2011 2nd International Conference on Agricultural and Animal Science
IPCBEE vol.22 (2011) © (2011) IACSIT Press, Singapore

Leaching Curves of Highly Saline-Sodic Soil Amended with Phosphoric Acid and Phosphogypsum

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Abstract. Column experiments were conducted to determine desalinization and desodification leaching curves of a highly calcareous saline-sodic soil. Soil columns were amended with phosphoric acid and by-product gypsum (phosphogypsum) and leached with canal water. Phosphogypsum was applied to soils at application rates of 15, 20, 30, and 40 ton ha^{-1}, while phosphoric acid was dissolved in leaching water at application rates of 450, 600, and 900 kg ha^{-1}. Desalinization curves showed that both amendments had similar efficiency in reducing soil salinity, whereas desodicfication curves revealed a superiority of phosphoric acid in reducing soil sodicity. In addition, the Hoffman's approach was adopted to determine the leaching constant (*k*) of both amendments. Desalinization curves showed that application rates did not appear to have a strong effect on *k* in both amendments, while desodification curves showed that increasing rates of phosphoric acid appeared to have no affect on *k*. The leaching constants (*k*) of phosphogypsum and phosphoric acid averaged 0.26 and 0.24 for desalinization and 0.23 and 0.18 for desodification, respectively. The smaller values of k in phosphoric acid treatments depicted lesser amounts of water required for leaching and reclamation compared to phosphogypsum.

Keywords: leaching curves, saline-sodic soil, reclamation, phosphoric acid, gypsum

1. Introduction

Globally, it is estimated that 100 million hectares are classified as salt affected soils [1], half of which are saline-sodic soils [2]. These soils are commonly found in arid and semi arid regions and characterized by high levels of sodium that deteriorate soil structure, reduce water intake, and cause fertility problems leading to reduction in crop production [3]. Reclamation of these soils is accomplished by either an addition of chemical amendment(s) commonly mixed with the upper parts of the soil or directly dissolved in water, or by planting crops (phytoremediation) capable of accumulating salts in their parts [4].

Gypsum ($CaSO_4.2H_2O$) is mostly used for the reclamation of saline-sodic and sodic soils and to a lesser extent calcium chloride ($CaCl_2.2H_2O$) or sulfuric acid (H_2SO_4). The first two amendments provide a direct source of calcium ions to replace exchangeable sodium, while sulfuric acid increases the dissolution of calcite in soil [5]. Recently, phosphoric acid (H_3PO_4) was recommended as a reclaiming material for highly saline sodic soils [6].

Reclamation requires high amounts of water to leach salts. The principle of leaching is very simple; the salts must be washed downwards and away from the root zone by means of flooding and presence of good drainage conditions. In practice, the quantity of drained water is used as an index of the actual amount of leaching water.

It is important to have reliable estimate of the required amount of leaching water needed to reduce soil salinity/sodicity to a desirable level. The empirical approach is by far the most suitable way that can be adopted to tackle this problem. This approach involves plotting the decrease in soil salinity in relation to the

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required amount of leaching water. Therefore, the leaching relationship is considered a useful tool for deciding which amendment is most suitable and economically justified for for soil reclamation, taking into account local soil and agricultural conditions.

In Jordan, it is estimated that more than 30% of agricultural land in the Jordan valley is salt affected soils [7]. Salinity and sodicity problems are expected to be enlarged in future as a result of using poor quality irrigation water [8]. Moreover, little work has been done to evaluate the efficiency of moderate saline-sodic water in soil reclamation. It is reported that such water contains adequate calcium and magnesium ions that can potentially prevent destruction of soil structure and improve water penetration [9].

The objectives of this study were: (1) to establish desalinization and desodicfication leaching curves of a highly calcareous saline sodic soil amended with gypsum and phosphoric acid under continuous ponding of moderate saline-sodic canal water, (2) to compare the efficiency and optimum application rate of gypsum and phosphoric acid needed for soil reclamation, (3) and to determine the depth of water required to accomplish reclamation process.

2. Materials & Methods

Soil cores [19 cm i.d., 40 cm long (DS)] equipped with sampling cutter were used to extract undisturbed soil samples from agricultural fields in the southern parts of the Jordan valley. Selected physiochemical properties of used soil are shown in table 1. Each core was pressed into the soil to a certain depth, then a trench was excavated around the core, the core was then pressed down to about 50 cm depth. Soil cores (columns)were carefully trimmed away avoiding as much as possible any sample disturbance, sealed from the bottom and amended with phosphogypsum (a by-product from the phosphate industry, 80% pure) and phosphoric acid (50% pure) according to earlier work by Gharaibeh et al. [6]. Gypsum was applied at application rates of 0, 15, 20, 30, 40 t ha^{-1}, while phosphoric acid rates were 450, 600, and 900 kg/ha. Gypsum requirement (GR) is the amount of applied gypsum (application rate) required to reduce the exchangeable sodium percent (ESP) to 10%. Water from King Abdullah Canal (KAC) was used to leach soil cores (EC = 2.2 dS m^{-1}, pH = 8.4, SAR = 4.8). Five pore volumes of leaching water were allowed to pass through each column. Each pore volume is equivalent to 19.6 cm depth of leaching water. Water was applied at 5 cm constant hydraulic head and leachates were collected in successive 300 mL aliquots. The depth of infiltrated water (DW) was determined during leaching process. Leaching was terminated when salinity of leachate approached that of leaching water. Soil samples were taken out and analyzed for electrical conductivity in saturated paste extract (ECe) and exchangeable sodium percentage (ESP). Treatments were carried out in triplicates, and soil chemical and physical analysis was determined according to the standard methods of soil analysis [10, 11].

Table 1: Selected physiochemical properties of used soil.

ECe (dS m^{-1})	pH	BD (Mg m^{-3})	CEC ($cmole_{(+)}$ kg^{-1})	ESP %	$CaCO_3$ %	Texture
50	7.8	1.35	49	35.7	27	SCL

3. Results & Discussion

Leaching curves are useful tools to determine the efficiency of amendments and the optimum quantities of water needed for successful reclamation. Leaching curves are only applicable for specific soil and salt conditions and used to describe the relation between soil salinity (desalinization) or sodicity (desodification) and the depth of leached water. Since it is not feasible to carry out time-consuming and expensive leaching experiments in the field; column experiments were used for this purpose.

The leaching curves (desalinization curves) are constructed by plotting (EC-EC_{eq} / EC_o- EC_{eq}) on the ordinate and DW/DS on the abscissa. EC is soil salinity after an application of specified leaching depth, (EC_o) is the initial salinity of soil, DW is the depth of leaching water, DS is the depth of soil, and EC_{eq} is the salinity of soil at the end of reclamation process (equilibrium). EC_{eq} is either equal to the salinity of the upper 5 cm of reclaimed soil. When EC_{eq} is subtracted both from the initial salinity (EC_o) and salinity after specified leaching depth (EC); the relationship becomes independent of salinity of irrigation water and evaporation conditions. Similarly, desodification curves can be constructed by plotting ($ESP-ESP_{eq}$ / ESP_o-ESP_{eq}) on the ordinate and DW/DS on the abscissa. ESP is soil sodicity (exchangeable sodium percent, ESP) after an application of specified leaching depth, (ESP_o) is the initial sodicity of soil, and ESP_{eq} is the target or desired sodicity after reclamation (ESP = 10).

Desalinization curves (Fig. 1) show that both amendments had similar efficiency in reducing soil salinity and required similar amounts of leaching water. The control was slightly less efficient in reducing soil salinity when comparing with the two amendments. The steepness of the curves (slope) denotes that salt leaching was not rapid to reduce soil salinity to acceptable levels (4 dS m^{-1}). This could be attributed to different migration velocities of various ions during leaching (hydrodynamic dispersion and molecular diffusion), and it is expected that the concentration of different ions will not decrease proportionally.

Desodification curves (Fig 1) show that ESP decreased considerably with leaching. Soils amended with gypsum required higher amounts of water to reduce soil sodicity compared to those amended with phosphoric acid. Both amendments showed greater disodification compared to the control (simple leaching with canal water). The efficiency of leaching is influenced by the solubility of amendment and the homogeneity of leaching solution. Phosphoric acid is more soluble, increases the dissolution of calcite, therefore supplies a steady source of calcium ions, and produces homogeneous solutions. In contrast, gypsum less soluble and produces high electrolyte solution mostly at the early stages of reclamation. As shown in figure 1, phosphoric acid was more efficient than gypsum and required substantially lesser amounts of leaching water.

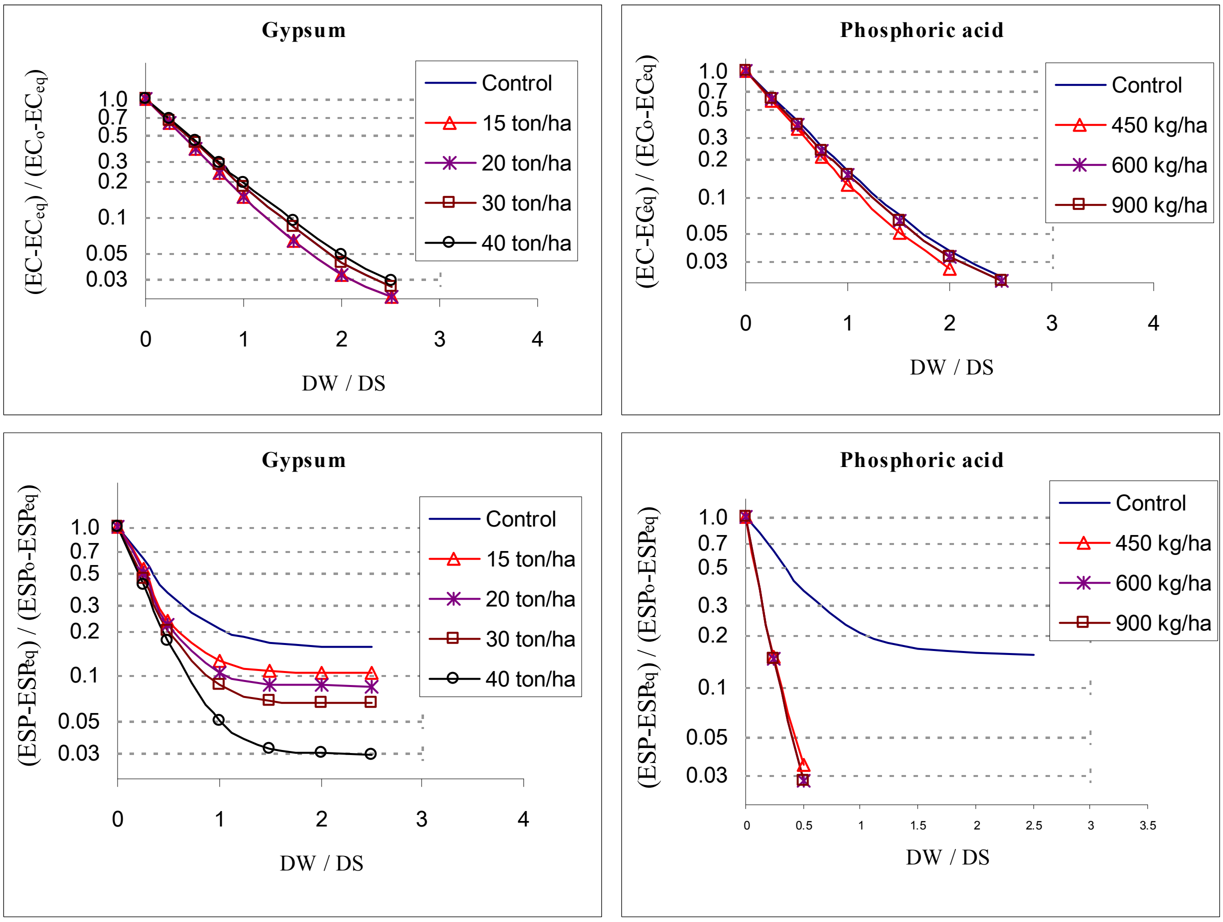

Fig. 1: Desalinization & desodification leaching curves.

Hoffman [12] described the leaching constant by the following equation: $k = (EC/EC_o)*(DW/DS)$, where k is an empirical coefficient that differs with soil type. In general, k values range from 0.1 for sandy soils to 0.3, a for clay soils. This equation is valid only when *(DW/DS)* exceeds k.the initial offset of the curve is indicative of the amount of water that must be added to the profile before leaching commences. Larger *k* values indicate more water is required for leaching.

The leaching constant was calculated and averaged per each amendment rate and depth of leached water. *k* ranged from 24 to 28%, and from 22 to 24% (26% control) per gypsum and phosphoric acid rates, respectively, while *k* ranged from 2 to 85% and from 2 to 78% (27% control) per depths of leached water of gypsum and phosphoric acid, respectively. Average *k* for all rates and depths of leached water was 26 and 23%; an application of a depth of leaching water equal to the depth of soil, reduced initial salinity levels by 78-82% and by 83% (80% control) for gypsum and phosphoric acid, respectively. Typically, 70% or more of initial salt content will be removed by leaching with a depth of water equivalent to the depth of soil to be reclaimed when water is ponded continuously on the soil surface. Desalinization curves show that gypsum and phosphoric acid rates did not appear to have a strong effect on *k* (Table 2).

The Hoffman approach could also be adopted for soil desodification as follows: $k = (ESP/ESP_o)*(DW/DS)$. The leaching constant was calculated and averaged per each amendment rate and depth of leached water. *k* ranged from 20 to 26%, and 18% (33% control) per gypsum and phosphoric acid rates, respectively, while *k* ranged from 8 to 64% and from 7 to 62% (27% control) per depths of leached water of gypsum and phosphoric acid, respectively. Average *k* for all rates and depths of leached water was 23 and 20%; an application of a depth of leaching water equal to the depth of soil, reduced initial sodicity levels by 76-82% and by 84% (80% control) for gypsum and phosphoric acid, respectively. It is obvious *k* did not appear to be related to phosphoric acid rates (Table 2). In other words, the lowest rate of phosphoric acid was as efficient as the highest one and was substantially enough to reduce soil sodicity to a safe level (10% or less).

Table 2: Leaching constants (*k*) for soil desalinization and desodification.

	Desalinization [$k = (EC/EC_o)*(DW/DS)$]				
	Gypsum rates (ton ha^{-1})				
	0	15	20	30	40
k	0.27	0.24	0.24	0.27	0.29
	Phosphoric acid rates (kg ha^{-1})				
k	0	450	600	900	
	0.27	0.22	0.24	0.24	
	Desodification [$k = (ESP/ESP_o)*(DW/DS)$]				
	Gypsum rates (ton ha^{-1})				
	0	15	20	30	40
k	0.33	0.26	0.24	0.23	0.20
	Phosphoric acid rates (kg ha^{-1})				
k	0	450	600	900	
	0.33	0.18	0.18	0.18	

The amount of water required for leaching salts from soil profile can be minimized by intermittent application of leaching water. The effect of soil type is minimal and the required time for reclamation in intermittent leaching (application) is much longer than in ponding method. For intermittent ponding, the leaching constant, *k* is equal to 0.1 whereas, *k* for continuous ponding is a function of soil type (texture).

The depth of water needed to reduce the salt content for a given application rate can be calculated from these graphs. For example, given initial soil salinity EC_o of 50 dS m^{-1}, then the amount of water required to decrease soil salinity of 40 cm soil depth to an EC of 4 dS m^{-1} with simple leaching (control) is equal to 78 cm depth of leaching water. Assuming the intermittent leaching method was adopted [12], the calculated amount of water would be 30 cm. Therefore, the amount of water required for leaching is reduced to more than one third of that needed when using ponding method.

Moreover, if a salt tolerant crop (e.g. barely) was cultivated, then desodification curves can be used to calculate the required amount of leaching water to reduce soil sodicity to an acceptable level (10%). For example, given initial soil sodicity ESP_o of 36, and an application rate of 450 kg ha^{-1} of phosphoric acid, then the amount of water required to decrease soil sodicity of 40 cm soil depth to an ESP of 10 is equal to 20 cm depth of leaching water. The assumption of applying an intermittent leaching can not be adopted; since the calculated amount of water would be 10 cm and this amount does not promote any water flow/leaching through soil profile.

4. Summary & Conclusions

Leaching curves are useful tool to determine the efficiency of amendments and the optimum depth of leaching water needed for successful reclamation. Desalinization and desodification leaching curves showed that a highly calcareous saline-sodic soil could be reclaimed efficiently with phosphoric acid with considerably less amounts of water compared with gypsum. Application of 450 kg ha^{-1} of phosphoric acid with 0.5 DW/DS substantial reduced soil sodicity to acceptable level, whereas soil salinity could be reduced substantially with an addition of extra 0.5 DW/DS of leaching water. Phosphoric acid could be used as reclaiming material however further field experimentation is required before any certain recommendation is drawn.

5. References

[1] I. Szabolcs. Soils and salinization. In: M. Pessarakli (eds). *Handbook of Plant and Crop Stress.* New York: Marcell Dekker. 1994, pp. 3–11.

[2] K. K. Tanji. Nature and extent of agricultural salinity. In: K. K. Tanji (eds). *Agricultural salinity assessment and management.* ASCE manuals and reports on engineering practices 71. New York: ASCE. 1990, pp. 1–17.

[3] D. L. Suarez. Sodic soil reclamation: Modeling and field study. *Aust. J. Soil Res*. 2001, **39**: 1225–1246.

[4] M. Qadir, and J. D. Oster. Vegetative bioremediation of calcareous sodic soils: History, mechanisms, and evaluation. *Irrig. Sci.* 2002, **21**: 91–101.

[5] J. E. Mace, C. Amrhein, J.D. Oster. Comparison of gypsum and sulfuric acid for sodic soil reclamation. *Arid Soil Res. Rehab.* 1999, **13**: 171-188.

[6] M. A. Gharaibeh, N. I. Eltaif, S.H. Shra'ah. Reclamation of a calcareous saline-sodic soil using phosphoric acid and by-product gypsum. *Soil Use Manage.* 2010, **26** (2): 141- 148.

[7] A. M. Mashali. *Salinization as a major process of soil degradation in the Near East*. FAO. Rome (Italy). Land and Water Development Div. FAO-AGL/RNEA--LWU/89/9. 1989.

[8] M. A. Gharaibeh, N. I. Eltaif, O.F. Shunnar. Leaching and reclamation of calcareous saline-sodic soil by moderately saline and moderate-SAR water using gypsum and calcium chloride. J. Plant Nutr. Soil Sci. 2009, 175 (5): 713-719.

[9] J. E. Mace, and C. Amrhein. Leaching and reclamation of a soil irrigated with moderate SAR waters. *Soil Sci. Soc. Amer. J.* 2001, **65**: 199-204.

[10] A. Klute. Method of soil analysis, Physical and mineralogical methods, part I, 2nd edition, Agronomy monograph 9, ASA, Madison, WI, 1986.

[11] A. L. Page, R.H. Miller, D. R. Keeney. Methods of soil analysis, Chemical and microbiological properties, part II, 2nd edition. Agronomy monograph 9. ASA and SSSA, Madison, WI. 1982.

[12] G. J. Hoffman. Guidelines for reclamation of salt-affected soils. Appl. Agr. Sci. 1986, **1** (2): 66-72.