Calcium Required as an Amendment for Irrigation Waters with High Bicarbonate Content in Relation to the Drainage Conditions

I. PLA

Instituto de Edafologia, Facultad de Agronomia, Maracay Venezuela

In a previous paper (PLA [6]) a method was proposed for calculating the leaching and drainage requirements for irrigation waters with a high bicarbonate content, in order to prevent the accumulation of excessive amounts of Na in the soil. Occasionally, when a relatively low hydraulic conductivity of the soil, or a high cost of drainage installations makes it impractical to fulfill the leaching requirement for Na control, a practical solution would be the addition of Ca amendments (usually $CaSO_4 \cdot 2\,H_2O$) to the irrigation water to reduce the %L (leaching requirement expressed as a percentage of the applied irrigation water that is leached through the root zone). This practice would be especially applicable for irrigation waters with low salt contents, because in this case the amendment not only would reduce the leaching requirements, but it would also contribute to an increase in the hydraulic conductivity of the natural soil by increasing the total salt concentration of the percolating solution. On the other hand, the amendment required for low concentration waters would be much less.

DARAB [1] suggested that the method is economic when the salt content of the water is low, and computed the required amount of Ca salt from the following equation:

$$X = SZ_e \cdot G$$

where SZ_e = soda equivalent of the irrigation water, G = equivalence number of the melioration agent, X = doses of the agent required.

EATON [3] concludes that adequate leaching is dependent upon the maintenance of a suitable degree of soil permeability, stressing the importance of a knowledge of Ca requirements for the maintenance of such a permeability. His Ca requirement formulas have as their object the maintenance of sufficient soluble Ca in the soil solution so that Na will not be greater than 70% of the cations present. In the calculation a 70 per cent precipitation of bicarbonates is predicted, but the author admits that this index is largely empirical, and possibly wide departures will inevitably occur in certain cases. For Ca requirement he proposes the use of the equation:

$$\text{Ca requir. in meq./l} = Na \cdot 0.43 - (Ca + Mg) + (CO_3 + HCO_3) \cdot 0.7 + 0.30$$

where $Na \cdot 0.43 - (Ca + Mg)$ is the Ca required to adjust Na to 70 per cent or less in the irrigation water, $(CO_3 + HCO_3)$. 0.7 is the Ca required to compensate the Ca + Mg that may precipitate in the soil, and 0.30 is the amount of Ca required to compensate the Ca + Mg in excess of Na that is removed from the soil by average crops.

A machine for the continuous dissolution of commercial gypsum in irrigation water was developed by KELSALL, CROCKFORD, and DAVEY [4]. Several influences of dissolved gypsum on the physical properties of irrigated soils have been observed and recorded by DAVIDSON and QUIRK [2], LOVEDAY and SCOTTER [5] and SCOTTER and LOVEDAY [8].

Using the same reasoning presented by the author in a previous paper (PLA [6]) there was developed and tested a non-empirical equation for calculating the Ca requirements of irrigation waters in relation to the leaching percentage (%L).

Theory

Using the following equation (PLA, 1968):

$$Na_s = Na_r \cdot 100/\%L \tag{1}$$

$$Ca_s = CaSA_r \cdot 100/\%L + CaB_s \tag{2}$$

$$SAR = Na_s/\sqrt{Ca_s/2} \tag{3}$$

where s = equilibrium solution in saturated soil, r = irrigation water, SAR = = sodium adsorption ratio (USDA [9]), Ca = Ca + Mg, CaSA = Ca associated with anions different from bicarbonates = total Ca − bicarbonates, B = bicarbonate ion.

Equation (4) is obtained:

$$Ca_s = 2(Na_r)^2/(SAR)^2 \cdot (100/\%L)^2 \tag{4}$$

where Ca_s is the concentration of Ca + Mg that must be maintained in the equilibrium soil solution in order to keep the SAR below a chosen value, when an irrigation water with a given Na_r is used with a limiting %L.

The concentration of CaSA in the amended water will be:

$$CaSA\ (\text{amended water}) = CaSA_r + CaSA \tag{5}$$

where

$$CaSA_r = Ca_r - B_r = C_r - Na_r - B_r \tag{6}$$

(in the original water). (C = total salt concentration)

$$CaSA_R = Ca_R = \text{amendment added} \tag{7}$$

Using equation (2), the equilibrium concentration of Ca in the soil solution when the amended water is used will be:

$$Ca_s = (CaSA_r + CaSA_R) \cdot 100/\%L + CaB_s \tag{8}$$

Substituting (6) and (7) in (8), we have:

$$Ca_s = (C_r + Ca_R - Na_r - B_r) \cdot 100/\%L + CaB_s \tag{9}$$

Combining equations (4) and (9), and solving for Ca_R

$$Ca_R = Na_r + B_r + 200(Na_r)^2/(SAR)^2 \cdot \%L - (CaB_s \cdot \%L/100 + C_r) \quad (10)$$

where Ca_R is the Ca requriement expressed in meq./l. for an irrigation water with determinate total salt concentration (C_r), sodium concentration (Na_r), and bicarbonate concentration (B_r), which is going to be used with a limited leaching (%L), in order to keep the SAR in soil solution below a preselected value.

For the same reasons given in a previous paper (PLA [6]), when $Ca_r + Ca_R \geqslant B_r$ in the amended water, we have:
$CaB_S \approx 10$ meq./l. if $CaB_r \cdot 100/\%L \geqslant 10$ (precipitation of $CaCO_3$)
$CaB_s = B_r \cdot 100/\%L$ if $CaB_r \cdot 100/\%L < 10$ (no precipitation of $CaCO_3$).

In unusual cases when $Ca_r + Ca_R < B_r$, the following approximation (due to the presence of Na bicarbonate in soil solution) can be made:

$$Ca_R \approx B_r - Ca_r$$

Using the amended water, with a particular leaching, the total salt concentration to be reached at equilibrium, would be:

$$C_s = Na_s + Ca_s \quad (11)$$

and using the values of Na_s and Ca_s calculated with equations (1) and (9), we have:

$$C_s = (C_r + Ca_R - B_r) \cdot 100/\%L + CaB_s \quad (12)$$

If that value of C_s is higher than the maximum permissible total salt concentration in a saturation extract for any particular situation, it is possible to calculate the minimum leaching requirement under which the amended water can be used. Substituting the value of Ca_R (equation (10)) in equation (12) and solving for %L, we have:

$$\%L = \frac{50\, Na_r \left(1 + \sqrt{1 + 8\, C_s/(SAR)^2}\right)}{C_s} \quad (13)$$

where %L is the minimum leaching requirement when to an irrigation water with a given Na_r there is added an amendment required for that particular %L, in order to keep the SAR and the total salt concentration in water saturated soil (C_s) below preselected values. If control is required of both the SAR and C_s, and the %L calculated with equation (13) is possible for a given soil and drainage condition, that value of %L would be the one used in equation (10) for calculating the Ca requirement (Ca_R). In all cases the concentrations are given in meq./l.

Values of Ca_R were calculated for irrigation waters with C_r values of 2.5 and 5.0 meq./l., and different concentrations of Na_r and B_r, when the values of %L are 5, 10, 15, 20 and 25. For those calculations a limiting SAR of 10 was used. In order to be able to draw two dimensional graphs, relating three variables (Ca_R Br, and Na_r) the equation (10) was rearranged

$$Ca_R - B_r = 200(Na_r)^2/(SAR)^2\ \%L + Na_r - (CaB_s \cdot \%L/100 + C_r)$$

With those values the nomograms of Figure 1 were drawn. The %L required for salinity control using the amended water were calculated using equation (13), and limiting values of $C_s = 40$ meq./l. and SAR = 10. Using these values, for any Na_r, a line was traced on each monogram separating a shaded area where any combination of $Ca_R - B_r$ and %L would lead to C_s values higher than 40 meq./l. (Figure 1).

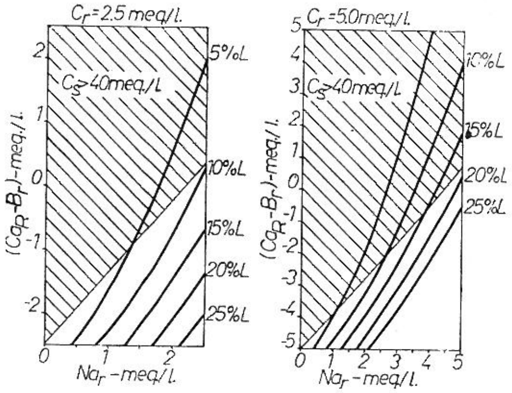

Figure 1

Nomograms for estimating the Ca amendment requirements (Ca_R) of irrigation waters for preventing the development of SAR values higher than 10, with a given leaching percentage (%L), knowing the total salt (C_r), sodium (Na_r), and bicarbonate (B_r) concentrations in irrigation water

Experimental

In order to test the validity of the theory, laboratory equilibrium experiments with a surface sandy loam (soil A) and a surface silty loam (soil B) (described by PLA [6]) were carried out, using the irrigation waters (3) and (3G). Their composition appears in Table 1. Water (3G) is the water (3) plus the Ca amendment required ($Ca_R = 4.4$ meq./l.) for reaching an SAR of about ten in the equilibrium soil solution with a 25 %L. The Ca amendment was added in the form of $CaSO_4 \cdot 2\,H_2O$. The results of those experiments were reported in a previous paper (PLA [6]). They consisted of repeated wetting (to saturation) and drying (to one bar suction) cycles on 500 g. portions of soil located in porcelain Richards funnels with a porous asbestus filter. After each wetting the soil remained saturated for 24 hours, and after that a fraction representing the leaching per cent (%L) for each treatment, was extracted using vacuum. The leachates were analyzed for cations and anions, and the process repeated until equilibrium in the Na—Ca exchange reaction was approached (Table 1).

The results of a lysimeter type of experiment, using a silty loam alluvial soil (Maracay series) are also reported here. This soil is typical of the Aragua Valley irrigated area in Venezuela. Sudan grass was grown under greenhouse conditions in soil columns 25 cm in diameter by 50 cm in height, packed to a uniform bulk density of 1.31. Tensiometers were used for guiding irrigation management and provisions for controlled leachings were made with porous

Table 1

Composition of the irrigation waters used in the experiments

Water	Total	Ca^{2+}	Na^{2+}	HCO_3^-	Cl^-	SO_4^{2-}
	meq./l.					
(3)	10.0	3.0	7.0	6.0	4.0	—
(3G)	14.4	7.4	7.0	6.0	4.0	4.4

ceramic filters placed horizontally at the lower end of the soil columns. The experiment was carried out for approximately 12 months, after which the soil columns were sectioned at 10 cm depth increments, and the soil properties measured. Synthetic waters (3) and (3G) were used for irrigation. The leachates and soils were analyzed using the methods proposed by the U. S. D. A. [9]. Structural indices in compacted cores of soil, equilibrated to 0.5 bar suction, were determined by the method proposed by Richards et al. [7].

Results and discussion

Table 2 presents the chemical and physical data of the soils, when equilibrium was reached in laboratory experiments, as well as the predicted values calculated with the equations previously proposed. The agreement between the observed and the predicted values is evident. It is also shown that after the addition of the amendment the leaching requirement in order to reach an SAR of ten is reduced from 57 to 25% (Table 2).

Table 2

Observed and predicted chemical composition, and observed structural indices of the soil at the end of the laboratory equilibrium experiments (Experimental data taken from Pla 1968)

Soil	Water	%L	Soluble Salts in SS meq./l. $Ca^{2+}+Mg^{2+}$ Obs.	$Ca^{2+}+Mg^{2+}$ Pred.	Na^+ Obs.	Na^+ Pred.	HCO_3^-	Cl^-	SO_4^{2-}	SAR Obs.	SAR Pred.	ESP Obs.	ESP Pred.	BD	HC cm/hour
(A)	(3)	25	2.5	3.0	27.6	28.0	14.0	15.8	—	24.6	22.8	25.4	24.8	1.51	0.05
		57	2.4	3.0	13.0	12.3	7.4	8.0	—	11.8	10.0	11.5	12.0	1.52	0.28
	(3G)	25	15.2	15.6	30.4	28.0	9.0	17.1	20.0	11.0	10.0	10.0	12.0	1.52	0.21
(B)	(3)	57	2.6	3.0	12.3	12.3	7.4	7.5	—	10.8	10.0	10.9	12.0	1.31	0.06
	(3G)	25	15.8	15.6	27.6	28.0	8.2	16.4	19.6	9.9	10.0	9.3	12.0	1.30	0.08

%L = leaching percentage; SS = solution of saturated soil; SAR = sodium adsorption rato; ESP = =exchangeable sodium percentage; BD = bulk density of compacted cores; HC = hydraulic conductivity of compacted cores, using tap water.

Table 3 and Figure 2 show the same results for the lysimeter experiment. In this experiment, due to the slow percolation of water through the soil, it was not possible to reach a precise 25 %L. Therefore, the predicted values were calculated with the proposed equations, using the actual values of %L (23.1 and 20.0%). After one year treatment, equilibrium was not reached in the Na—Ca exchange reaction, especially in the deeper soil. Anyway, the measured values in the top 30 cm of the soil column are very close to the predicted ones. The increase in effects as the soil surface is approached is

Table 3

Observed and predicted equilibrium values of C_s and SAR in saturation extract, and ESP in the Maracay silty loam soil of the lysimeter experiment after one year treatment

Water	%L	Depth cm	C_s		SAR		ESP	
			Obs.	Pred.	Obs.	Pred.	Obs.	Pred.
(3)	23.1	0—10	33.9	33.3	20.2	24.7	18.1	25.7
		10—20	27.2		17.1		17.4	
		20—30	23.9		15.6		16.5	
(3G)	20.0	0—10	75.0	52.0	11.7	12.0	12.1	14.0
		10—20	46.6		9.2		10.3	
		20—30	37.3		9.0		11.1	

clear and in agreement with the results reported by PLA [6] in similar lysimeter experiments using a different silty loam soil. Comparing the values of total salt concentration (C_s), exchangeable sodium percentage (ESP), and hydraulic conductivity (HC) with the same data in the treatment with water (3), the marked increase in HC as a consequence of the lower ESP and higher C_s values in the treatment with the amended water (3G) is evident (Table 3) (Figure 2).

It is concluded that the use of the relation between leaching and accumulation of Na and Ca in soil solution, taking into consideration the precipitation of Ca and Mg carbonates in the soil, is not only useful for calculating the approximate leaching requirements for salinity and sodium control (PLA [6]), but also for the determination of Ca requirements of irrigation waters in order to reduce the leaching and drainage requirements. The selection of the leaching or Ca requirement approach would depend on economic and practical considerations. The use of Ca amendments would be more economical and practical when natural drainage conditions are very poor and difficult to improve with artificial drainage, and the irrigation waters have a low

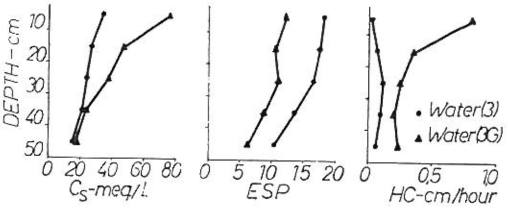

Figure 2

Variation with depth of total salt concentration in saturation extract (C_s), exchangeable sodium percentage (ESP), and hydraulic conductivity (HC), in columns of Maracay soil after being irrigated for one year with waters (3) and (3G), with 23.3 %L and 20.0 %L respectively total salt concentration with a high proportion of bicarbonates. Those are the prevailing conditions in the irrigated areas of Venezuela.

Under field conditions some departures from the calculated requirements have to be expected due to the many variable factors, besides leaching, influencing the effects. Improvements to the equations proposed in this paper can be introduced in the future when more knowledge is acquired about the influence of those factors.

Summary

A new, simple and non-empirical equation for calculation of the Ca required as an amendment for irrigation waters, in order to reduce the leaching and drainage requirements for the control of Na accumulation in soils is proposed. The equation uses the relation between leaching and accumulation of Na and Ca in soil solution, taking in consideration the possibilities of precipitation of Ca and Mg carbonates in the soil. The validity of the equation was tested in controlled laboratory and lysimeter experiments, using different surface soils. The correspondence obtained between the observed and calculated values supports the applicability of the method. The conditions for a practical and economical use of the proposed method are discussed.

References

[1] DARAB, K.: Application of the principles of soil genetics to irrigation in the Great Hungarian Lowland. Genetikus talajtérképek. Ser. 1. N° 4. Budapest. 1962.

[2] DAVIDSON, J. L. & QUIRK, J. P.: The influence of dissolved gypsum on pasture establishment on irrigated sodic clays. Aust. J. Agric. Res. **12.** 100—110. 1961.

[3] EATON, F. M.: Total salt and water quality appraisal. In „Diagnostic criteria for plants and soils". Univ. Calif. Div. Agric. Sci. 501—509. 1966.

[4] KELSALL, D. F., CROCKFORD, R. H. & DAVEY, E. T.: Development of a machine for the dissolution of gypsum. J. Agric. Eng. Res. **5.** 355—362. 1960.

[5] LOVEDAY, J. & SCOTTER, D. R.: Emergence response of subterranean clover to dissolved gypsum in relation to soil properties and evaporative conditions. Aust. J. Soil Res. **4.** 55—68. 1966.

[6] PLA, I.: Evaluation of the quality of irrigation waters with high bicarbonate content in relation to the drainage conditions. Trans. 9th Congr. Int. Soil Sci. Soc. Adelaide. **1.** 357—370. 1968.

[7] RICHARDS, S. J., WEEKS, L. V. & WARNEKE, J. E.: Compacted bulk density and hydraulic conductivity for indicating the structural status of soils. Trans. 7th Congr. Int. Soil Sci. Soc. Madison. **1.** 249—255. 1960.

[8] SCOTTER, D. R.& LOVEDAY, J.: Physical changes in seedbed material resulting from the application of dissolved gypsum. Aust. J. Soil Res. **4.** 69—75. 1966.

[9] U.S.D.A.: „Diagnosis and improvement of saline and alkali soils". Agric. Hb. U.S. Dep. Agric. 60. 1954.