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Effect of saline water on soil salinity and on water stress, growth, and yield of wheat and potatoes

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Abstract

Wheat and potatoes were grown in tanks filled with loam and clay and irrigated with water of three different levels of salinity and, for the wheat, with two irrigation regimes. A combination of soil water sampling and salt balance was used to study the development of soil salinity and the composition of the soil water. This revealed an increase in adsorbed sodium, a decrease in adsorbed calcium and magnesium, and precipitation of a mixture of calcium and magnesium carbonate. Predawn leaf-water potential and stomatal conductance can be used as parameters for water stress, and show good coherence with growth and yield. That potatoes are more sensitive to water stress than wheat was reflected by greater differences in leaf-water potential and stomatal conductance, and a more severe yield de-crease. Soil, salinity and water regime affect water stress, growth, and yield. The water efficiency of wheat and potatoes was not affected by soil and salinity.

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INTRODUCTION

A previous paper (Katerji et al., 1992) described the aim of these experiments. It explained the experimental procedure and the results of the first year, which were concerned with broadbeans and the effect of soil salinity on water stress, growth and yield. This paper presents the results of the second and third year, during which, respectively, wheat and potatoes were grown.

The experiment comprised 15 tanks filled with loam and 15 tanks filled with clay. The tanks were irrigated with water of three different qualities. In the second year, when wheat was grown, two irrigation regimes were applied. During the third year when potatoes were grown, only one irrigation regime was applied to decrease the number of variables and to improve the accuracy of the measurements. The experimental procedure presents only those points that changed in comparison with the first year.

Wheat is a deep rooting and salt-tolerant crop, whereas potatoes are shallow rooting and are more sensitive to salinity and drought. Besides studying the development of soil salinity with different saline waters, this experiment allowed the two crops to be compared in their reaction to water stress, caused by soil or salinity, and the effect of water stress on growth and yield.

Experimental procedure

Crop

Wheat (*Triticum turgidum*, variety ISA) was sown at a density of 100 grains per tank (diameter of 1.20 in). Fertilizing was equivalent to 100 kg P_20_5/ha, 150 kg N/ha and 300 kg K_2SO_4/ha. When 50% of the plants had attained a phenological stage, this date was noted, which gave the following picture of the period: sowing 22 November, 1990 (day *t*), emergence *t*+3 (fresh water) and *t*+11 (saline waters), tillering *t*+58 (fresh water), and *t*+65 (saline waters), start of elongation *t*+90 (fresh water) and *t*+96 (saline waters), end of elongation *t*+134 (fresh water) and *t*+142 (saline waters), flowering *t*+147 (clay) and *t*+160 (loam), yield formation *t*+164 (clay) and *t*+177 (loam), start of ripening *t*+185 (clay) and *t*+196 (loam), harvest *t*+207 (clay) and *t*+214 (loam).

Potatoes (*Solanum tuberosum*, variety Spunta) were planted at a density of 11 tubers per tank. This number was gradually reduced to 6 tubers at harvest time to determine the biological parameters during the growth period. Fertilizer was applied at a rate of 250 kg P_20_5/ha and 200 kg N/ha. In accordance with the criteria of Sparks (Doorenbos and Kassam, 1979) the main phenological dates were noted when attained by 50% of the plants. This gave the following picture of the crop development: sowing 3 February, 1992 (day t), establishment t+ 12, start of early vegetative period t+ 32, stolonization and tuberinitiation t+ 50, yield formation t+ 100, early ripening t+ 105, harvest t+ 125.

Irrigation

During the second year, the wheat received three different water qualities: local fresh water with a chloride concentration of 3.7 mEq/l, an EC of 0.9 dS/m and a SAR of 1.3 as a control, and two saline waters obtained by adding equivalent amounts of NaCl and $CaCl_2$ to the fresh water. For each of these treatments, the same tanks were used as in the foregoing year. In view of the buildup of soil salinity during the first year, lower salt concentrations were chosen, with chloride concentrations of 10 and 20 mEq/l, EC values of 1.7 and 2.7 dS/m, and SAR values of 2.4 and 3.6, respectively.

Because, during the first year, the broadbeans had already indicated a tendency towards a lower evapotranspiration with increasing salinity, it was decided that if the evapotranspiration differed between the three water qualities, the water application should differ too. This was the case from the second irrigation onwards.

Two irrigation regimes were applied, equalling 75 and 125% of the evapotranspiration. Of the 10 tanks available for each water quality, two were used as guides to determine the evapotranspiration in the following way. After estimating the evapotranspiration with the help of the Class A pan, an amount of water equalling about 1.25 times the estimated value was applied. The following day, the amount of drainage water was measured. Since the drainage water generally attained 20 to 30% of the irrigation water, it was assumed that the soil water content corresponded with field capacity and that the evapotranspiration could be simply calculated as the difference between the amounts of irrigation and drainage water. Then, one day later, water was applied to the other tanks at 75 and 125% of the evapotranpiration determined in the guide tanks. The evapotranspiration was calculated again for the tanks irrigated at 125% and this value is presented in Table 8 as the evaporation of wheat.

During the third year, again fresh water and two saline waters were applied to the same tanks, but now with salinity levels expected to cause slight and moderate yield declines in potatoes. On the loam soil, the saline waters had chloride concentrations of, respectively, 15 and 30 mEq/l, EC values of 2.3 and 3.6 dS/m, and SAR values of 3 and 4.7; on the clay soil, the chloride concentrations were 15 and 20 mEq/l, EC 2.3 and 2.7 dS/m, and SAR 3 and 3.6.

Since the evapotranspiration of the previous wheat crop had shown a dependence on water quality as well as on soil, one tank per treatment was used as a guide to determine the evapotranspiration as the difference between the amounts of irrigation and drainage water. Thus, a total of six values were obtained for the evapotranspiration. One day later, water was applied to the remaining four tanks of each treatment at 125% of the evapotranspiration, thus aiming at a leaching fraction of 0.2. As the guide tank often still produced some drainage water after one day, the evapotranspiration obtained from the guide tanks was generally too high. So the evapotranspiration found afterwards from the other four tanks was somewhat lower and the leaching fraction somewhat higher than 0.2.

Soil salinity

In the previous paper (Katerji et al., 1992), the chloride concentration of soil water calculated from the salt balance was converted into electrical conductivity with the use of the correlation: 1 dS/m to 8 mEq/l. As more data became available over a wider range during the following years, a linear relationship between EC in dS/m and Cl^- in mEq/1 was revealed on double logarithmic paper. This can be expressed by the equation $\ln EC = 0.824 \ln Cl - 1.42$. This equation was used to convert Cl into the EC of soil water, which value was divided by 2 for the conversion into EC_e.

Water stress in the plant

In the first year, the difference in radiation temperature between the saline treatments and the control proved to be a less suitable criterion for the diagnosis of water stress. This parameter was, therefore, no longer used.

The predawn leaf-water potential of wheat was determined on 8 leaves distributed over 2 tanks per treatment, and that of potatoes on 5 leaves distributed over 5 tanks per treatment.

The stomatal resistance was determined at midday on the upper leaf surface of 10 leaves, well exposed to sunlight, for both the wheat and the potatoes.

Growth and yield

The leaf area and dry matter of wheat were determined at the successive phenological stages, from tillering onwards, by taking a total of 40 plants distributed over 2 tanks per treatment.

The leaf area and dry matter of the above-ground part of potatoes were determined at the successive phenological stages from the start of vegetative growth onwards, by taking each time 5 plants distributed over 5 tanks per treatment.

The yield was determined as the average production of the 2 tanks per treatment for wheat, and of 5 tanks per treatment for potatoes. Besides the total yield of potatoes, the number of tubers and the percentage of water per kg fresh weight were measured.

Experimental results and discussion

Soil salinity

Table 1 shows the effect of the irrigation regime on the chloride concentration of the soil water, obtained from the salt balance and from soil water sampling. For the 75% application, the salinity increased throughout the irrigation season, whereas it remained almost stable for the 125% application. The leaching fraction on the loam soil ranged around 0.15. On the clay soil the salinity even declined for the 125% application because the leaching fraction ranged around 0.3. This difference in leaching fraction was due to the difference in evapotranspiration between the two soils. As the evapotranspiration on clay was lower than on loam (Table 8) and the applications were equal for the same water quality, more leaching occurred in the clay soil.

Table 1

Chloride concentration of soil water in the layer 0-100 cm (in mEq/l) after irrigation; loam, irrigation water containing 10 mEq Cl/l

1990-91	22.11	12.2	24.3	17.4	6.5	21.5	5.6	Average
Application 75%								
Salt balance	48.8	50.2	52.8	56.0	58.9	61.8	64.3	56.1
Sampling	53.9	55.1	58.7	59.9	62.3	63.5	65.0	59.8
Application 125%								
Salt balance	48.8	45.4	47.5	48.0	47.2	47.5	48.3	47.5
Sampling	53.9	55.9	54.0	51.5	48.2	47.5	46.9	51.1

Table 2

Distribution of the chloride concentration of soil water (in mEq/l) after irrigation, obtained by sampling; loam, irrigation water containing 10 mEq Cl/l

1990-91	Application 75%				Application 125%			
Depth (cm)	28.5	22.11	17.4	5.6	28.5	22.11	17.4	5.6
12.5	37.5	25.9	33.1	28.9	37.5	25.9	30.5	20.8
37.5	36.8	28.2	50.5	57.2	36.8	28.2	31.9	29.6
62.5	42.5	69.8	58.9	81.5	42.5	69.8	59.5	49.2
87.5	43.8	92.0	97.0	92.5	43.8	92.0	84.0	87.8
Average	40.2	53.9	59.9	65.0	40.2	53.9	51.5	46.9

Table 2 presents the distribution of the chloride concentration with depth, obtained by sampling of soil water. The chloride concentration at the end of the first year (28.5) increased only slightly with depth, because, during the first year, salinity developed from a non-saline start.

After the first water application at the start of the second year (22.11) the increase with depth became quite pronounced and remained so, somewhat more pronounced for the 75% that was applied after 22.11.

For the four saline treatments of the third year, Table 3 presents the chloride concentration of the soil water obtained from the salt balance and from soil water sampling. Although the sampling values were obtained as an average of 4 depths and 16 soil water samplers per depth (4 tanks $\times$ 4 samplers), the values were often considerably different from those obtained from the salt balance. The data of the salt balance showed a slight decrease, as may be expected since the leaching fraction ranged around 0.3 for both soils. In contrast, the sampling data generally showed an increase. After the first irrigation on 30 November, when about 300 mm were applied to replenish the soil and to leach the treatments that had received no leaching during the previous season, the sampling data were much lower than those of the salt balance. Afterwards, the sampling data increased and ended up still lower, higher, or almost equal.

A second aspect of the development of soil salinity concerns the change in ionic composition of the soil water. Except for chloride, such changes are influenced by ion exchange reactions, dissolution, or precipitation. The change in the ionic concentration of soil water was determined by comparing the increase according to soil water sampling and that according to the salt balance. For chloride, no reactions occur, so the increases obtained by both methods should be equal. If not, this can be attributed mainly to soil heterogeneity. Assuming that the salt-balance value is a better approximation of the real value and that the effect of heterogeneity is the same for all ions, the sampling values of the other ions can be corrected by multiplying with the ratio of the chloride concentration obtained from the salt balance and that of soil-water sampling.

For two treatments on loam at the end of the second year, Table 4 presents the comparison between the increase in the ion concentration according to sampling and the increase according to the salt balance. For the treatment of 10 mEq Cl/l, all the observed sampling values were multiplied by the correction factor for chloride 44.1/42.7, and for the treatment of 20 mEq Cl/l by 119.2/78.3. The salt-balance values were then substracted from the corrected sampling values, revealing, with the exception of Cl^-, a positive or negative difference.

Table 3

Chloride concentration of soil water in the layer 0-100 cm (in mEq/l) after irrigation

1991-92	30.11	15.2	20.3	9.4	2.5	20.5	Average
Loam, 15 mEq Cl/l							
Salt balance	50.5	50.1	45.9	45.2	46.7	45.8	47.4
Sampling	32.4	37.0	38.0	39.0	40.5	41.7	38.1
Loam, 30 mEq Cl/l							
Salt balance	136.8	134.5	133.7	133.2	131.6	125.7	132.6
Sampling	88.0	74.3	63.6	64.3	71.2	84.3	74.3
Clay, 15 mEq Cl/l							
Salt balance	43.9	43.9	43.0	43.4	43.5	41.8	43.3
Sampling	26.1	39.4	41.1	43.2	49.7	51.2	41.8
Clay, 20 mEq Cl/l							
Salt balance	61.7	62.3	61.2	62.1	60.5	56.5	60.7
Sampling	36.6	54.7	48.9	53.9	54.2	56.1	49.2

Table 4

Comparison between the increase in the ion concentration (in mEq/l) obtained from soil-water sampling and the increase calculated from the salt balance after 2 years

Ion	Loam, 10 mEq Cl/l Application 125%				Loam, 20 mEq Cl/l Application 125%			
	Sampling		Balance	Diff.	Sampling		Balange	Diff.
	Obs.	Corr.			Obs.	Corr.		
Na+	9.7	10.0	39.8	-29.8	20.6	31.3	79.0	-47.7
Ca^{2+}	37.7	38.8	17.7	+21.1	63.7	96.8	50.8	+46.0
Mg^{2+}	5.4	5.6	16.4	-10.8	8.6	13.1	16.8	-3.7
Cl^-	42.7	44.1	44.1	0	78.3	119.2	119.2	0
SO_4^{2-}	6.8	7.8	-3.7	+10.7	8.0	12.2	-2.1	+14.3
HCO_3^-	3.6	3.7	35.2	-31.5	7.2	10.9	33.5	-22.6

The negative difference of Na^+ can be attributed to the exchange between soil water and adsorption complex where Na^+ is replacing $Ca^{2+}$and Mg^{2+}. Table 5 presents the cation-exchange capacity and the adsorbed ions at the end of the second year, revealing an increase in Na^+ and a decrease in Ca^{2+} and Mg^{2+}. Since the tank contains about 1600 kg soil, corresponding with 500000 mEq adsorbed ions, an increase of 5.1% for Na^+ corresponds with an exchange of approximately 25000 mEq. As a tank with loam contains 4101 water at field capacity, the negative difference in soil water between sampling and salt balance of 47.7 mEq Na^+/l (Table 4) corresponds with $47.7 \times 410 = 19500$ mEq, which is of the same order of magnitude as the exchange calculated from Table 5. For clay, the trend appeared to be the same.

Table 5
Cation-exchange capacity and absorbed cations after 2 years; loam, application 125%

Irrigation water	Layer (cm)	CEC (mEq/Kg)	Na^+ (%)	K^+ (%)	Ca^{2+} (%)	Mg^{2+} (%)
Fresh	0.25	319	1.3	2.3	88.0	8.4
20 mEq Cl/l	0 - 25	319	4.6	3.7	83.6	8.1
	25 - 50	310	7.2	2.7	83.4	6.7
	50 - 75	318	8.3	2.7	83.0	6.0
	75 -100	327	5.7	2.0	86.0	6.3
Average		319	6.4	2.8	84.0	6.8

From Table 4, the following calculation can be made for the treatment of 10 mEq Cl/l. Ca^{2+} plus Mg^{2+} not exchanged against Na^+ equal 29.8 - (21.1-10.8) = 19.5 mEq/l. Ca^{2+} dissolved from gypsum equals 10.7 mEq/l.

For Ca^{2+} plus Mg^{2+}, this yields a total deficit in the soil water of 19.5 + 10.7 = 30.2 mEq/l against a deficit of 31.5 mEq/l for HCO_3^-.

The negative difference of Na^+ should be balanced by an equal positive difference of Ca^2 plus Mg^{2+}, if no precipitation of these ions occurs. A positive difference Of SO_4^{2-} indicates the dissolution of gypsum, present in traces in the loam, which should also increase Ca^{2+} by an equal amount, whereas a negative difference indicates the precipitation of gypsum. A negative difference of HCO_3^- indicates the precipitation of carbonate salts.

Table 6

Cumulative differences (in mEq/l) between the ion concentrations of soil water found by sampling and salt balance after 1, 2 and 3 years. The treatments are indicated by the chloride concentrations of the irrigation water of the third year

Treatment		Year	Na^+	Ca^{2+}	Mg^{2+}	SO_4^{2-}	HCO_3^-
Soil	Water						
Loam	15 mEq/l	1990	-17.2	17.0	-2.3	8.3	-11.2
		1991	-29.1	20.0	-8.0	8.4	-26.6
		1992	-41.0	8.4	-12.6	-2.7	-39.4
Loam	30 mEq/l	1990	-33.0	28.1	6.6	9.9	-8.3
		1991	-46.1	39.9	-3.8	9.6	-22.3
		1992	-68.3	43.5	-4.3	4.7	-33.8
Clay	15 mEq/l	1990	-9.7	0.4	-9.2	-1.8	-16.1
		1991	-16.4	2.8	-13.6	-1.4	-27.6
		1992	-26.3	-1.3	-16.6	-6.9	-36.9
Clay	20 mEq/l	1990	-14.3	0.3	-6.4	-2.1	-16.4
		1991	-23.8	9.1	-13.0	-0.3	-25.3
		1992	-39.6	8.9	-15.7	-9.2	-33.8

Table 6 presents the cumulative differences between the ion concentrations of soil water found by sampling and salt balance after 1, 2, and 3 years. The values of the second year are the averages of the two water regime treatments.

Table 7 presents the cumulative deficits of Ca^{2+} plus Mg^{2+} and of $HCO3_3^-$ in soil water at the end of the first, second, and third year. The deficit of Ca^{2+} plus Mg^{2+} is more or less equal to the deficit of $HCO3_3^-$

Table 7

Cumulative deficits of calcium, magnesium and bicarbonate concentration (in mEq/l) in soil water after 1, 2 and 3 years

		Loam		Clay	
		15 mEq/l	30 mEq/l	15 mEq/l	20 mEq/l
1990	Deficit of Ca^{2+} + Mg^{2+}	10.8	8.2	16.7	18.3
	Deficit of HCO_3^-	11.2	8.3	16.1	16.4
	Difference	-0.4	-0.1	0.6	1.9
1991	Deficit of Ca^{2+} + Mg^{2+}	25.5	19.6	25.8	27.4
	Deficit of HCO_3^-	26.6	22.3	27.6	25.3
	Difference	-1.1	-2.7	1.8	2.1
1992	Deficit of Ca^{2+} + Mg^{2+}	42.5	33.8	37.3	37.2
	Deficit of HCO_3^-	39.4	33.8	36.9	33.8
	Difference	3.1	0.0	0.4	3.4

Under normal agricultural conditions, magnesium does not precipitate as magnesium carbonate in irrigated soils (Suarez, 1975, 1981), and no precipitation of magnesium was assumed when the concept of the adjusted SAR was introduced (Ayers and Westcot, 1985). Nevertheless, field studies of groundwater indicate the precipitation of magnesium, although to a lesser degree than calcium (Lennaerts et al., 1988). These tank experiments point towards precipitation of a mixture of calcium and magnesium carbonate, with a rather high percentage of magnesium, or to precipitation of magnesium as an unknown, possibly a magnesium-silicium compound (Miyamoto and Hendrick, 1990).

Water stress in the plant

On loam, the predawn leaf-water potential of potatoes (Fig. 1), increasing at each irrigation and afterwards decreasing, differed significantly with the three water qualities, from the start of the measurements onwards (after the third irrigation on 20 March). On clay, where the difference in soil salinity between the two saline treatments is less than on loam, significant differences between the control and the saline treatments appeared from the start, and from day *t*+85 also between the saline treatments. The higher the salinity, the lower the leaf-water potential. The differences between the treatments varied, attaining their maximum value between the days *t*+85 and *t*+105. The leaf-water potentials of the controls on loam and clay were generally quite similar whereas, for the saline water with 15 mEq Cl/l and almost the same soil salinity, loam systematically had higher values than clay. The same trends appeared in wheat, but not in a clear, significant way.

The stomatal conductance fluctuated in much the same way with the water applications, but, unlike the leaf-water potential, maximum values did not occur immediately after irrigation but some days later (Fig. 2). This behaviour in potatoes, not observed in broadbeans (Katerji et al., 1992) has also been observed by other authors (Epstein and Grant, 1973). Here too, on loam, significant differences between the three water qualities appeared from the start of the measurements onwards, whereas on clay they appeared first between the control and the saline treatments and afterwards also between the saline treatments. The higher the salinity, the lower the stomatal conductance. The stomatal conductance clearly differed between loam and clay for the control as well as for the saline water of 15 mEq Cl/l. These trends were the same in wheat, but much less clear than in potatoes.

According to both parameters, potatoes are more sensitive than wheat to water stress caused by soil or by salinity.

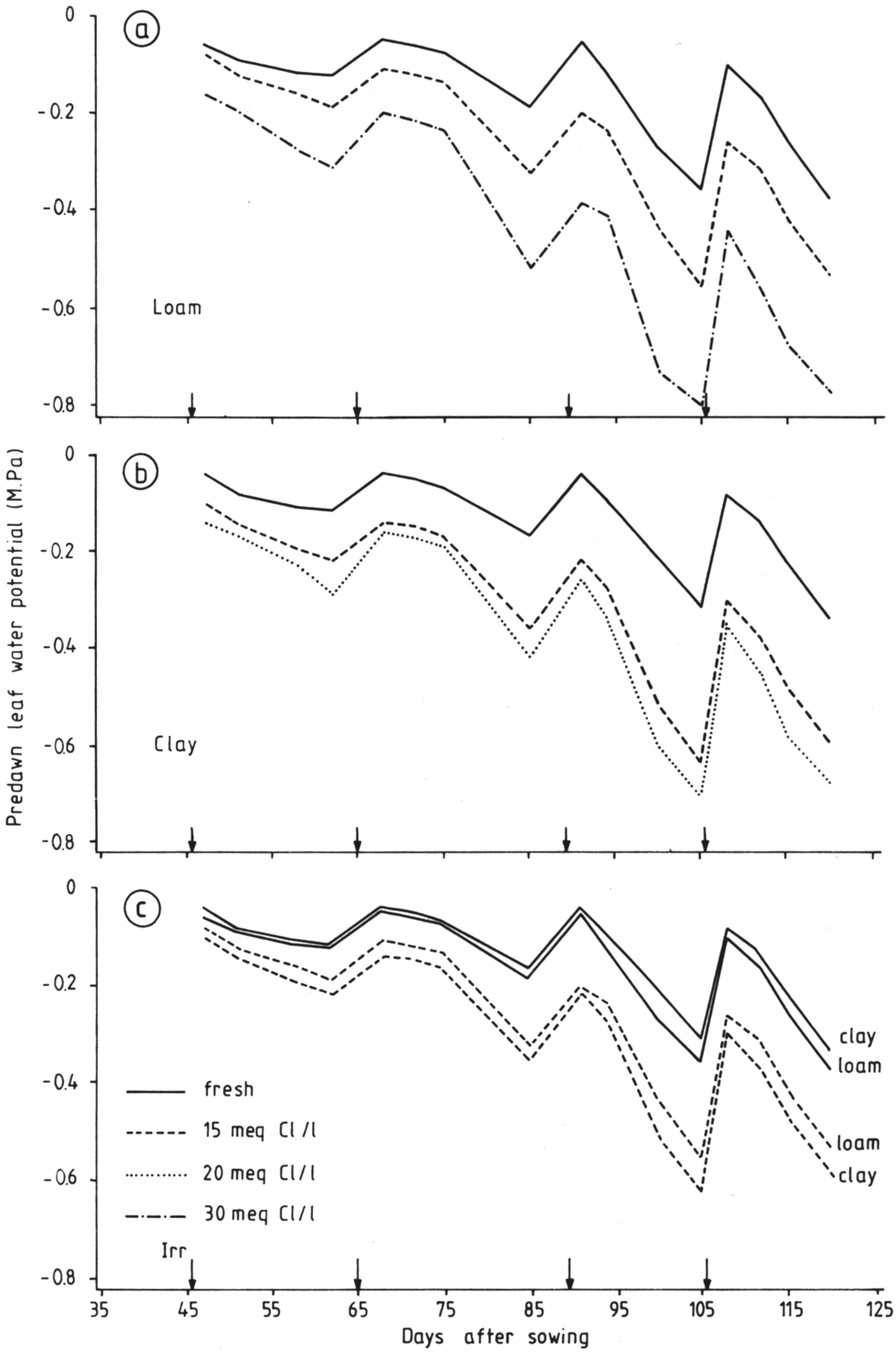

Fig. 1. *Predawn leaf-water potential of potatoes vs days after sowing.*

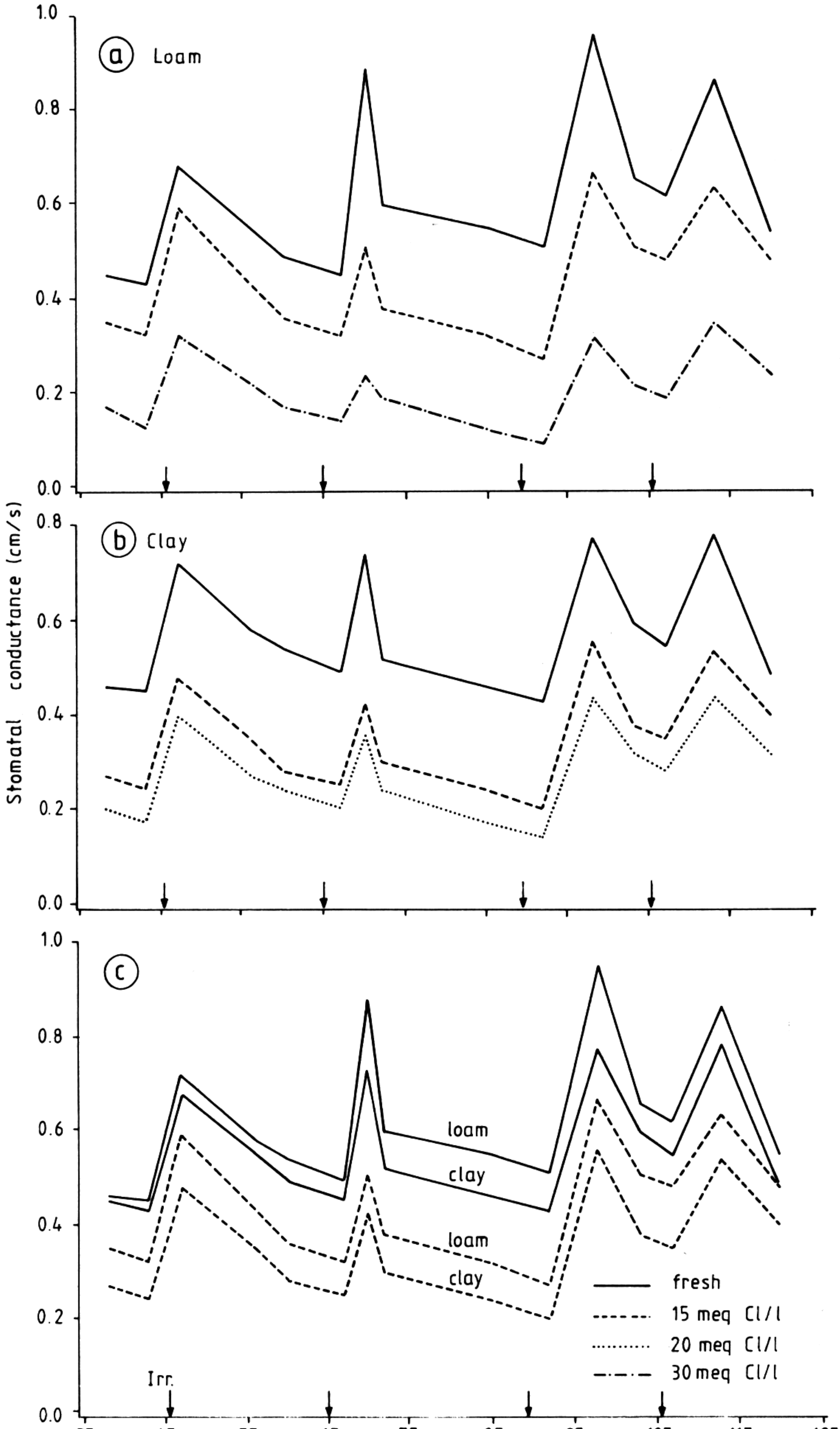

Fig. 2. *Stomatal conductance of potatoes vs days after sowing Evapotranspiration*

The differences in water stress finally appear as differences in evapotranspiration, presented in Table 8 for wheat and in Table 9 for potatoes. The evapotranspiration was calculated as the average difference between the amounts of irrigation and drainage water for three lysimeters per treatment for wheat and for five lysimeters for potatoes. Although the leaf-water potential and stomatal conductance of wheat did not show systematically significant differences, the evapotranspiration clearly differed from the second irrigation on 12 February onwards. If conditions for high evapotranspiration exist during germination and emergence, crops at this stage also show differences due to salinity (van Hoorn, 1991). For the period from mid-February till mid-May, the evapotranspiration of potatoes was much lower than that of wheat. This can be attributed to the later sowing date, resulting in a later development of the leaf area, and to the lower density of plants, resulting in a smaller leaf area.

Growth and yield

Figure 3 presents the salinity effect on the development of the leaf area of potatoes and Figure 4 on the development of dry matter of leaves and stems. Differences appeared somewhat later than differences in leaf-water potential and stomatal resistance, at day *t*+60 near the fourth irrigation on 9 April.

Table 8

Evapotranspiration of wheat (in mm/day) from 29.11.90 till 5.6.91

Soil	Water	29.11-12.2	12.2-24.3	24.3-17.4	17.4-6.5	6.5-21.5	21.5-5.6	Total (mm)
Loam	Fresh	0.9	3.8	7.0	9.0	10.9	10.7	883
	10 mEq Cl/l	0.85	3.6	6.8	7.6	9.8	9.2	800
	20 mEq Cl/l	0.8	3.2	6.0	6.9	8.9	8.0	721
Clay	Fresh	0.85	3.7	6.3	7.4	8.7	6.5	733
	10 mEq Cl/l	0.75	3.4	5.7	6.4	7.3	5.7	648
	20 mEq Cl/l	0.75	3.1	5.0	5.6	5.9	4.5	563

The lower the salinity, the better the growth expressed by these parameters. Figures 3 (c) and 4 (c) present the effect of soil texture, with loam showing a better growth than clay.

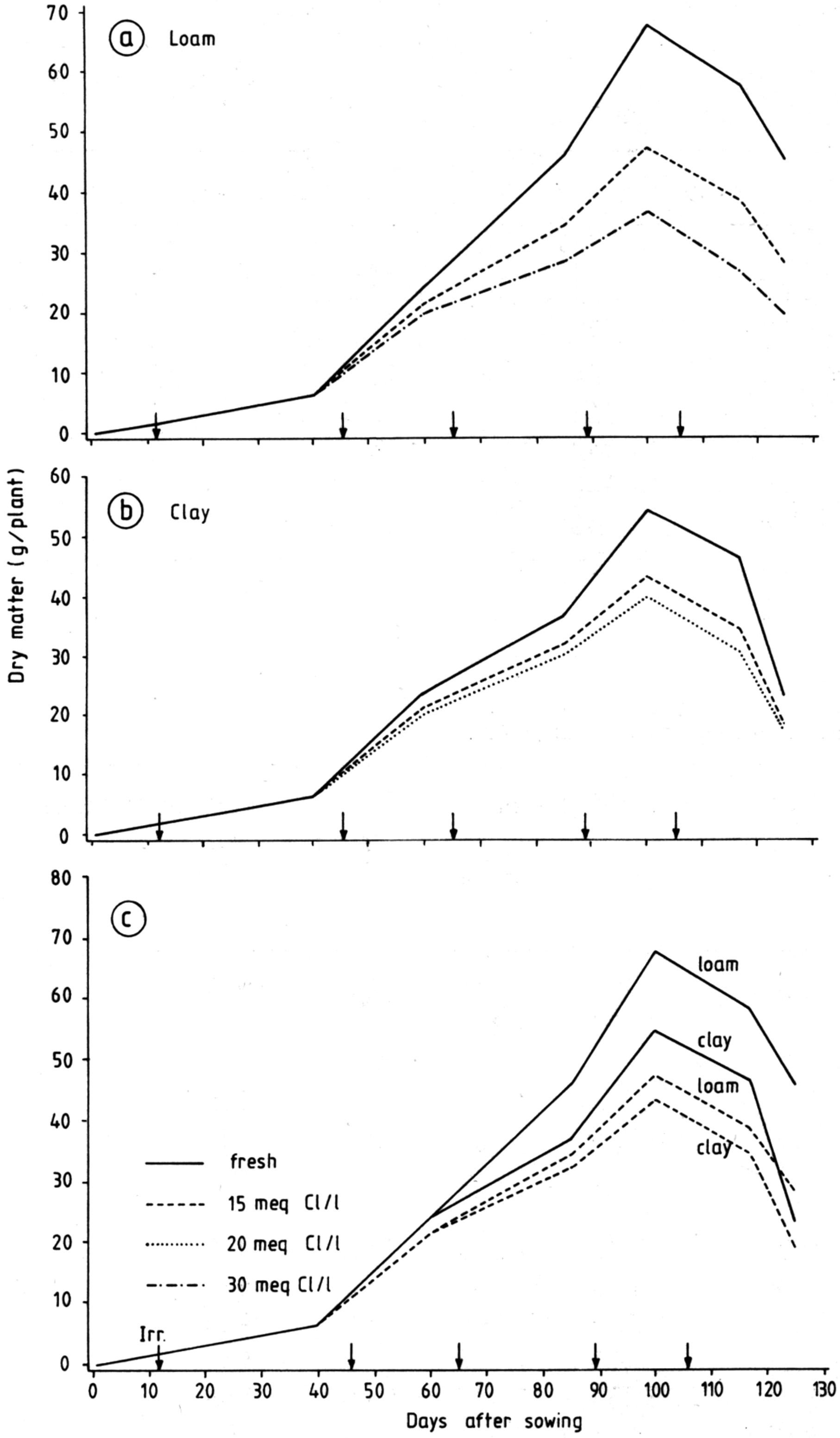

Fig. 3. Leaf area of potatoes vs days after sowing.

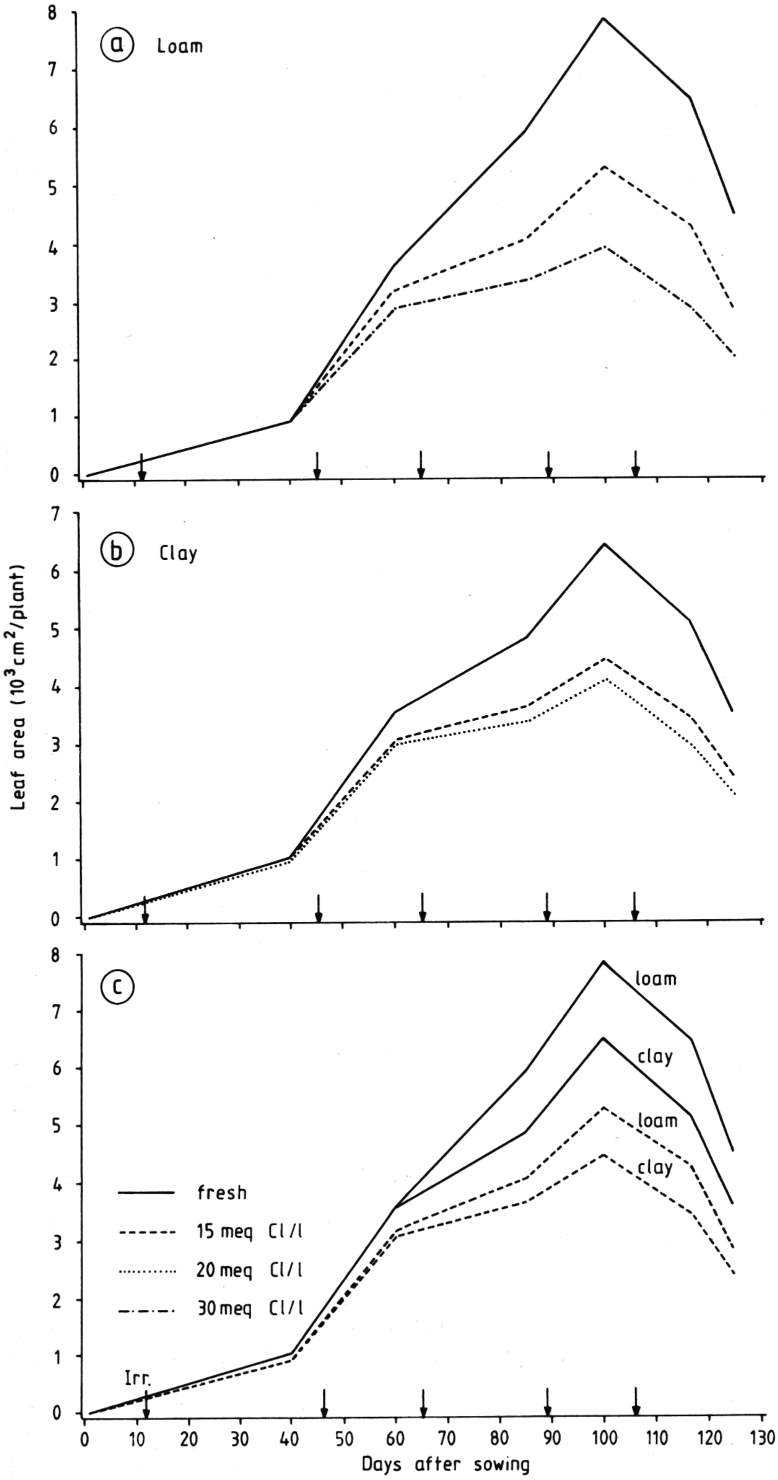

Fig. 4. *Canopy dry matter of potatoes vs days after sowing.*

Table 9

Evapotranspiration of potatoes (in mm/day) from 30.11.91 till 20.5.92

Soil	Water	30.11-15.2	15.2-20.3	20.3-9.4	9.4-2.5	2.5-20.5	Total (mm)
Loam	Fresh	1.0	1.5	3.6	5.1	6.2	415
	15 mEq Cl/l	1.0	1.5	3.2	4.7	5.6	382
	30 mEq Cl/l	0.8	1.4	2.9	3.9	4.8	328
Clay	Fresh	0.9	1.5	3.8	4.1	4.8	363
	15 mEq Cl/l	0.9	1.3	2.9	3.9	4.3	327
	30 mEq Cl/l	0.9	1.2	2.8	3.5	3.9	304

Wheat showed a development in leaf area similar to that of potatoes, whereas dry matter continued to increase till harvest time. Clear differences appeared from the end of elongation onwards, with a better growth on loam than on clay, a better growth for the irrigation regime at 125% of evapotranspiration, and a decline with increasing salinity. Table 10 presents the leaf area and dry matter of wheat at the start of ripening.

The results of these growth parameters were confirmed by the yield, presented in Table 10 for wheat. EC_e was calculated as previously described using the average chloride concentration obtained by the salt balance from the first till the last irrigation. The evapotranspiration refers to the same period. The water application refers to the total amount from the second irrigation onwards, when water applications started to differ, so not including the first irrigation in November for replenishing the soil. Since evapotranspiration on loam was higher than on clay and the water applications were the same for the same irrigation regime, the amount of drainage water was lower on loam, yielding an average leaching fraction of 0.16 against 0.32 on clay.

Table 10
Leaf area and dry matter of wheat at the start of ripening

Water	Application (%)	Leaf area (cm^2/plant)		Dry matter (g/plant)	
		Loam	Clay	Loam	Clay
Fresh	125	950	461	28.0	24.8
	75	768	364	27.2	24.5
10 mEq Cl/l	125	596	353	26.4	21.7
	75	577	352	24.5	21.7
20 mEq Cl/l	125	569	347	24.3	19.9
	75	560	346	19.7	19.2

The treatments with fresh water and water of 10 mEq Cl/l can be used to compare the effect of soil and water application on yield, because the fresh water shows approximately the same EC_e, values on both soils and the water of 10 mEq Cl/l too at equal applications, whereas soil salinity differs considerably for the water of 20 mEq Cl/l. The average grain yield equalled 0.823 kg/m^2 on loam against 0.715 kg/m^2 on clay, a decrease of 13%.

The average yield was 0.819 kg/m^2 for the 125% application against 0.719 kg/m^2 for the 75% application, a decrease of 12%.

The wheat yield was slightly affected by salinity, although wheat is considered moderately to well salt-tolerant. According to Ayers and Westcot (1985), the decrease for durum wheat starts from an EC_e, of 5.7 dS/m onwards. The stronger reaction of wheat in this experiment may be attributed to the variety, because wheat varieties can differ considerably in their salt reaction.

The water-use efficiency can be calculated for the 125% application the evapotranspiration of which was known from the first till the last irrigation.

Table 12 does not show any clear differences due to soil or salinity.

Adding 100 mm to the evapotranspiration for the period between the last irrigation and harvest gives an average water-use efficiency of 0.95 kg/ m^3, corresponding with the range between 0.8 and 1.0 kg/m^3 reported by Doorenbos and Kassam (1979).

Table 13 presents soil salinity, yield, evapotranspiration, and water application for potatoes. Since potatoes are a shallow-rooting crop, the EC_e refers to the layer 0-50 cm. The chloride concentration, obtained from soil water samples in that layer, was calculated as an average for the period from the first till the last irrigation, then corrected according to the salt balance and converted into EC_e. The evapotranspiration also refers to the period from the first till the last irrigation and the water application to the total amount from the second irrigation onwards, so not including the first irrigation in November. The average leaching fraction on both soils was about 0.3, higher than originally intended owing to an overestimate of the evapotranspiration in the guide tank. The yield is expressed in kg fresh weight and the percentage water refers to the fresh weight.

Table 11

Soil salinity, yield of wheat, evapotranspiration and water application

Soil	Treatment		EC_e (dS/m)	Yield (Kg/m^2)		ET (mm)	Water application (mm)
	Water	Application (%)		Grain	Straw		
Loam	Fresh	125	0.8	0.900	1.315	883	1079
		75	1.0	0.795	1.300		648
	10 mEq Cl/l	125	2.9	0.820	1.250	800	930
		75	3.3	0.775	1.210		558
	20 mEq Cl/l	125	6.0	0.805	1.070	721	846
		75	6.3	0.760	1.040		508
Clay	Fresh	125	0.8	0.775	1.305	733	1079
		75	1.0	0.640	1.250		648
	10 mEq Cl/l	125	1.7	0.780	1.305	648	930
		75	2.3	0.665	1.140		558
	20 mEq Cl/l	125	3.1	0.665	1.035	563	846
		75	4.0	0.575	0.940		508

Table 12

Water use efficiency for grain yield of wheat

	Loam			Clay		
	Fresh	10 mEq/l	20 mEq/l	Fresh	10 mEq/l	20 mEq/l
Grain yield (Kg/m^2)	0.900	0.820	0.805	0.775	0.780	0.655
Evapotranspiration (m^3/m^3)	0.883	0.800	0.721	0.733	0.648	0.563
Water-use efficiency (Kg/m^3)	1.02	1.03	1.12	1.05	1.20	1.16

Table 13

Soil salinity, yield of potatoes, evapotranspiration, and water application

Treatment		Ec_e (dS/m)	Yield (Kg/m^2)	No. of Tuber/m^2	Weight of Tuber (Kg)	% Water	ET (mm)	Water application (mm)
Soil	Water							
Loam	Fresh	0.8	8.62	62	0.139	77.4	415	545
	15 mEq Cl/l	2.6	6.54	55	0.119	73.4	382	552
	30 mEq Cl/l	5.9	5.40	50	0.108	70.7	328	491
Clay	Fresh	0.8	5.80	51	0.114	71.9	363	507
	15 mEq Cl/l	2.5	5.00	50	0.100	70.9	327	457
	30 mEq Cl/l	3.4	4.84	50	0.097	69.5	304	464

Table 14

Water-use efficiency for tuber dry-matter yield of potatoes

	Loam			Clay		
	Fresh	15 mEq/l	30 mEq/l	Fresh	15 mEq/l	30 mEq/l
Dry matter (kg/m^2)	1.95	1.74	1.58	1.63	1.46	1.48
Evapotranspiration (m^3/m^2)	0.415	0.382	0.328	0.363	0.327	0.304
Water-.use efficiency (kg/m^3)	4.70	4.55	4.82	4.49	4.45	4.86

The average yield for fresh water and water of 15 mEq Cl/l, treatments that produced almost the same EC_e values on both soils, equalled 7.58 kg/m^2 on loam against 5.40 kg/m^2 on clay, slightly compensated by the percentage water of 71.5 on clay against 75.5 on loam. The decrease of almost 30% from loam to clay is much more severe than that of about 15% for the grain yield of wheat, thereby confirming that potatoes are far more sensitive to the factor soil.

Figure 5 compares the yield (kg fresh weight) of the saline treatments (expressed in a percentage of the maximum yield obtained on each soil) with the relation between yield and soil salinity as published by Ayers and Westcot (1985). The values obtained in this experiment were equally distributed around the straight line that starts at an EC_e of 1.7 dS/m.

The water-use efficiency could be calculated from the tuber dry-matter yield (yield in $kg/m^2 \times$ % water) and the evapotranspiration. Using the evapotranspiration from the first till the last irrigation yields the values of Table 14, which show no systematic differences due to soil or salinity. Adding about 90 mm for the average evapotranspiration between the last irrigation and harvest gives an average value of 3.7 kg/m^3. The average total dry-matter yield equalled 1.95 kg/m^2, yielding a water-use efficiency for total dry matter of potatoes of 4.4 kg/m^3. Both values correspond with those derived from sprinkling experiments, as reported by Feddes (1978).

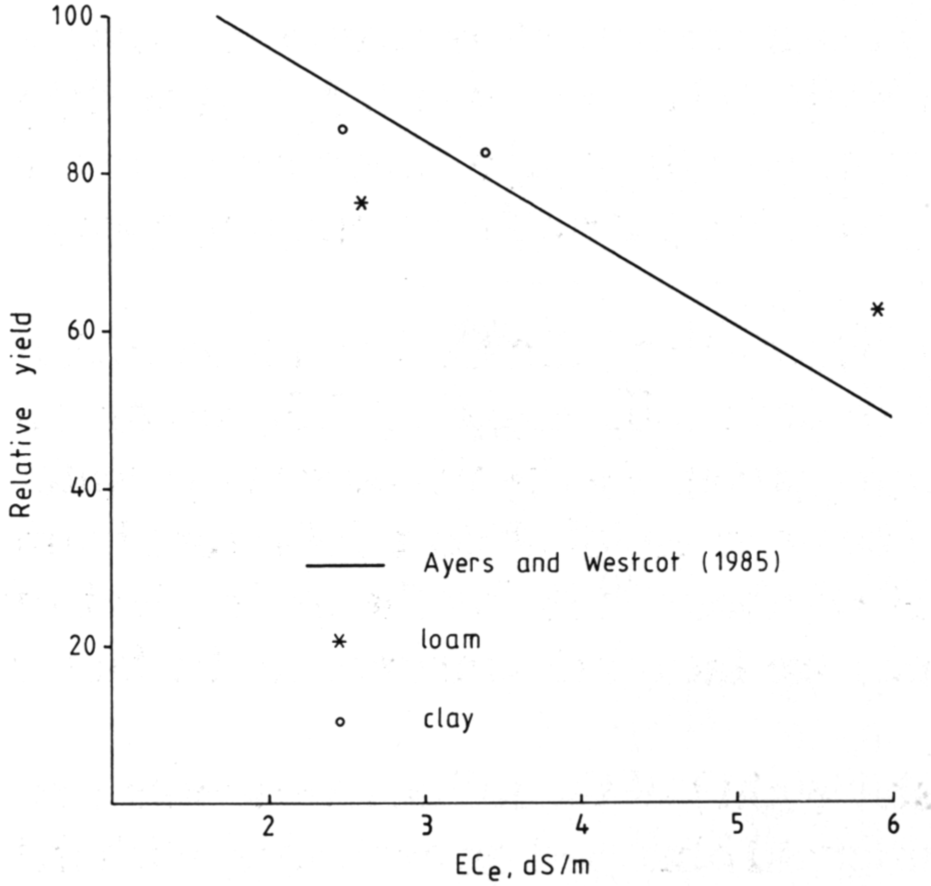

Fig. 5. Relation between relative yield of potatoes and soil salinity.

Conclusion

Values of the chloride concentration obtained by soil water sampling often differed greatly from those calculated from the salt balance, but unlike the balance method, soil water sampling has the advantage of revealing the distribution within the soil profile. Soil water sampling, in combination with the salt balance, makes it possible to determine the real composition of the soil water and the changes due to an exchange of ions with the adsorption complex and the precipitation or dissolution of salts. In these experiments, the combination of the two methods revealed an increase in adsorbed sodium and a decrease in adsorbed calcium and magnesium, which was confirmed by the ion analysis of the adsorption complex, and the precipitation of a mixture of calcium and magnesium carbonate.

Predawn leaf-water potential and stomatal conductance can be used as parameters for measuring differences in water stress. Expressed by both parameters, potatoes had a more severe reaction to water stress than wheat, which is confirmed by growth and yield. Growth and yield are affected by soil, water regime, and salinity, more pronounced for potatoes than for wheat. The water-use efficiencies obtained in this experiment correspond with values reported in literature and are not affected by soil and salinity. The same was observed for maize by Stewart et al. (1977). The stronger sensitivity of potatoes to soil and salinity, compared with wheat, is an expression of its sensitivity to water stress.

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