The effect of salinity and sodium adsorption ratio in the irrigation water, on growth and productivity of bananas under drip irrigation conditions.

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EFFET DE LA SALINITE ET DU SAR DE L'EAU D'IRRIGATION SUR LA CROISSANCE ET LA PRODUCTIVITE DU BANANIER EN CONDITIONS D'IRRIGATION GOUTTE A GOUTTE:

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RESUME - Après avoir isolé leurs systèmes racinaires les uns des autres à l'aide de feuilles de plastique enterrées, on a soumis des bananiers adultes de plein champ à des apports d'eau enrichie ou non en NaCl et $CaCl_2$, de manière à obtenir en quatre traitements (a = témoin, b, c, d) une gradation de la conductivité électrique (1,09 - 3,61 - 6,02 - 5,86 . 10^{-3}), puis du taux d'adsorption de Na (SAR = 3,39 - 6,63 - 6,76 - 13,20).
La forte salinité (c) affecta la croissance, retarda la floraison de 35 jours et diminua la productivité de 49 p. 100, chiffres que Na porta à 57 jours et 60 p. 100 pour le traitement (d), sans qu'aucun symptôme foliaire ne soit décelable.
Les teneurs en Cl dans le limbe III, en N, K, Mg et Na dans le pétiole VII, et en Na et Cl dans les racines, furent modifiées par la salinité. Dans les trois organes, Cl était en bonne corrélation avec les taux du même élément dans le sol et l'eau. Pour le sodium, très fortement retenu par les racines, ces dernières renseignent mieux sur les excès.

INTRODUCTION

Bananas are usually grown in the humid lowland tropical zones, where water or soil salinity is not common. The literature on this subject is therefore very limited. Some cases of «plant failure» and plantation degeneration attributed to the effect of salinity, were reviewed by WARDLAW (12) and STOVER (11). Concentration of 500 ppm of total soluble salts in the soil water extract was mentioned as a toxic level (12). The effect of alkalinity was also documented (12). Disorders as a result of sodium toxicity were reported in publications from Ecuador (1) , Colombia (2) and the Canary Islands (4). Poor drainage, insufficient water application and the use of saline water, were all mentioned to cause soil salinity (11, 12). However, in none of the reported cases, was a controlled experiment involved.

Salinity problems as a result of high underground water tables were reported from Jamaica (3) and have been known for many years in the Jordan Valley in Israel. In extreme cases the result was an early decline of the plantation (10). In the Jordan Valley the salinity problems were practically solved by subsurface drainage. However, some

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salinity problems appeared again in banana plantations with the replacement of surface irrigation by drip irrigation, this time for different reasons.

In the drip irrigation method, salts accumulate on the soil surface near the margin of the wetted area. These salts are leached downward during the rainy season. The mean annual precipitation in the Jordan Valley is only about 400 mm/year and the salinity of irrigation water is moderate (250-280 ppm Cl/l). Under these conditions the salts are leached insufficiently and their level in the soil is higher in drip irrigated plantations (E.C. in spring = 0.67 dS/m, and in autumn = 0.95 dS/m) than in sprinkler irrigated ones (E.C. in spring = 1.08 dS/m, and in autumn = 1.37 dS/m) (5). About 30 mm of irrigation water is applied immediately after the first rain to minimize year to year salt accumulation, and thus bananas are successfully grown under drip irrigation, but the necessity for better understanding of the effect of salinity on bananas is obvious.

The purpose of the present work was therefore to study the effect of salinity and sodium level in the irrigation water on the growth, development and production of bananas under drip irrigation conditions. Because of the relatively high salinity and sodium levels, special emphasis was given to identify symptoms indicating salinity stress, and to define critical levels of Cl and Na in the various plant organs.

MATERIALS AND METHODS

The experiment was conducted in an established banana plantation of 'Dwarf Cavendish' in the Jordan Valley, bearing its second crop (first ratoon). The soil was calcareous sierozem with 75% clay and silt, pH 7.5, total $CaCO_3$ 43%, and a cation-exchange capacity of 33-41 meq/100 g. The planting distance was 3 x 2.5 m. About 3 000 mm of water was applied by the drip system during the dry season of April-November. This is the usual amount applied in the Jordan Valley, where temperatures in the summer may exceed 40°C and daily Class A pan evaporation reaches 9 to 10 mm. About 4 00 mm of winter rain was recorded. Each plant was irrigated every second day by four drippers with 4 l/h discharge. Ten kg of chicken manure and 900 g of $(NH_4)_2SO_4$/mat/year were applied.

The root system of each plot - a mat with two bunches - was isolated from the neighbouring mats by polyethylene sheets to a depth of 1 m. Each mat with two bunches could thus serve as an experimental plot. The experimental design was Latin square with 4 treatments x 4 replications.

The four irrigation treatments included four combinations of salinity and SAR as detailed in Table 1. The low-low treatment was the local irrigation water (the control). The three salt solutions were prepared in elevated containers by adding NaCl and $CaCl_2$ to the irrigation water. The four combinations were thus chosen that a partial factorial analysis of two salinity levels and two SAR levels could be done : (a) comparison of medium and high salinity under medium SAR ; (b) comparison of medium and high SAR under high salinity ; and (c) a comparison of simultaneous increase of salinity and SAR from low-low to medium-medium and high-high.

Since by the end of the first season no external symptoms appeared, it was decided to increase the salinity and sodium levels in the second year.

The water was sampled and analysed three times a week (Table 1). The variations during the irrigation season were negligible.

The following parameters were recorded : flowering date, bunch weight, and number of hands and fingers per bunch. Height of the followers was recorded in the autumn. The soil was sampled at the beginning of the experiment and at the end of the two seasons. The samples were taken from each experimental plot, 30 cm from a dripper, from three 30-cm layers to a depth of 90 cm. Analyses were performed on saturated extracts.

TABLE 1 - Chemical properties of the irrigation water in the four treatments.

Season	1st				2nd			
Salinity	Low	Medium	High	High	Low	Medium	High	High
SAR	Low	Medium	Medium	High	Low	Medium	Medium	High
Cl (mg/l)	268	622	1326	1358	259	1122	2027	1924
Cl (meq/l)	7.5	17.5	37.4	38.3	7.3	31.6	57.1	54.2
E.C. (dS/m)	1.25	3.03	4.25	4.34	1.09	3.61	6.02	5.86
Ca + Mg (meq/l)	5.28	15.3	20.58	12.98	4.9	15.4	28.5	16.4
K (meq/l)	0.20	0.52	0.28	0.28	0.16	0.20	0.22	0.24
Na (meq/l)	6.0	17.3	21.4	32.1	5.3	18.4	25.5	37.8
SAR	3.68	6.10	6.64	12.85	3.39	6.63	6.76	13.20

Third leaf lamina and 7th leaf petiole were sampled in the autumn from fully grown followers (7). Five pieces of roots (15 cm long and more than 3 mm thick) were sampled from the same plants, 30 cm from the pseudostem at a depth of 5 to 25 cm. After being washed, ground and ashed, N, P and K were determined by autoanalyser, Ca and Mg by atomic absorption spectrophotometer, Cl by chloridometer, and Na concentration by flame photometer.

RESULTS

Both growth and productivity were affected by the salinity of the irrigation water. At the end of the first year, followers irrigated with high salinity and high SAR water tended to be 27 cm shorter (19%) than the control followers, but this difference was not significant (Table 2). Shooting date and number of hands and fingers per bunch were apparently unaffected in the first season. However, a significant decrease in bunch and finger weight was obtained.

During the second year of experimentation, a pronounced and significant influence was evident for all the recorded parameters of growth, development and production. Even for the moderate salinity treatment, a significant delay of 35 days in shooting time, 31% drop in bunch weight and 23% decrease in finger weight were recorded. As a matter of fact, the fruit harvested from all plants (except the control) was unmarketable.

The relationship between salinity or SAR in the irrigation water and bunch weight is presented in Figures 1 and 2. The increased SAR had an additional adverse effect at the high salinity level (Fig. 1) and the increased salinity had also an additional adverse effect at the medium SAR level (Fig. 2).

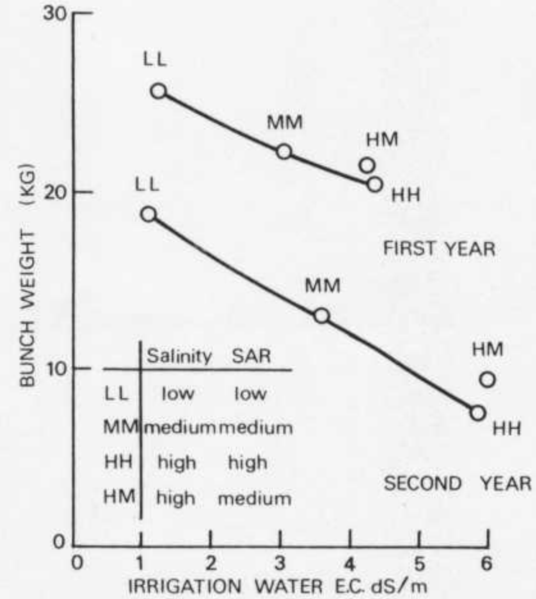

Fig. 1 • The relashionship between bunch weight and electrical conductivity of the irrigation water during the two seasons.

The general suppression of growth and production was not followed by symptoms of marginal chlorosis and necrosis, known as Na, Cl or salt toxicity (3, 7).

The quality of irrigation water had a dominant influence on the chemical properties of the soil (Table 3) ; in particular E.C., Cl, Ca+Mg and Na were affected. The effect

TABLE 2 - The effect of water salinity and SAR on growth, development and production of bananas.

Season	Salinity	Low	Medium	High	High	S.E.	Sig.
	SAR	Low	Medium	Medium	High		
First	Mean shooting date	1/8	28/7	22/7	24/7	5.1	N.S.
	Height of followers (cm)	139	121	117	112	6.3	N.S.
	Hands/bunch	11.7	11.4	11.9	11.7	0.3	N.S.
	Fingers/bunch	236	227	234	229	6.8	N.S.
	Bunch weight (kg)	25.7a	22.3b	21.5b	20.4b	0.9	*
	Mean finger weight (g)	101a	94ab	85b	81b	3.6	*
Second	Mean shooting date	30/7a	3/9b	4/9b	26/9b	7.3	*
	Height of followers (cm)	135a	101ab	73b	67b	11	*
	Hands/bunch	10.7a	10.1ab	9.0b	8.7b	0.4	*
	Fingers/bunch	202a	181ab	144b	146b	11	*
	Bunch weight (kg)	18.9a	13.0b	9.6bc	7.6c	1.3	*
	Mean finger weight (g)	84a	65b	60b	47c	4.3	*

Values which share a common letter do not differ significantly by the Student-Newman-Keuls Multiple Range Test at $P < 0.05$

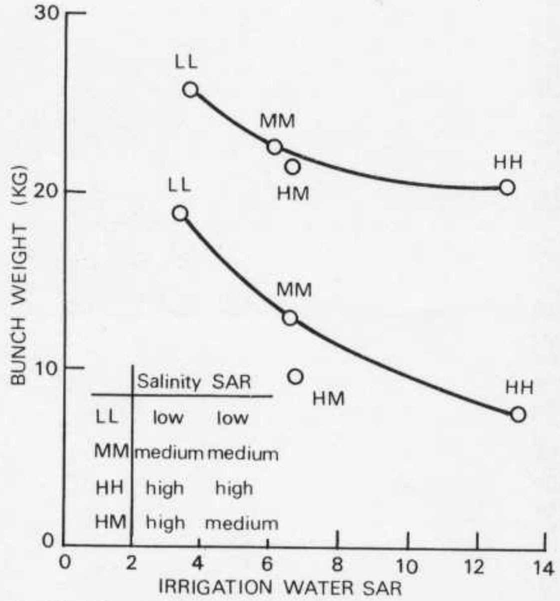

Fig. 2 • The relationship between bunch weight and sodium adsorption ratio in the irrigation water.

of salts in the irrigation water on salt accumulation in the soil was also expressed by comparing the levels in the spring before the start of the experiment, with those in the autumn in the low-low (control) plots.

The increase in both salinity and SAR increased Cl concentration significantly in the 3rd leaf lamina and in the roots, Na in the 7th leaf petiole and in the roots, and N and Mg in the 7th petiole (Table 4). Other nutrients were also affected, but not significantly.

DISCUSSION

Both growth and production of the banana were significantly affected by the quality of irrigation water. Growth retardation and yield decline were evident even with the medium levels of water and soil salinity (E.C. in the water = 3,6 dS/m, and in the soil = 3.0 dS/m). These levels of salinity of irrigation water were found to be harmful to bananas in Jamaica (3) and the coastal plain in Israel. In none of these areas could a critical salt level be determined, since the salt damage to bananas was gradual. However, in our experiment the medium salinity level with about 600 ppm Cl/l was already above the threshold for growing commercial bananas.

In the first year, only bunch weight and finger size were affected. Other parameters, such as flowering time and number of hands per bunch, were not affected, since they had been determined before the start of the treatments. The second year effect on growth, productivity and nutrient concentrations was much more pronounced. Bunch weight, for example, decreased under high salinity and SAR by 18% in the first year and by 60% in the second year. This was due in part to the increased salinity during the second year of the experiment, but also because the plants which carried the second year bunches, grew throughout the first year and were affected by the treatments during the two seasons.

Under the experimental conditions both salinity and SAR changed, as is the case in commercial banana plantations in the Jordan Valley. It was evident that sodium had a specific additional adverse effect on the banana growth and yield.

The Na levels in the roots were found to be six times higher than those in the lamina or petiole (8). The increased salinity and SAR in the irrigation water resulted in an even higher retention of Na in the roots. We found the concentration in the roots to be 37 to 77 times higher than that in the leaf lamina and 16-29 times higher than that in the petiole. It is also clear that the leaf lamina has lower concentrations of Na and Cl in comparison with the petiole. Thus, the toxic elements are excluded from the photosynthesis site - the lamina.

The significant increase of Na in the roots was followed by a decrease in K concentration at the end of the first year (Fig. 3). Such an antagonism was also found in the

TABLE 3 - Soil chemical properties in the spring before the start of the experiment and in autumn 2 years later. Mean for 0-90 cm depth.

Salinity	Before start of experiment	Low	Medium	High	High
SAR		Low	Medium	Medium	High
Cl (meq/l)	5.3	10.9	23.0	44.5	31.4
E.C. (dS/m)	1.10	1.58	3.00	5.04	3.68
Ca + Mg (meq/l)	5.7	12.7	20.9	37.6	26.9
K (meq/l)	0.15	0.19	0.42	0.42	0.25
Na (meq/l)	5.8	5.9	11.0	14.3	14.7
SAR	3.40	2.36	3.34	3.48	4.01

TABLE 4 - The effect of irrigation with saline water on nutrient levels (% of dry matter) in 3rd leaf lamina, 7th leaf petiole and roots. Samples were taken from developed suckers, at the end of 2 years.

Salinity		Low	Medium	High	High	S.E.	Sign.
SAR		Low	Medium	Medium	High		
3rd leaf lamina	N	3.48	3.24	3.35	3.49	0.073	N.S.
	P	0.212	0.214	0.218	0.218	0.007	N.S.
	K	3.68	3.71	3.67	3.43	0.277	N.S.
	Ca	1.31	1.67	1.42	1.59	0.257	N.S.
	Mg	0.46	0.45	0.48	0.49	0.037	N.S.
	Na	0.013	0.020	0.020	0.020	0.003	N.S.
	Cl	0.98c	1.08bc	1.50a	1.28b	0.070	*
7th leaf petiole	N	0.69c	0.86b	0.77bc	1.00a	0.036	*
	P	0.113	0.143	0.137	0.107	0.013	N.S.
	K	3.80b	4.80a	5.13a	4.00b	0.201	*
	Ca	1.61	1.83	1.90	2.02	0.091	N.S.
	Mg	0.47b	0.59ab	0.52b	0.69a	0.032	*
	Na	0.030b	0.048a	0.040ab	0.053a	0.004	*
	Cl	2.08	2.67	3.29	3.03	0.340	N.S.
Roots	N	1.10	1.19	1.28	1.15	0.114	N.S.
	P	0.099	0.119	0.165	0.121	0.027	N.S.
	K	3.58	3.88	4.75	3.48	1.005	N.S.
	Ca	2.08	2.20	2.94	2.78	0.496	N.S.
	Mg	0.86	1.24	0.71	0.74	0.201	N.S.
	Na	0.480b	1.005 ab	0.940ab	1.535a	0.188	*
	Cl	2.26b	3.35a	3.73a	3.66a	0.259	*

* - Treatments which share a common letter do not differ significantly by the Student-Newman-Keuls Multiple Range Test at $P < 0.05$.

Canary Islands (4), and under controlled K nutrition in Israel (6). In extreme K deficiency, up to 1% Na was found in the conductive tissues. This might suggest the explanation for the mechanism of this effect. Replacement of K by Na is probably possible by non-specific processes, when the cell turgor is raised (9). Thus the importance of adequate K supply under high Na level is obvious. The K:Na antagonism was not found in the second year analyses. It may result from K contamination in the technical NaCl used for preparation of the solutions, as was found also by the increased K levels in the soil (Table 3).

The effect of salinity in this study is assumed to be related mainly to the increase in osmotic pressure of the soil solution which results in difficulties in water uptake. The level of almost all elements - including the non-toxic elements which were supplied equally to all the plants - increased in the roots and petioles with the increasing salinity levels. The difficulties in water uptake probably increased sap concentration. This is also in accordance with the lack of Na- and Cl-specific toxicity symptoms despite the increased salinity level in the second year. If this is the case, climatic conditions and rate of water supply should have a major influence on the relationship between water and soil salinity on the one hand, and the growth of the banana plant on the other hand. Under the hot and dry summer of the Jordan Valley, an adverse effect of even moderate salinity is to be expected, while no such effect would appear in a cooler and more humid area. Moreover, the banana plant may be able to stand a higher salinity level when water supply is increased. The interaction between water salinity and water supply is clear, and under higher salinity levels water supply should be increased.

Since growth and productivity on the one hand, and mineral levels in the various organs on the other hand, were all affected by the water and soil salinity and by the SAR, a high correlation between them was expected. As an example, a highly significant linear correlation can be seen between Na concentration in the roots and flowering time (Fig. 4). The delay in the rate of growth and flowering under high salinity level is clear.

The level of minerals in the various organs might give us some indication as to their suitability for the assessment of Cl and Na levels in the banana plant. Moreover, the fact that no specific external symptoms were detected as a result of the salinity treatments, emphasizes the importance od the determination of Na and Cl critical concentrations. Significant linear correlations ($r = 0.96$-0.98) were found between E.C. or Cl level in the water or soil, and Cl concen-

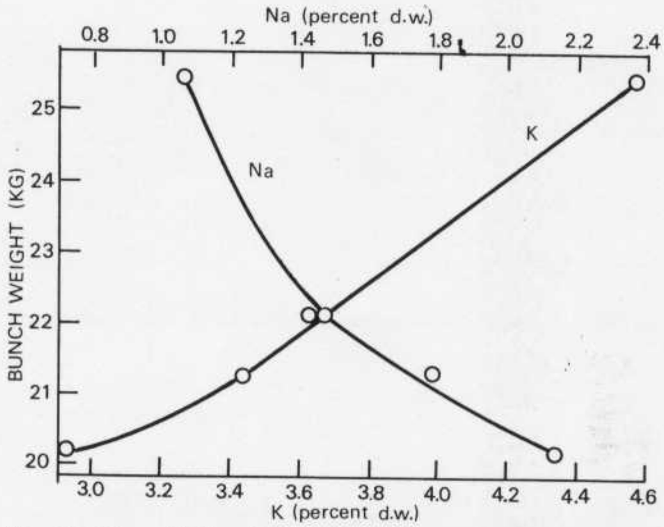

Fig. 3 • The relationship between the level of Na and K in the roots and bunch weight, at the end of the first year.

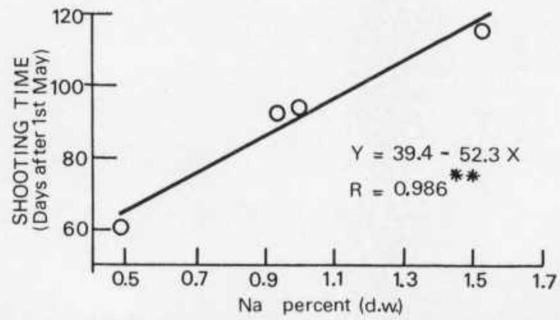

Fig. 4 • The relationship between Na level in the roots and shooting time in the second year.

tration in the 3rd leaf lamina and roots. Similar significant correlations were found between SAR or Na level in the water and soil, and Na concentration in the roots. The concentrations in the roots revealed also a linear relationship with the growth and yield. Cl and Na levels in the roots seem to be most indicative with regard to salinity stress. This is true of course only when Na and Cl are the dominant ions in the soil solution which is, however, the common case in Israel. The roots (and corm) are very rich in Cl and Na. It was already found that 20% of the total Cl and 40% of the total Na are found in the banana roots (8).

Bananas, as many other plants, are thought to be more sensitive to Na than to Cl (1,7). Toxicity levels of Na and Cl in the banana plants have not yet been established. On the basis of the present study, some damage occurred at 3.3% Cl and 1.0% Na in the roots. Therefore, the tentative critical concentration in the roots should not be higher than those values.

Since, in the present study, salinity and SAR were not completely separated, a more detailed study with a complete separation of these factors under various climatic conditions is required.

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