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LEACHING EFFICIENCY

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INTRODUCTION

One of the major problems of irrigation with saline water is that of finding effective methods of leaching. This leaching is necessary either to desalt very saline soils with the objective of their improvement, or to maintain salinity of soils heretofore non-saline or only slightly so, at a level acceptable for cultivation.

With the objective of maintaining soil salinity at an acceptable level, we may consider leaching as a continual process, adding to each irrigation an excess of water beyond consumption by the crop, or as a seasonal procedure which is employed at certain times -- either at the beginning or the end of cultivation or on fallow land. Seasonal leaching, as opposed to continual leaching, offers the advantages of being able to:

reduce the maximum amount of irrigation water in an irrigated area in summer.

adapt leaching to crop requirements and avoid excess water which threatens to suffocate the plants.

lessen the amount of leaching water. In reality the amount of water necessary for leaching is not directly proportionate to soil salinity. The amount of salts extracted by a mm of drainage water increases in proportion as soil salinity becomes greater.

In a recent publication (van Hoorn et al, 1969) we have set forth results of irrigation experiments set up to study the relationship between application of water, crop yield and development of soil salinity. It turns out that differences of production in terms of amounts and frequencies of irrigation are relatively slight -- in the neighborhood of 0 to 15%, and varying from one year to the next. In spite of a slight decline in production, we are interested in directing irrigations toward water conservation in summer. On a crop such as lucerne (alfalfa), continual leaching may even lead to a decrease in yield and a disappearance of plants owing to suffocating conditions created by a surplus of water. In Tunisia, since the availability of irrigation water is scarce and the price high, this perspective allows for a better evaluation of water. We can have water application on maize, tomato and sorghum fodder crops for the equivalent of 5 to 6 mm per day and for lucerne at 4 to 5 mm per day.

The study of soil salinity has shown that leaching in winter and at the time of first and last irrigations on summer crops can reduce salinity to its original level of the preceding spring. For both the salinity of the soil and crop production, it does not, therefore, seem necessary to apply an excess of water in summer in order to obtain continual leaching.

In using leaching the question is raised -- if one is concerned with employing a massive application or else spreading small amounts, which will be stretched out over a longer period of time. In originating leaching formulas (Reeve, 1957) it was alleged that irrigation water and rainfall mix thoroughly with the soil solution. Since water passes more quickly through cracks and large pores than through small pores, it is still entirely possible that this mixing is not complete, especially in the upper layers of the soil. The water percolating to the lower boundary of the root zone would then be less saline than the soil solution. We can mitigate this disadvantage by introducing a factor f, which is smaller than 1 and represents leaching efficiency (Dieleman et al, 1963).

In sections II, III, and IV, we shall explain results obtained with respect to leaching at the stations of Cherfech, Utique and Tozeur, which make evident the influence of certain factors ~~concerning~~ on leaching. In section V we shall examine the comparison between observed values and those calculated theoretically for leaching.

"WINTER LEACHING" EXPERIMENT AT CHERFECH

The Cherfech station is located in the lower valley of the Medjerdah River near Tunis, where rainfall is approximately 400 to 450 mm in winter. The soil can be defined as being of a clay-loam and loamy-clay texture with a calcium content of about 40%. Bulk density varies from 1.3 at the surface to 1.6 in depth. Permeability is approximately

0.5 to 1 m per day up to 1.50 m depth -- the level of tile drains. Below this level and down to 3.50 m in depth permeability is about 2.5 m per day. From this depth on we encounter a very heavy clay layer which can be considered as impermeable.

Irrigation water coming from the Medjerdah River has fluctuation in salinity during the year ranging from 1 to 3 grams per liter, the averages in summer and winter being respectively 2.4 and 2.1 grams per liter, of which nearly 60% is sodium chloride and 40% calcium sulfate and magnesium. The S.A.R. value varies from 6 to 7 between winter and summer.

The problem of irrigating with saline water is that of decreasing soil salinity, which increases during the summer, either by adding to each irrigation a complement (continual leaching), or by giving small applications and using leaching during certain times when water availability is greater (water conservation in summer and seasonal leaching).

As we have already mentioned in the introduction, in view of the results of different irrigation tests, we are interested in directing irrigation toward conservation of water in summer, while leaching is done at the first and last irrigations and especially in winter.

In order to obtain more information concerning the amount of water to apply in winter leaching, we set up a "winter leaching " experiment. This test in the winter of 1966-67 consisted of two applications and two methods of irrigation. Application D_1 was the quantity necessary for reaching the end of the plot; application D_2 received 40% more water. The two irrigation methods were border and furrow.

The amounts of irrigation water in four irrigations were 458 mm for application D_1 and 640 mm for application D_2, the amounts of drainage water being approximately 180 and 360 mm. The treatments did not have a distinct effect on the production of rye-grass. Furrow, probably allowing a better drying, seems very slightly superior to border irrigation. With regard to soil salinity, which was observed regularly during the winter (see Table 7, Chapter V), neither the application nor the irrigation methods made any differences evident.

In order to make use of a greater range for the applications, the winter 1967-68 experiment consisted of four applications, the method being border irrigation.

D_1 irrigation at sowing

D_2 irrigation at sowing, followed by a second irrigation

D_3 several irrigations in winter, depending upon the rainfall

D_4 like D_3, the application being increased by 40%

Table 1 shows the irrigations. Rainfall during this period was about 300 mm. The amount drained by application D_1 would be approximately 75 mm.

Table 1 WATER APPLICATIONS ON THE "WINTER LEACHING" TEST

Date	10.11.67	26.11.67	8.4.68	20.4.68	Total
D_1	112.5 mm	0mm	0 mm	0 mm	112.5 mm
D_2	112.5	97.5	0	0	210
D_3	112.5	97.5	211	112	533
D_4	157.5	122	295	157	731.5

At the first cutting of rye-grass a difference appeared in favor of treatment D_1, which received a single irrigation, which probably reduced plant suffocation. The other two cuttings before resumption of irrigation on April 8 did not indicate any differences. The fourth cutting in May reacted favorably to the spring irrigations.

From the viewpoint of soil salinity, the four treatments did not bring about any distinct differences.

From these two winters of testing it is evident then that small applications have the same result as large ones. This leads one to assume that efficiency of percolating water declines if the amount increases.

LEACHING EXPERIMENT AT UTIQUE

Conditions of the soil, irrigation water and climate at Utique, also located in the lower valley of the Medjerdah, are identical to those at nearby Cherfech, though the soil is a little more loamy and the irrigation water in winter during the tests measured 1.4 grams per liter.

It is a very saline region, drained to a depth of 1.40 m and intended to be put into irrigated crops. It is made up of a mosaic consisting of green spots which support a halophilous vegetation, and of completely bare spots -- the area occupied by each being nearly equal.

A first experiment was conducted in winter 1966-67, consisting of three treatments:

D_0 : 0 mm

D : 400 mm at a rate of 100 mm per day

2D : 800 mm at a rate of 100 mm per day

During this first experiment the irrigations did not reduce the soil salinity to a level acceptable for cultivation. The most saline spots without vegetation were slightly desalinized, but the less saline spots with vegetation were salinized.

In the summer of 1967 half the plot was plowed to a depth of 25 cm. During the second test in winter 1967-68 we applied -- both on the tilled and untilled sections -- the following treatments:

D : 400 mm at a rate of 100 mm every 2 weeks

2D : 800 mm at a rate of 100 mm each week

4D : 1600 mm at a rate of 200 mm each week

A more detailed account of the results was recently published (Ollat et al, 1969). We are confining ourselves here to results of desalinization of very saline spots without vegetation.

Figure 1 shows soil salinity before and after leaching. Although salinity at the beginning of the experiment was not the same for all six treatments, we can see that:

- the plowed sections were desalinized better than those unplowed. Even before the irrigations, the configuration of the salinity depth curve indicated for the tilled sections a beginning of desalinization, the surface layer being less saline, contrary to what is observed on the untilled sections. This can be explained because the rain which fell between the time of plowing and the beginning of irrigation effected a more thorough leaching, the plowing having made the cracks disappear and thus making the permeability more general.

- on both the plowed and unplowed sections salinity - decreased markedly, without the three applications of water having made distinct differences evident. In Table 2 we have summarized the mean values EC_e of the profile before and after leaching, as well as the differences. For the tilled sections desalinization appears to be the more important when the salinity was higher at the outset.

Table 2 - AVERAGE SALINITY (EC_e) OF THE 0-100 cm PROFILE BEFORE AND AFTER LEACHING

	D - 400 mm		2D - 800 mm		4D - 1600 mm	
	Plowed	Unplowed	Plowed	Unplowed	Plowed	Unplowed
EC_e before	22.5	42.1	32.8	25.0	27.2	23.5
after	4.8	30.2	3.8	18.7	3.8	13.8
difference	17.7	11.9	29.0	6.3	23.4	9.7

The difference with regard to the first experiment, in which we did not determine any lessening of salinity, could be explained by:

1. Difference in rainfall between the two years: 15 mm of rain fell during the month preceding the first test and 135 mm during the one preceding the second test, so that in the latter case, the soil was more moist at the start. In addition, only 35 mm rain fell during the first test as compared with 130 mm during the second.

2. The irrigation method: daily applications utilized in the first experiment were replaced in the second by weekly or bi-monthly applications. The alternation of wetting and drying of the soil, effecting a modification of the regime of cracks in the soil, produced a better contact of water with soil, thus allowing a more efficient leaching.

LEACHING TESTS AT TOZEUR

"Water Balance and Salt Balance" Plot

The Soil may be classified as being of a fine sandy-loam texture with a gypsum content of 50 to 60%. Bulk density varies from 1.3 to 1.4. Permeability is approximately 1 m per day down to 1.60 m depth -- the level of the open drains -- followed by 2 m per day to great depth (about 30 m). The irrigation water contains 2.1 grams of salt per liter, of which nearly half is sodium chloride. The climate is desertic, rainfall being about 80 mm per year.

At the beginning of the experiments in 1964 the soil was very saline owing to the combined results of an under-irrigation and a lack of drainage. The irrigation system has been improved and now allows irrigating with a theoretical continuous flow of approximately 0.8 l/sec/hectare in summer, or an application of 75 mm every 10 days. The old drainage network, which consisted of collecting drains of 1.25 in depth and open drains spaced at 20 m and 0.70 m deep, has been replaced by a new system: collecting drains of 2 to 2.25 m deep and drains spaced at 40 m and 1.60 m deep. The interval of 40 m was selected to permit us to have the use of a sufficient number of drains for flow measurement. The plot is planted in date palms.

Figure 2 shows the development of soil salinity during the four years of experiments. During the first year a very great desalinization resulted. Thereafter, it seems that the salinity has stabilized or maintains a slight tendency toward decreasing. The EC_e value of the surface layer does not decrease below 5 to 6, which fact can be considered as an equilibrium value, given the gypsum content on the one hand, and the salinity of the irrigation water on the other.

In Table 3 we have summarized the amounts of irrigation water, rainfall and drainage, as well as the salt balance. The balance consists of two parts:

- the amount of salts removed according to the analyses of irrigation and drainage water.

-amount of salt removed according to soil analyses to 1.60 m depth

Table 3 AMOUNTS OF IRRIGATION WATER, RAIN AND DRAINAGE WATER AND THE SALT BALANCE

Time Period	Irrigation in mm	Rain in mm	Drainage in mm	Salts removed in tonnage/hectare	
				Soil	Water
July 64-65	1138	54	252	90.8	13.2
65-66	1782	64	256	2.1	5.3
66-67	2325	68	412	3.4	5.8
67-May 68	1525	142	379	3.0	10.0

Examination of this table shows a lack of agreement between figures obtained from the soil and those obtained from the water. For the first period this imbalance is very large and contrary to that which we also ascertained at Cherfech. For the following time spans it is less pronounced and goes in the same direction as at Cherfech, where we likewise determined that the amount of salts removed according to the soil analyses down to 1.50 m depth is smaller than that computed according to the water analyses. At Cherfech this is owing to the fact that the profile below 1.50 m was not taken into account and that the salinity of the water from the drains should thus be higher than that of the water percolating the 120-150 cm layer. But taking into consideration salts removed at a depth below the level of the drains, the amount of salts removed according to the soil analyses corresponds quite well with that estimated according to the water analyses. One may thus suppose that the same reasoning is valid for the period from July, 1965, to May, 1968, at Tozeur.

In a gypseous soil such as that at Tozeur, the gypsum can become soluable in the waters percolating the soil without there being a lessening of the conductivity measured in the sample of saturated paste. Thus, it is also possible that the difference for the period from July, 1965, to May, 1968, may be owing to this phenomenon.

On the other hand the first time span -- from July, 1964 to July, 1965 -- indicates an imbalance in the opposite direction. The amount of salts removed according to the soil analyses was higher than that estimated according to the water analyses. Given the very high soil salinity at the beginning of the experiment, it may be that the salinity of the drainage water was less during this period than that of the water percolating the 120-150 cm layer and that an accumulation of salts (which were removed later) resulted at a depth below the level of the drainage network. The salinity of the drainage water lessens during years of 15 to 10 grams per liter indicating a slow desalinization in depth. In order to prove this hypothesis we performed a series of experiments of leaching soil in a tank, which allows measurement of waters percolating the soil at 1 m depth withoutbeing affected by the presence of a phreatic level.

Pan Leaching Test

In a tank 4 m^2 wide and 1.20 m deep we reconstructed the profile of the plot by filling it with layers of 20 cm each. The leaching was accomplished with irrigation water testing 2.1 grams per liter. Three tests were performed:

first test : 1100 mm irrigation water, 86 mm rain water, 500 mm drainage water.

second test : 290 mm irrigation water, 6 mm rain water, 150 mm drainage water

third test : 618 mm irrigation water, 33 mm rain water, 300 mm drainage water

At the beginning of each test several successive irrigations were applied to saturate the soil, then irrigations of 50 mm every 4 or 5 days. For each of thes irrigations a drainage of about 20 mm resulted. The difference between the irrigation and the amount drained represents the amount accumulated in the soil and the evaporation of bare soil.

Table 4 SOIL SALINITY (EC_e) IN TANK LEACHING TESTS

Layer	1st Test 500 mm drained Beginning	End	2nd Test 150 mm drained Beginning	End
0-20 cm	94.8	5.9	84.3	11.1
20-40	63.5	5.8	47.3	14.4
40-80	25.2	5.4	21.5	34.4
80-120	17.4	5.0	14.3	30.4
Average	45.2	5.4	37.0	25.9

Table 4 shows the soil salinity at the beginning and end of the first and second tests. After 150 mm drainage we find that the salts have been displaced in depth, with regard to their distribution at the outset. After 500 mm drainage the salinity of the soil is nearly homogeneous, the value EC_e of 5 to 6 corresponding to the values measured on the "Balance" plot.

Figure 3 shows the relationship between the conductivity of the drainage water and the amount of water removed. We find that in fact at the beginning the salinity of the water percolating at 1.20 m depth was very high, to decrease later to a value of 12 to 13. We shall discuss in part V the curve showing the theoretical values.

In conclusion then, it can be stated that the pan leaching tests confirms the hypothesis formulated concerning salt balance, for the waters percolating the soil at 1.20 m depth have at the beginning of leaching a very high salinity, which decreases proportionately later as the salts are removed.

LEACHING EFFICIENCY

According to Reeve (1967) observations of leaching experiments carried out in different locations in the United States enabled the following equation to be set up for leaching extremely saline soils:

$$\frac{D_{lw}}{D_s} = \frac{(EC_e)i}{5(EC_e)f} + 0.15 \qquad (1)$$

In the equation D_{lw} represents the amount of leaching water passed through a profile at depth D_s, $(EC_e)_i$ and $(EC_e)_f$ being the mean values of the profile before and after leaching, respectively. It appears that the amount of leaching water D_{lw} may be considered equal to the water application and that it is a matter, then, of leaching performed on bare soil in a relatively short time, with the result that evaporation is negligible. Although this was not the case in our tests, the pan tests at Tozeur and on the plot at Utique best approximate these conditions. In applying the formula (1) we arrive at the results appearing in Table 5.

In the case of Tozeur the theoretical amount D_{1w} is nearly twice as high as the amount of irrigation water measured and four times larger than the amount drained. This is likewise the case for the plowed sections at Utique, which received applications of 400 and 800 mm. On the other hand the value D_{1w} is much lower for the unplowed sections which received applications of 800 and 1600 mm. This makes it appear that either the condition of the soil or the irrigation methods, particularly that of periodic applications are the causes and that these two factors affect leaching efficiency.

Table 5. COMPARISON OF THE THEORETICAL VALUE D_{1w} WITH THE amount of irrigation water and DRAINAGE WATER

	Irrigation measured in mm	Drainage measured in mm	$(EC_e)i$	$(EC_e)f$	D_{1w} in mm
Tozeur-tank	1100	550	45.2	5.4	1990
	290	150	37.0	25.9	520
Utique-plowed					
D	400	-	22.5	4.8	1090
2D	800	-	32.8	3.8	1880
4D	1600	-	27.6	3.8	1570
unplowed					
D	400	-	42.1	30.2	430
2D	800	-	25.0	18.7	420
4D	1600	-	23.5	13.8	490

Starting from the premise that leaching results through a mixing of irrigation water (or rain water) at concentration C_i with the water of the soil solution at concentration C_s, the concentration of the soil solution after mixture C_{x1} of the first layer can be computed in the following manner:

$$a \text{ mm of irrigation water} \times C_i + b \text{ mm of soil water} \times C_{s1} = (a + b) \text{ mm} \times C_{x1}$$

If the amount of water retained in the first layer is equal to c mm, an amount (a - c) having a concentration C_{x1} percolates in depth and mixes with the soil solution of the second layer. The concentration of the soil solution after mixture C_{x2} of the second layer can be calculated in the same way:

$$(a - c) \text{ mm} \times C_{x1} + d \text{ mm} \times C_{s2} = (a - c + d) \text{ mm} \times C_{x2}$$

In assuming that the concentrations are approximately proportional to the conductivities, we can make the calculations using electrical conductivity. After having computed this process for all succeeding layers, we finally arrive at the conductivity of the water percolating the lowest layer, which can be compared with that measured, for example, in the tank leaching experiments.

In order to be able to make these calculations, it is necessary to use the following values:

1. Conductivity of the soil solution at the beginning. This value can be calculated starting from conductivity C_{ex}

of the sample of the saturated paste and from moisture contents of the soil M_s and of the saturated paste M_{ex}:

$$C_s = \frac{M_{ex}}{M_s} C_{ex}$$

2. ~~Soil water~~ Moisture content before and after irrigation. The moisture content after irrigation corresponds to that of the water holding capacity M_{fc} and can be converted into mm of water according to the following formula:

b mm water = depth of the layer in mm x M_{fc} x bulk density.

Moisture content before irrigation depends upon how the amount of water used by the plant is spread on the profile. Moisture profiles in possible combination with the root system can guide us in this respect.

3. Since the distribution of pores through which the water passes ~~are~~ is not homogeneous and water passes more easily through large pores, it is possible that the mixing is not complete, but that a part of the irrigation water infiltrates directly in depth without mixing with the soil solution. In the calculations we can take into account this phenomenon while introducing a factor f, which stands for leaching efficiency, that is, the percentage of irrigation water which mixes with the soil solution.

If, for example, 50% of the irrigation amount mixes in the 0-40 cm layer, 25% plus the surplus water of the first layer in the 40-80 cm layer and 25% plus the surplus water of the second layer in the 80-120 cm layer, factor f for the 0-120 cm profile is, on the average, equal to (4 x 0.5 + 4 x 0.75 + 4 x 1.0)/12 = 0.75.

Figure 3 shows the theoretically estimated curve for the pan leaching experiment, assuming a complete mixing of the irrigation water with the soil solution. We can see that the measured values of the drainage water conductivity were lower at the beginning of the experiments, probably because the mixing was not complete, and that they rise when the calculated values already begin to decline. Afterward the measured values declined more rapidly, but at the end of the experiments the measured and calculated conductivities are nearly equal.

Since it is possible to convert again calculated conductivity of the soil solution into conductivity of the saturated paste taking into account the moisture content of the soil and the paste, we can compare the values calculated for the conductivity of the saturated paste with those measured at the end of the tests. Table 6 shows the results for the tank leaching tests at Tozeur.

Table 6 TANK LEACHING TESTS AT TOZEUR

	Conductivity of the saturated paste			
	after 150 mm drainage		after 500 mm drainage	
	measured	calculated	measured	calculated
0- 20 cm	11.1	9.0	5.9	3.6
20- 40	14.4	19.8	5.8	4.0
40- 80	34.4	30.2	5.4	5.5
80-120	30.4	28.4	5.0	6.4

We can see that values calculated after 150 mm drainage correspond quite well to the measured values. It is the same after 500 mm drainage -- with this exception -- that the calculated conductivities for the 0-20 and 20-40 cm layers are lower than the measured conductivities. This could be explained by the fact that in a soil like that at Tozeur, the gypsum can become soluble and maintain conductivity at a higher level than that calculated without taking into account this phenomenon.

In the same way we calculated desalinization of the "Balance" plot at Tozeur, supposing a complete mixing (efficiency equal to 1) and taking into account this time the fact that the gypsum maintains conductivity at an approximate value of 5 in the surface layer. Table 7 compares measured and calculated conductivities for July, 1965, after approximately 250 mm drainage and indicates that the calculated values agree rather well with the measured ones.

Table 7 "BALANCE" PLOT AT TOZEUR

Layer	EC - July, 1965	
	measured	calculated
0- 20	5.7	4.8
20- 40	6.8	6.0
40- 80	8.9	8.3
80-120	8.8	10.3

For Cherfech, where there is an increase in salinity in summer and a decrease in winter, these calculations were made on the one hand for the "Balance" plot and on the other for the leaching test in winter, 1966-67.

Starting with an efficiency equalling 1, that is, of a complete mixing, we then introduced lower efficiency factors in order to be able to compare these succeeding calculations with the measured values. According to statistical analysis of measured conductivities on the "Balance" plot, the difference between the measured value and the theoretically calculated value is not significant, if that difference is less than 10 to 15%. So we considered that for lesser differences the theoretical value corresponds with the measured one.

Table 8. COMPARISON OF MEASURED AND CALCULATED CONDUCTIVITIES
LEACHING TEST - PLOT 1

Date	Layer	Analysis	D1: f 100%	D1: f 0-40 50%, 40-80 75, 80-150 100 → 80	D2: f 100%	D2: f 0-40 50%, 40-80 75, 80-150 100 → 80	D2: f 0-20 30%, 20-40 40, 40-80 60, 80-120 70, 120-150 80 → 60
16.11.66	0-20	2.9	1.7	2.7	1.5	2.0	2.4
	20-40	3.4	2.7	3.9	2.3	3.1	3.4
	40-80	4.8	4.6	4.7	4.1	4.2	4.7
	80-120	7.1	7.7	6.4	6.9	6.0	7.0
	120-150	6.5	6.9	6.7	6.5	6.1	6.1
13.12.66	0-20	2.3	2.1	2.5	1.9	2.2	2.3
	20-40	2.8	2.6	3.3	2.3	2.8	2.9
	40-80	4.0	4.2	4.3	3.9	4.1	4.3
	80-120	6.6	7.1	6.7	6.8	6.4	7.1
	120-150	6.5	6.2	6.1	6.0	5.8	5.8
28. 3.67	0-20	1.7	1.4	1.5	1.3	1.4	1.5
	20-40	1.8	1.7	1.9	1.4	1.7	1.7
	40-80	3.1	2.9	2.9	2.6	2.5	2.9
	80-120	5.4	5.4	5.1	5.2	4.8	5.3
	120-150	5.9	6.2	6.2	5.7	5.6	5.7
13. 4.67	0-20	2.1	1.7	2.0	1.6	1.9	2.0
	20-40	2.2	1.8	2.1	1.6	1.9	1.9
	40-80	3.8	3.0	3.2	2.8	2.9	3.2
	80-120	5.1	5.2	4.9	4.9	4.0	5.0
	120-150	5.6	5.4	5.3	5.1	4.7	5.0
Degree of correlation			14 to 20	17 to 20	9 to 20	12 to 20	18 to 20

Table 8 presents an example of the results for two variations of mixing in the case of the small application D_1 and three variations in the case of the large application D_2 in the leaching experiment. An efficiency of 80%--arising from a 50% mixing in the 0-40 layer, 75% in the 40-80 layer and 100% in the 80-150 layer -- gives for D_1 a better correlation than a 100% efficiency, that is, a complete mixing, but lower efficiencies make the correlation decrease again. For the D_2 application the best result was obtained for a 60% efficiency resulting from a 30% mixing in the 0-20 layer, 40% in the 20-40 layer, 60% in 40-80 layer, 70% in the 80-120 layer and 80% in the 120-150 layer, while 20% of the water passes directly into the subsoil.

For the "Balance" plot an efficiency of 95% for the winter period and 85% for summer resulted from the calculations. It appears then that

- proportionately as the amount of irrigation water becomes larger, the water mixes less well with the soil solution -- which lessens leaching efficiency.

- the efficiency is higher in winter than in summer, which can be explained on the one hand by the absence of drying cracks, on the other by the fact that application of water in winter to a large extent comes from rainfall, the hourly intensity of which is generally lower than that of an irrigation application.

- for the same soil, efficiency can vary considerably owing to factors mentioned above (in the case of our tests, from 60 to 95%).

This confirms the results of leaching tests at Utique where we have also seen that the irrigation method -- the technique of massive application as opposed to periodic irrigations -- has a very great influence on leaching.

Thus, it seems likely that differences between our results and those cited by Reeve arise partly from the irrigation method employed and partly from the quality of the soil and its condition at the time of leaching.

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Figure 1

Leaching experiment at UTIQUE

Development of soil salinity

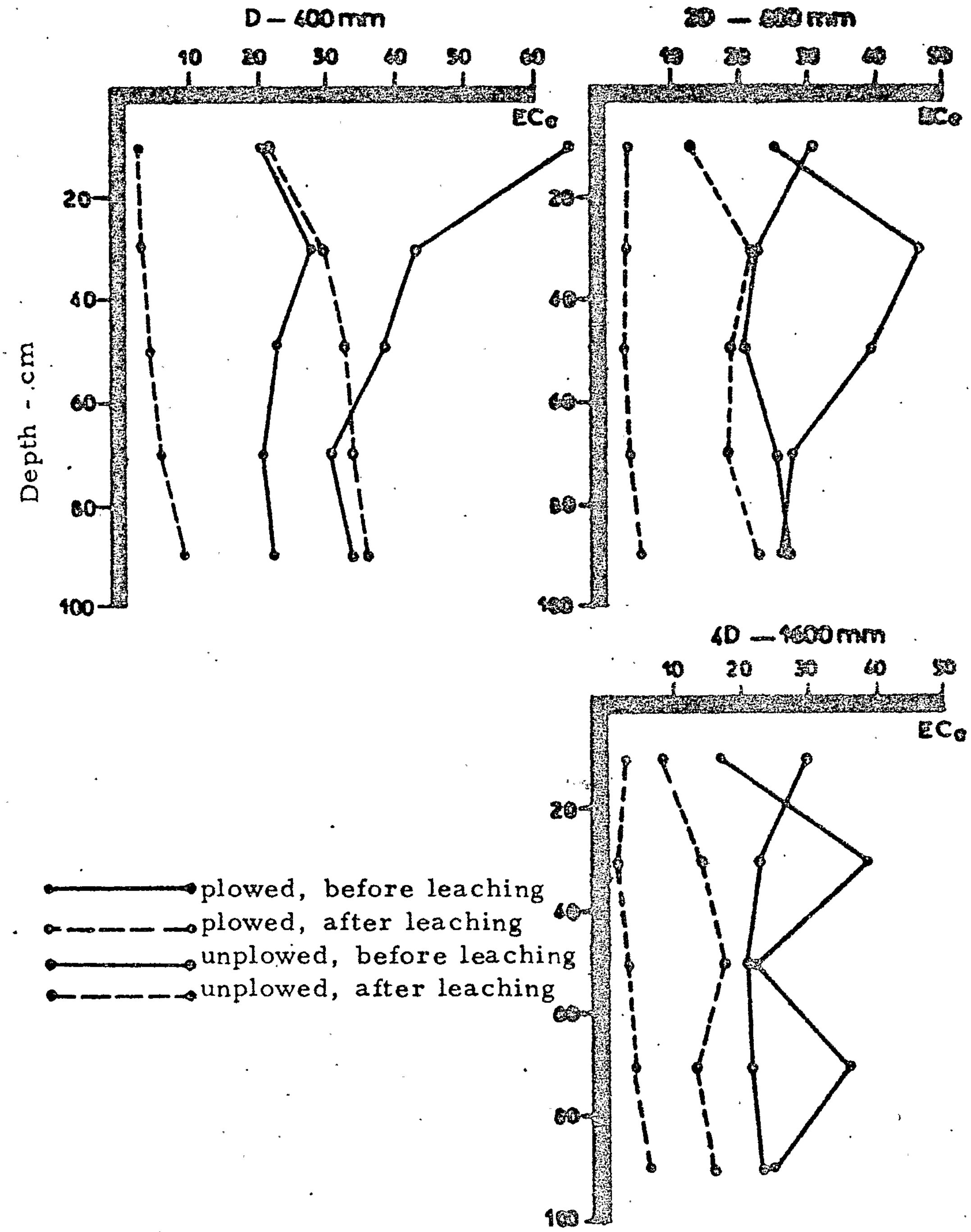

Figure 2

TOZEUR STATION "Balance" Plot

Development of soil salinity

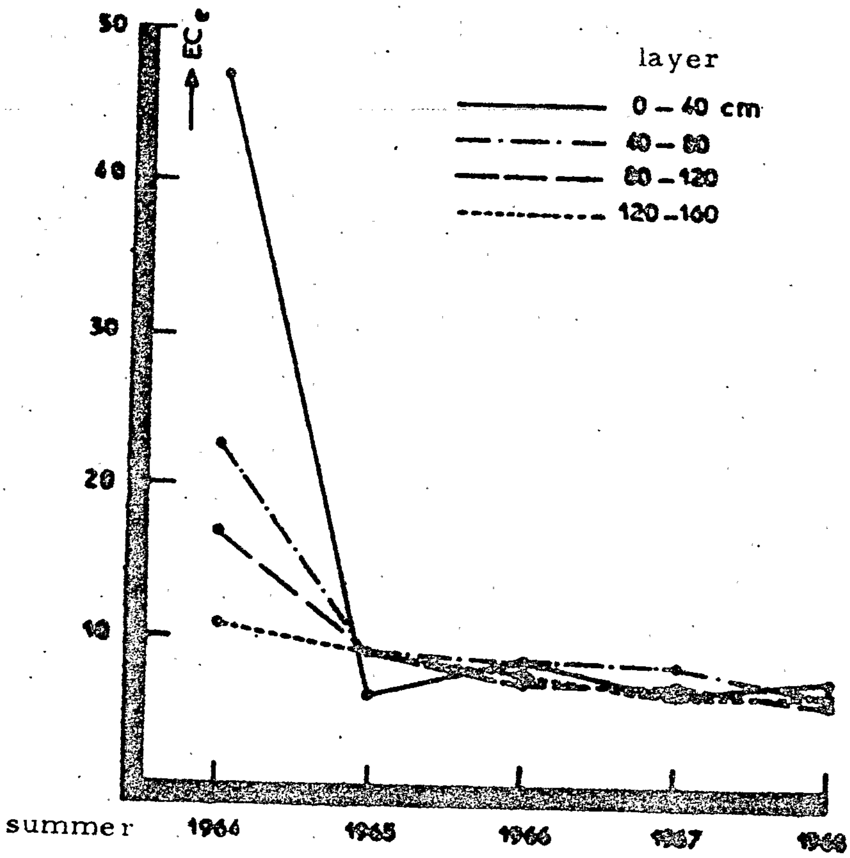

Figure 3

TOZEUR STATION - Tank leaching

Relationship between conductivity and amount of drainage water