CASE STUDY LEACHING (CHACUPE)

R.J.Oosterbaan On website www.waterlog.info March 2003-03-14

Data from CENDRET/SUDRET project, Peru, 1968 - 1974

Exercise in the International Course on Land Drainage (ICLD)
International Institute for Land Reclamation and Improvement (ILRI)
Wageningen, The Netherlands

Topics of study:

Item 1. The salt balance from soil analysis

Item 2. Salt balance from water balance

Item 3. Comparison item 1 and item 2.

Item 4. Evapo-transpiration

Item 5. Percolation

Item 6. Leaching curves

Item 7. Gypsum requirement

CASE STUDY LEACHING (CHACUPE)

Introduction

In this case study of the drainage pilot area Chacupe, in the arid coastal area of Peru, for the reclamation of a strongly salinized sodic soil is dealt with. Water and salt balances are made, a leaching curve is prepared, the required leaching time is estimated, and the necessity of Ca amendments is studied.

Description of the reclamation experiment

In the study area originally the groundwater table was found at a depth of 0.8 to 1.1 m. The soil is salinized and the area was barren. The climate is arid and the presence of a shallow water table under such conditions indicates the presence of upward seeping groundwater.

A detailed reclamation experiment was carried out on a 4.9 ha plot which formed a part of a larger pilot area in which a drainage system was installed. The reclamation plot is underlain by 6 field drains at a depth of 2.0 m and a spacing of 36 m, discharging into an open collector drain.

The soil from the surface down to a depth of approx. 1.0 m is fine textured; the deeper layers are more sandy although clay lenses occur. In Table 1 a description is given of a typical soil profile and in Table 2 of some initial characteristics. Clay mineral analyses were also made (Table 3).

After the installation of the drainage system the soil was levelled as well as possible and plowed to a depth of 15 cm. The depth of ploughing could not be more because of the hardness of the soil. Eight tons of gypsum per ha were applied and incorporated at shallow depth for fear of sodicity problems. The effectiveness of this measure is to be evaluated.

After an initial leaching period, rice was planted. The rice season in the region is about 150-200 days depending on climatic conditions and the rice variety. The rice crop is followed by a fallow season. During the fallow season no water is available for a second crop or for leaching. In the following years, again a rice crop was grown.

Irrigation water used for leaching and rice cultivation is of good quality: EC = 0.6 dS/m at 25°C and SAR value = 2. Predominant anions are Cl^- and $SO_4^=$.

Table 1 Description of a typical soil profile

0 - 130 cm	testpit
130 - 400 cm	auger bore hole
0 - 10 cm	clay loam, dry, without structure, powdery, salt crystals
10 - 30 cm	clay loam, dry, 10 YR 3/2 (when moist), consistency hard, moderate angular and sub-angular blocky structure with platy elements, little porosity, salt crystals
30 - 70 cm	clay, moist, 10 YR 3/2, weak sub-angular blocky structure, little porosity, $CaCO_3$ concretions, iron mottling
70 -100 cm	silty clay loam, moist, 10YR 3/2, weak sub-angular blocky structure, little porosity, $CaCO_3$ concretions, iron mottling
100 - 130 cm	loam, wet, 10 YR 4/2, structure-less, little porosity, $CaCO_3$ concretions, iron mottling, water table
130 - 400 cm	loam to loamy sand with clay lenses.

Table 2: see last page

Table 3 Mineralogical composition of the clay fraction (%)

Depth in cm	Amor-phous	Na-Ca (feld-spars)	Quartz	Kaoli-nite	Illite	Montmo-rillo-nite
0- 10	9	5	6	15	35	30
20- 40	8	5	10	12	29	36
120-160	10	5	6	10	19	50

The leaching period

The leaching period prior to the transplanting of rice was 61 days only (15 Nov. 1970 - 15 Jan. 1971). In total 22,100 m^3 of irrigation water was given, in 4 applications, of which 6,170 m^3 were stored in the soil profile down to 2.0 m bringing the soil to field capacity. The remainder part either percolated through the soil profile or evaporated at the soil surface. No rainfall was recorded during the leaching period. The discharge of the tile drainage system totalled 8,500 m^3 of water and the EC of the drainage water was 33 dS/m at 25°C or 22.0 grams of salt per liter.

There is a basic recharge to the drainage system, caused by upward seepage from deeper strata. This upward seepage is independent of the excess of irrigation water percolating through the soil profile. The seepage water has an EC of 10 dS/m at 25°C. The total basic recharge for the 4.9 ha plot amounts to 0.6 l/sec.

Table 4 Chemical characteristics of the soil after the leaching period

Depth in cm	EC_e dS/m	SP %	SAR
0- 10	35	57	31
10- 20	46	62	42
20- 40	54	64	54
40- 60	46	60	72
60- 80	42	57	54
80-100	41	57	48
100-120	35	54	46
120-160	30	49	42
160-200	29	41	27

The first rice crop

From the 15th of January to the 1st of July, 1971 (167 days) a rice crop was grown. The yield obtained, 580 kg/ha, was very low, mainly due to high salinity at the moment of transplanting (Table 4).

In total 57,700 m^3 of irrigation water was applied and a rainfall of 50 mm measured.

The change in soil moisture content in the soil profile can be considered zero, because the soil was wetted prior to transplanting.

The tile drainage system discharged 27,785 m^3 and the average EC of the drain water was 30 dS/m at 25°C.

Surface drainage was considered necessary when the water ponded in the rice fields attained an EC of more than 4 dS/m at 25°C. In total an amount of 6,300 m^3 of surface was let off having an average salt content of 3.1 g/l.

The upward seepage from the underground probably remains approximately constant at about the same rate and salt concentration as during the leaching period.

Table 5. Chemical characteristics of the soil after first rice crop

Depth cm	EC_e dS/m	SP %	SAR	pH	gypsum %
0- 10	20	59	25	7.8	0.3
10- 20	22	62	29	7.9	0.3
20- 40	32	63	40	7.9	0.2
40- 60	33	62	48	8.0	0.4
60- 80	36	60	54	7.9	0.5
80-100	37	58	53	7.8	0.6
100-120	35	56	52	7.8	0.4
120-160	29	51	49	7.8	0.3
160-200	22	43	37	8.0	0.3

The second rice crop

A second rice crop was grown from the 1st of January to the 31st of May, 1972 (151 days). The yield obtained 4,850 kg/ha, was slightly above the regional average.

The total amount of irrigation water applied was 83,000 m^3, while there was an additional rainfall of 74 mm.

The change in moisture content in the soil profile again can be considered zero.

The tile drainage discharge amounted to 24,200 m^3 of water having an average salt concentration of 15.3 g/l.

Surface discharge totalled 10,600 m^3 with an average salt concentration of 3.1 g/l.

The upward seepage from the underground probably remains approximately constant at about the same rate and salt concentration as during the leaching period.

Table 6 Chemical characteristics of the soil after second rice crop

Depth cm	EC_e dS/m	SP %	SAR	pH
0- 10	17	56	13	7.3
10- 20	16	57	17	7.5
20- 40	21	59	28	7.7
40- 60	26	60	38	7.7
60- 80	29	59	45	7.6
80-100	30	57	47	7.6
100-120	28	56	47	7.5
120-160	24	55	43	7.6
160-200	20	43	35	7.7

ITEMS TO BE STUDIED

The effect of the initial leaching and the leaching during the two rice crops on the desalinization of the soil should be studied in more detail and conclusions are to be drawn on when there comes a moment that less salt tolerant crops (e.g. maize) could be cultivated. To that purpose the salt and water balance for the various periods should be studied. When dealing with saline-sodic soils it has also to be studied whether chemical amendments such as gypsum are required.

Item 1. The salt balance from soil analysis

Use the EC_e data from tables 2, 4, 5, and 6 and convert these into T/ha assuming a constant BD value.

Use the conversion rate of EC_e in dS/m to salt content (Z_{10}) in T/ha per 10 cm soil depth:

$$Z_{10} = EC_e \times 0.667\ 10^{-2} \times SP \times BD$$

Using as a rule of thumb that 1 ECe corresponds to about 2/3 g salt/l water, derive this conversion rate for yourself. Complete the following table

Salt content in tons/ha

Depth in Cm	Initial leaching (1)	After rice crop (2)	After 1st rice crop (3)	After 2nd rice crop (4)
0- 10	70.3	18.91	11.2	9.0
10- 20		27.9	13.4	9.0
20- 40	83.5		40.8	25.1
40- 60	49.1	56.6		32.0
60- 80				
80-100	34.7	49.2	45.2	36.0
100-120				
120-160	47.8	58.6	59.1	52.8
160-200				
Total:				
Change in salt content:		(2)-(1) 32.2	(3)-(2)	(4)-(3) 68.5

Total change: (4)-(1) = 183.5

Item 2. Salt balance from water balance

Please complete the following equation for the salt balance

ΔZ = ...

where:

ΔZ = change in salt content; a negative value stands for a decrease in salt content
Zd = output of salts from subsurface drainage
Zsr = output of salts from surface drainage
Zi = input of salts from irrigation
Zs = input of salts from upward seepage

The value of Z is to be found from the amount of water multiplied by its salt concentration.

Express the Z values in tons of salt per ha (T/ha). Use the conversions: 1 l/s = 86.4 m^3/day, and: 1 l/s/ha = 8.64 mm/day.

Make also use of the conversions 1 dS/m = 2/3 g (salt) per l (water), and 1 g/l = 1 kg/m^3 = 10^{-3} T/m^3.

Complete the following table.

T/ha	Leaching period	1st rice crop	2nd rice crop	Total
Zd	38.2	112.8	75.6	226.6
Zsr	--	4.0	6.7	10.7
Zi		4.7	6.8	13.3
Zs	4.3		10.5	26.5
ΔZ	-32.1	-100.7		-197.5

Item 3. Comparison item 1 and item 2.

Compare the change in salt content ΔZ as calculated from the salt balance, with the change in salt content found from laboratory analysis. Draw your conclusions.

Item 4. Evapo-transpiration

It is of interest to see if the actual evapo-transpiration of (Ea) the crop is influenced by the soil salinity. The value of Ea can be found from the following water balance:

Ea = ...

where:

- P = precipitation
- I = irrigation
- S = upward seepage
- Ds = surface drainage
- Dd = sub-surface drainage
- Δm = change in moisture content of the soil

The terms of this water balance should be expressed in mm. Complete the following table.

mm	Leaching period	1st rice crop	2nd rice crop
P	--	50.0	74.0
I	451.0	1177.6	1693.9
S		176.7	159.8
Ds	--		216.3
Dd	173.5	567.0	
Δm	125.9	--	--
Ea	216.1	708.7	1217.5
ECe 0-10	35	20	17

Draw your conclusions about the relation between Ea and ECe.

Item 5. Percolation

It is of interest (item 6) to know the relation between the change in soil salt content and the amount of percolation (expressed in m^3 per m^2 soil surface, or m water layer). The amount of percolating water can be calculated from the following water balance

Perc = ...

where:
Perc = percolation
Dd = drain discharge
Su = upward seepage

Please complete the following table:

	Leaching period	1st Rice crop	2nd Rice crop	Total
Dd (m^3/ha)	1735	5670	4939	12344
Su (m^3/ha)		1767	1598	4010
Perc (m^3/ha)	1090		3341	8334
The cumulative				
percolation is:	1090	4993	8334	--
m^3/ha	0.109	0.499		--
m				--
mm	109	499	833	--

Item 6. Leaching curves

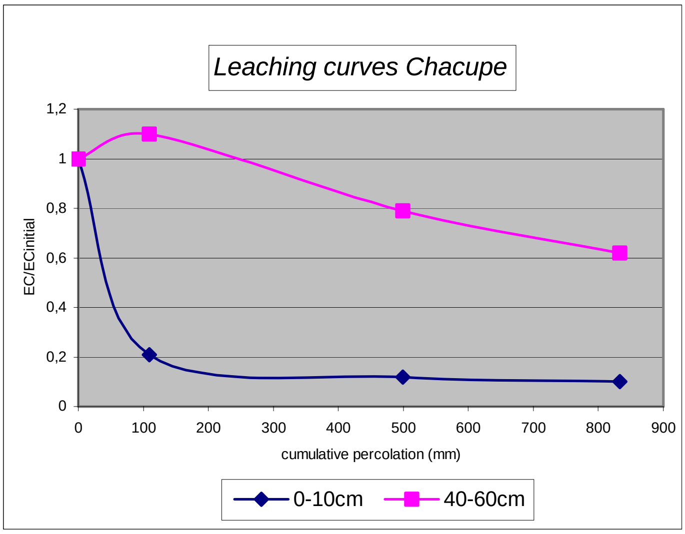
The ratios:
ECe after leaching/ECe initial
ECe after 1st crop/ECe initia]
ECe after 2nd crop/ECe initial
can be calculated for the various soil layers. Please complete the following table:

Depth	EC leaching / EC initial	EC 1st crop / EC initial	EC 2nd crop / EC initial
0 - 10			
10 - 20	0.35	0.17	0.12
20 - 40	0.72	0.43	0.28
40 - 60			
60 - 80	1.24	1.06	0.85
80 - 100	1.37	1.23	1.00
100 - 120	1.30	1.30	1.04
120 - 160	1.30	1.26	1.04
160 - 200	1.53	1.16	1.05

Please prepare a graph giving the relation between the various EC ratios (on the vertical axis) versus the cumulative amount of water that percolated through the soil profile (leaching curve).

For this exercise, a study of the curves for two representative layers, i.e. the layer 0-10 cm and 40-60 cm, will suffice. Explain the differences between the two curves.

Indicate in the graph the 1st and 2nd rice crop. Estimate the amount of percolation water required (and the number of rice crops involved) to arrive at an acceptable EC value in the root zone, at which less salt tolerant crops can be cultivated, by extrapolating the leaching curves. Discuss the results.



Leaching curves Chacupe (see print layout under VIEW)

Item 7. Gypsum requirement

The initial soil chemical properties (Table 2) give an indication that the soil is highly saline-sodic. The question therefore also arises whether an application of a chemical amendment, e.g. gypsum $CaSO_4.2H_2O$, is required (in fact 8 tons of gypsum per ha have been applied prior to leaching) or that an application could have been omitted. Consider 30 cm depth of soil to be improved. The efficiency of gypsum application is estimated at 60%.

The quantity of gypsum, G_{10} (T/ha per 10 cm depth), required for replacement of sodium by calcium at the exchange complex of the soil can be computed with

$$G_{10} = (ESP_i - ESP_f) \times CEC \times BD \times 8.6 / 1000 f$$

where:

ESP	=	Exchangeable Sodium Percentage, i.e. the percentage of sodium ions at the exchange complex, equal to 100 ES/CEC. For ES = Exchangeable Sodium (meq/100g soil) see Table 2
ESP_i	=	initial ESP value (%), see Table 2
ESP_f	=	final ESP value (%), safe value to be assumed
CEC	=	Cat-ion Exchange Capacity, i.e. the total amount of positive ions (Na^+, K^+, Ca^{++}, Mg^{++}, etc.) that can be adsorbed at the exchange complex (meq/100g soil), see Table 2
BD	=	Bulk Density of the soil (kg/dm^3), see Table 2
f	=	gypsum application efficiency (fraction: $0<f<1$)

Derive this equation for yourself (see the notes on the next page and the data in Table 2) and calculate G_{10} for the first 30 cm of soil depth (see the table on the next page), assuming that ESP_f needs to be about 5% (a very safe value).

Calculate also the calcium equivalent of the gypsum requirement (i.e. the calcium requirement), using the Ca equivalence ratio (see the notes on the next page).

Depth in cm	ESP_i %	ESP_f %	CEC meq/100g	BD kg/dm³	G_{10} T/ha	Ca equiv. of gypsum T/ha
0-10	43	5	28	1.42	21.7	5.0
10-20						
20-30	50	5	30	1.52	29.5	6.9

Notes:

- atomic weight (AW): Ca=40, S=32, O=16, H=1
- the molecular weight (MW) of the gypsum, $CaSO_4(2H_2O)$, is:
  MW(gypsum) = AW(Ca)+AW(S)+4AW(O)+2x2AW(H)+2AW(O) = ...
- the valence of gypsum is V(gypsum) = 2 because the Ca and SO_4 ions have a double electric charge (Ca^{++}, SO_4^{--})
- the equivalent weight (EqW) of gypsum is:
  EqW(gypsum) = MW(gypsum)/V(gypsum) = ...
- the Ca equivalence ratio ER(Ca) of gypsum is:
  ER(Ca) = AW(Ca)/MW(gypsum) = ...
- the Ca requirement or Ca equivalent of the gypsum requirement is $ER(Ca).G_{10}$ (to be used in the above table)

The soil contains a small quantity of gypsum and a substantial amount of calcium carbonate ($CaCO_3$). Calculate these quantities and their calcium equivalents from the data in Table 2 and complete the following table, keeping in mind that 1% of salt in the soil equals 1 g (salt) per 100 g (soil), or 10 kg (salt) per ton (soil), while the soil weighs BD ton per m^3, and that 10 cm soil depth over 1 ha corresponds to 1000 m^3 of soil. The atomic weight of Carbon (C) equals 12. Compare the quantities with the gypsum requirement and draw your conclusion.

Depth in cm	Gypsum %	Gypsum T/ha	Ca equiv. gypsum T/ha	$CaCO_3$ %	$CaCO_3$ T/ha	Ca equiv. $CaCO_3$ T/ha
0-10	0.5	7.1	1.6	4.3	61.1	24
10-20						
20-30	0.4	6.1	1.4	5.4	82.1	30

Irrigation water is of good quality and is a source of calcium. Is the amount of calcium applied by irrigation water substantial? It may be assumed that irrigation water (EC = 0.6 dS/m and SAR = 2) only contains Sodium (Na) and Calcium (Ca). The atomic weight of Na is AW(Na) = 23. Note that SAR stands for Sodium Adsorption Ratio.

The amount of calcium added by irrigation water is calculated as follows.

First we use the relation

EC = 0.6 dS/m --> [Ca+Na] = 6 meq/l

where the brackets [ ] indicate the concentration in meq/l. As a rule of thumb, the conversion factor of EC into meq/l is 10 (see lecture notes "Drainage for Agriculture", p 37).

Note that the concentration in meq/l stands for as many mg/l as the atomic weight (AW) divided by the valence V (valence of Na^{+} is 1, valence of Ca^{++} is 2, as Na has one electric charge and Ca has two). Remembering that the equivalent weight is EqW = AW/V, one can also say that the concentration in meq/l stands for as many mg/l as the equivalent weight.

Secondly, using the definition of SAR (Sodium Adsorption Ratio), we have the relation

$$SAR = [Na]/\sqrt{([Ca]/2)} = 2$$

Now we have two equations with two unknowns: [Ca] and [Na]. From these it can be found by trial and error that:

[Na] = ... meq/l, and [Ca] = ... meq/l

Using 1 meq/l = EqW mg/l = EqW g/m^3 = 0.001 EqW kg/m^3 and using the brackets { } to indicate the concentration in kg/m^3 we obtain:

{Na} = ... kg/m^3, and {Ca} = ... kg/m^3

{Ca} - {Na} = 0.008 kg/m^3

Hence with 10.000 m^3 irrigation water (i.e. 1 m depth of water over 1 ha) .... kg Ca is added <u>in excess</u> of Na per ha of soil.

Draw your conclusions about the necessity of gypsum application.
Take also into account the pH values of the soil (do they indicate a severe alkalinity problem?) and the fact that an ESP_f value of 5% is probably lower than actually required.

<u>Note</u>

From the expression of SAR it can be seen that SAR decreases upon dilution of the soil moisture by leaching. For example:

dilution factor	total salt concentration	SAR
	% of original value	
1	100%	100%
2	50%	71%
3	33%	57%
4	%	%
5	%	%

When the SAR comes down, the Na at the exchange complex is replaced by Ca from the soil solution, even if the solubility of $CaCO_3$ is very small. When Ca is removed from the soil solution, the $CaCO_3$ tends come into solution. During the process, Na_2CO_3 is being formed. This sodium carbonate needs to be removed by the leaching water, otherwise it can counteract the favourable exchange reaction, as it may give rise to the formation of NaOH, which raises the pH of the soil and reduces the solubility of $CaCO_3$ further.

GYPSUM REQUIREMENT IN T/HA PER 10 CM DEPTH

FOR SODICITY CONTROL

BASED ON ESP VALUES

AVAILABILTY OF Ca IN THE SOIL AND/OR IRRIGATION WATER IS NOT TAKEN INTO ACCOUNT

GIVEN: R = ESPi - ESPf (%)

Rabs = R (%) x CEC (meq/100g soil)	-->	meq/10kg soil
Rabs x EqW (mg/meq) / 10	-->	mg/kg soil
Rabs x EqW/10 x BD (kg soil/dm^3 soil)	-->	mg/dm^3 = g/m^3
Rabs x EqW/10 x BD x 0.1 (m depth)	-->	g/m^2
Rabs x EqW/10 x BD x 0.1 x 10^4 (m^2/ha)	-->	g/ha
Rabs x EqW/10 x BD x $10^3/10^6$ (g/Ton)	-->	Ton/ha

Hence:

Rabs x BD x 0.1 EqW / 1000 f   T/ha for 10 cm soil depth

(f = application efficiency)

Table 2 Initial soil characteristics

Depth in cm	ECe[7] dS/m	SP[6] %	pH[1]	ES[2] meq/ 100g	CEC[5] meq/ 100g	$CaCO_3$ g / 100 g	Gypsum g / 100 g	Ca+Mg[3] meq/l	Na[3] meq/l	Cl[3] meq/l	BD[4] kg/dm^3
0- 10	169	44	7.4	12	28	4.3	0.5	993	2256	3047	1.42
10- 20	130	48	7.5	12	28	5.0	0.4	796	1629	2258	1.47
20- 40	75	55	7.8	15	30	5.4	0.4	292	738	785	1.52
40- 60	42	57	8.0	18	30	4.9	0.3	103	415	414	1.54
60- 80	34	55	8.1	18	33	5.4	0.3	77	334	288	1.57
80-100	30	55	8.1	19	31	5.3	0.4	71	277	233	1.58
100-120	27	54	8.0	17	30	5.3	0.3	60	216	184	1.50[8]
120-160	23	52	7.9	14	27	4.8	0.3	69	154	160	1.50[8]
160-200	19	45	7.9	10	25	5.9	0.2	59	133	135	1.50[8]

1 pH measured in saturated paste

2 ES Exchangeable Sodium

3 In saturation extract

4 Bulk Density

5 Cation Exchange Capacity

6 Saturation Percentage of paste, g water/100g soil

7 Electrical Conductivity of Saturation extract from paste

8 Bulk Density estimated

2