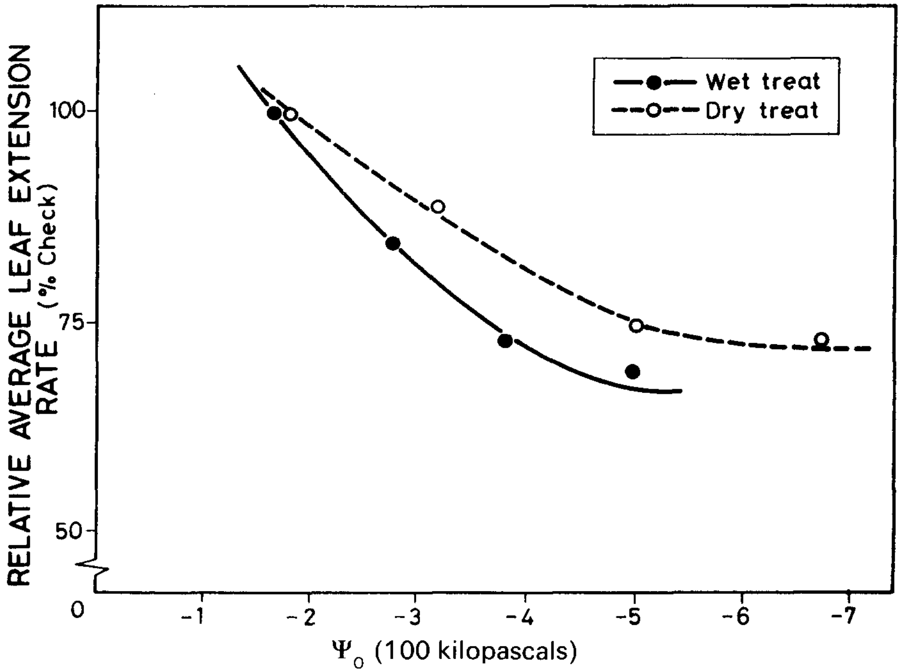

Fig. 7. Relative average leaf extension rate ($\overline{\text{RLER}}$) as a function of soil water osmotic potential (Ψ_0).

LERs of plants under dry treatment were lower than under wet treatments at all soil salinity levels, (Fig. 5 a-b). For example, at a $\Psi_0 = -170$ kPa, LER of the 'dry' check ($\Psi_M = -53$ kPa) was 67% of the 'wet' check ($\Psi_M = -28$ kPa). A 47% reduction in dry matter production of beans have been reported[10] when Ψ_M decreased from -28 to -40 kPa. Since absolute values of Ψ_M were small as compare to Ψ_0, results shown in Fig. 6 illustrate that a given decrement of Ψ_M brought about a larger reduction in LER than several fold higher decrements of Ψ_0. Therefore, matric and osmotic components of soil water potential do not have additive effects on plant growth as it was earlier suggested[17]. This fact is in accordance with the well known restriction to water movement in the soil produced by decreasing Ψ_M and not by decreasing Ψ_0.

It has been already mentioned that both growth and transpiration were reduced at increasing salinity and decreasing soil moisture. However, it is somewhat striking that a high correlation ($r^2 = 0.966$) was found between

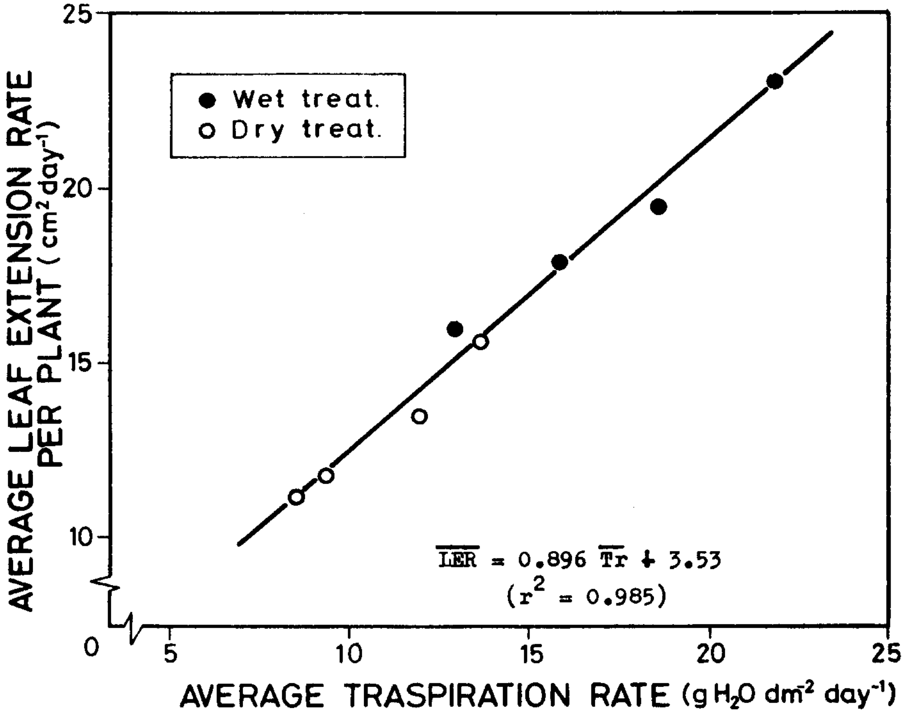

Fig. 8. Average leaf extension rate ($\overline{LER}$) as a function of average transpiration rate.

Table 2. Dry matter content of leaves and stems after 30, 40 and 50 days

Treatments		Dry matter, g/100 g of fresh tissue					
Irrigation regime	Salinity level	Leaves			Stems		
		30	40	50	30	40	50
Wet	Check	12.2a	12.4a	13.8c	14.7a	15.4a	16.2a
	Low	12.6a	11.7ab	12.6d	15.1a	15.1ab	15.6ab
	Medium	12.1a	10.9ab	11.9de	14.9a	14.3ab	14.8bc
	High	12.5a	10.3b	11.4e	14.8a	13.8b	14.1cd
Dry	Check	The same as Wet		16.1a	The same as Wet		16.4a
	Low			15.4ab			15.9ab
	Medium			14.6bc			15.2b
	High			15.1b			14.9bcd

Within each column treatments with one letter in common are not significantly different at 0.05% level by Ducan's new multiple range test.

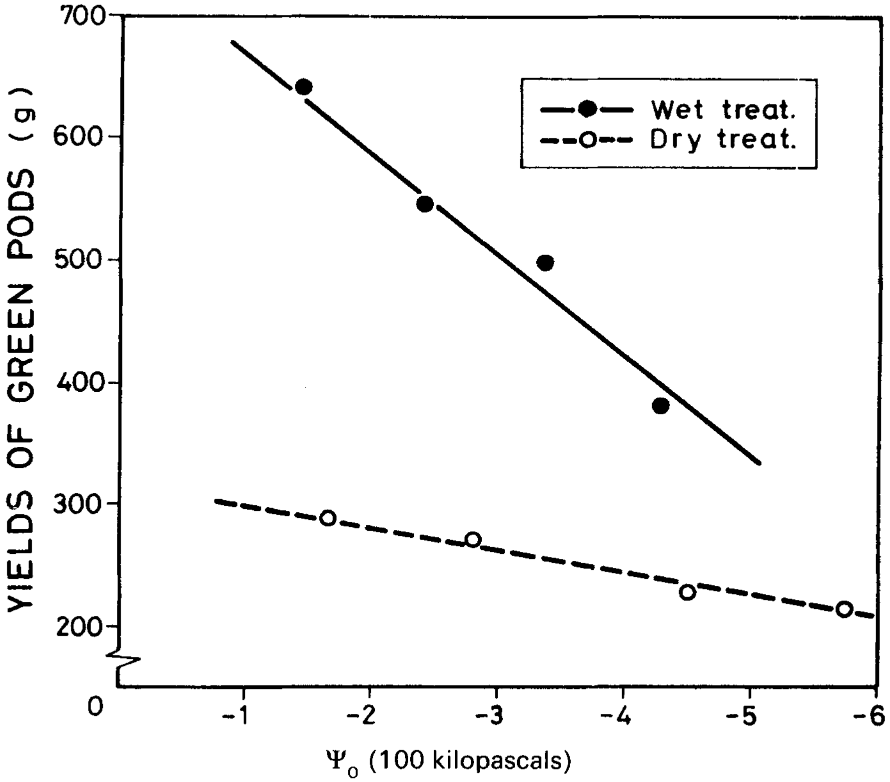

Fig. 9. Yields of green pods as a function of soil water osmotic potential (Ψ_0).

average values of Tr and LER for each treatment even when data from both irrigation regimes are pooled together as shown in Fig. 8.

Yields

The percentage of dry matter in green tissues on a weight basis, which is inversely related to plant succulence, is shown in Table 2. In general, succulence increases at increasing soil salinity and/or increasing soil moisture.

Absolute yields of green pods under the wet treatments were higher than under dry treatments at any soil salinity level (Fig. 9).

Relative yield depression produced by increasing soil salinity measured by EC_e (Fig. 10) was higher under the wet than under the dry treatments. A 25%

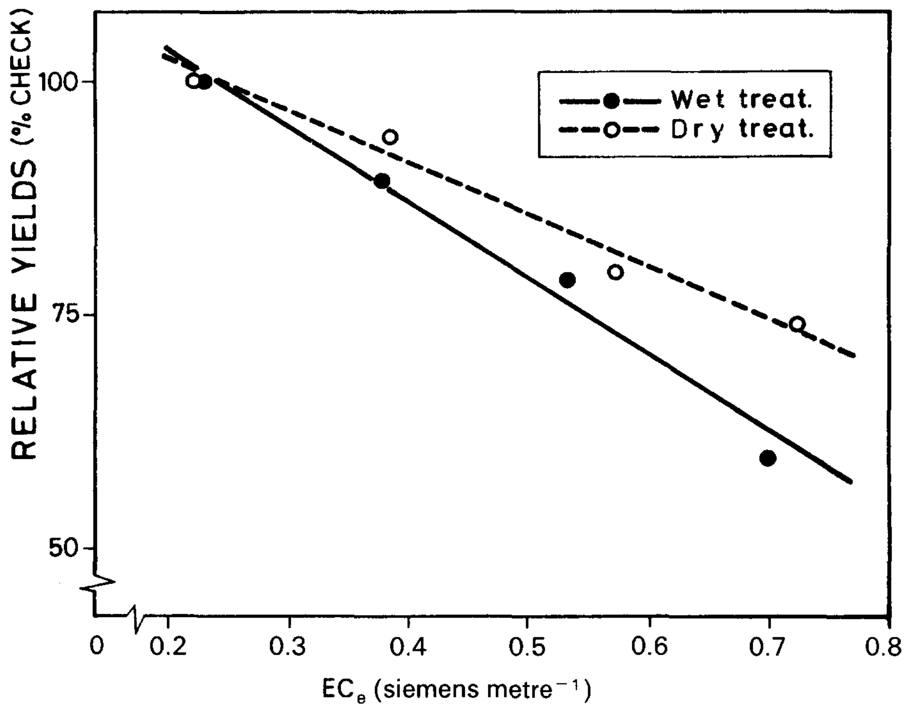

Fig. 10. Relative yields of green pods as a function of the electrical conductivity of the soil saturation extract (EC_e).

reduction in relative yields was brought about approximately at $EC_e = 0.5$ S/m in the wet treatment, while under the dry treatment occurred at $EC_e = 0.7$ S/m.

The experimental results illustrate that the common practice of evaluating salt tolerance of crop by the EC_e figure that produces a certain yield decrement, when no specification is made to irrigation regimes, have, at the most, a qualitative interest.

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