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Effects of Water Application Rate and Leaching Method on Reclamation of a Coastal Salt-Affected Soil of Harawah Region, Libya

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RECLAMATION of salt-affected soils depends on many factors related to soil properties, water availability and quality, method of leaching and irrigation systems. This study aimed at investigating the effects of both water supplication rate and the leaching method in reclaiming a calcareous salt-affected coastal soil (EC= 36.76 dS m-1 ESP= 23.8% pH= 8.38) using the water of the Man-made River (EC= 1.48 dS m-1 and SAR= 3.71). Disturbed soil samples were collected from the study area to a depth of 50 cm and packed into PVC cylinders (60 cm long and 10 cm i.d.).The experiment comprised the treatments of seven water application rates expressed by the average pore volume of the soil columns (0, 2, 4, 6, 8, 10 and 12 PV) and two leaching methods; continuous (CL) and discontinuous (DL) using a factorial design with three replications for each treatment. Soil EC, ESP and pH were determined and their relative changes to the initial values were calculated (ECrel, ESPrel and pHrel) and plotted against the number of PV of applied water to obtain the leaching curves. Reductions in parameters were significant with increasing the number of PV of water applied. The DL method proved to be more efficient than the CL method in reducing these soil parameters to acceptable levels (EC= 2.61 dS m-1, ESP= 4.61% and pH= 7.78) when 10 PV of water was applied. This means that less water and longer time period will be required if the DL method is adopted. Further field research must be conducted to account for field soil variability, efficiency of irrigation systems and climate and crop conditions.

Keywords: Salt-affected soil, Water application rate, Leaching method, Leaching curves, Efficiency.

Salts are the bane of both irrigated agriculture and of civilizations that are based on it, particularly if irrigation water and drainage are improperly managed. Excess salts in surface soils are a common condition in arid and semiarid regions (Szabolcs, 1989). The impacts that excess salts have on soil physical and chemical characteristics depends on the type of salts present in soil or irrigation water. Recent data indicate that poor irrigation practices result in the loss of an estimate of 10 million hectares of arable lands per year as a result of soil salinization (Essington, 2004).

Soils adjacent to oceans or other bodies of brackish water can receive cyclic salts. These soils may become salinized through the tidal actions or seepage, where the degree of salinization depends on climate, tidal character, hydrology and soil properties (Massoud, 1981). Under such conditions, these soils tend to be extremely saline. Therefore, irrigation water management in these regions must strike a balance between conservation and the needs of agricultural production (Ayers and Westcot, 1985).

Libya has about 1900 km long of coastal line along the Mediterranean Sea. Thousands of hectares along this coastal line are salt affected soil due to tidal action, windblown sea water spray and/or saline ground waters (Abdulaziz, 2005). About 80% of the Man-made River water budget is allocated for agricultural reclamation projects along the coastal line (GMRP, 1995). The saline soils are low-lying areas adjacent to sea shores where coastal soils are frequently support halophytic vegetation. Harawah region, located in Sirt Governorate is a region having the largest areas of saline soils on the Libyan coastal line. This condition restricts the extension in reclaiming more areas in this region (Bresler *et al*., 1982 and Rengasam & Olsson, 1991).

Traditionally, there are two methods of leaching, *i.e.*, continuous leaching (CL) and discontinuous (intermittent) leaching (DL). Continuous leaching is accomplished by continuously ponding of water on the soil surface and in discontinuous leaching ponded water application is interrupted to allow the redistribution of water and salts held in macro pores (Gupta and Gupta, 1987and Tagar *et al*., 2010). Continuous ponding is the preferred method when time is a limiting factor. This method can pass the same amount of water through the soil profile much faster. As a general rule, this type of leaching will require one centimeter of water for each centimeter unit of the soil profile to be reclaimed. However, the amount of water needed for leaching will vary, depending on the texture of the soil. If water resource availability is a limiting factor, the discontinuous method is adopted for reclamation (Gupta and Gupta, 1987). Thus, the objective of this study was to investigate the effects of water application rate and the method of leaching on reducing of salinity of a Sabkha soil from Harawah region.

Materila and Methods

Soil sampling

Soil sampling was carried out from one of the largest Sabkha areas in Harawah region located 75 km east of Sirt city along the coastal road of Libya (31^{o} 03' 47.37'' N, 17^{o} 18' 13.02" E). Both disturbed and undisturbed samples were collected to a depth of 50 cm. Some physical and chemical characteristics of the soil were determined according to Page *et al*. (1982) and Klute (1986) are shown in Table 1.

TABLE 1. Some selected chemical and physical characteristics of the studied soil.

Soil depth cm	pH	EC dS m^{-1}	Total $CaCO_3$,%	SAR	Bulk density kg m^{-3}	Texture	Moisture characteristics, %v		
							SP	FC	WP
0- 5	8.41	43.05	15.11	25.3	1631	Loamy Sand	37.1	15.2	5.8
5 – 25	8.37	39.12	14.51	21.4	1670	Loamy Sand	36.5	14.5	5.6
25 - 50	8.36	28.11	10.42	19.4	1712	Sandy	34.3	12.7	5.3

SP: Saturation Percent. FC: Field Capacity. WP:Welting Point.

Soil columns

PVC cylinders (60 cm long and 10 cm inside diameter) were sealed from one end (bottom) using PE square sheets (12x12 cm) with a central drainage hole. The cylinders' bottoms were lined with PVC screen and 1-2 mm gravels to a depth of 2.0 cm. The disturbed soil layers were packed into the cylinders to a 50 cm height according to their field arrangement and corresponding bulk densities (Sherif and Hedia, 2004). The average pore volume (PV) of the packed soil columns was calculated using the average total porosity and total volume of the soil column. An average calculated PV of 1450 ml was used as a reference value of the applied water to soil columns (Gharaibeh *et al.*, 2012). Each pore volume represented the amount of water required to saturate all soil pores and this was equivalent to 18.47 cm of leaching water.

Soil amendments

Gypsum was applied to the soil columns at the rate of 50 t/ha, spread on the top and mixed with the upper 10 cm of soil column before carrying the leaching session (Gharaibeh *et al*., 2012).

Irrigation water

Irrigation water, supplied from the Gerdabeya Reservoir of the Man-made River Project to the experimental farm of Sirt University, was used in the current study. Analysis of this source was carried out (Page *et al*., 1982) which showed that its EC, pH and SAR were 1.48 dS m-1, 7.66 and 3.71, respectively.

Leaching treatments

The effects of both water application rates and the leaching method were investigated in this study. Seven levels of water application rates were designed to represent 0, 2, 4, 6, 8, 10 and 12 multiples of the PV of soil columns. For each water application rate, two leaching methods; continuous leaching (CL) and discontinuous leaching (DL) were applied. In the continuous leaching method, the desired amount of water was continuously applied keeping a water head of 3.0 cm on the soil surface. In the discontinuous method, the desired volume of water was applied as one-half PV per 48 hr to allow for complete free drainage (Gharaibeh *et al.*, 2012). The surfaces of the soil columns were covered to minimize evaporation. Treatments were carried out in triplicates.

At the end of each leaching treatment, the PVC cylinders were longitudinally split using an electric rotating saw disc to have the soil column. The soil columns were divided into two sections; the top 5 cm and the rest of the soil column. Each section was air-dried, thoroughly mixed and representative samples were used to obtain soil paste extracts for the determination of ECe, pH and soluble Ca^{+2}, Mg^{+2} and Na^{+} ions and the soil SAR values were calculated. The obtained SAR values were used to calculate the soil ESP using the following expression (U.S. Salinity Lab Staff, 1954);

$$ESP = \frac{100(-0.0126 + 0.01475\,SAR)}{1 + (-0.0126 + 0.01475\,SAR)}$$

Leaching curves were established by plotting relative changes in soil salinity, ECrel= $(EC-EC_{eq})/(EC0-EC_{eq})$ on the ordinate and the amount of applied water expressed by the number of PV on the abscissa, where EC is the average soil salinity after an application of specified depth of leaching water, (EC_o) is the initial salinity of soil, and ECeq is the salinity of soil at the end of reclamation process. EC_{eq} is equal to the salinity of the upper 5 cm of reclaimed soil. When EC_{eq} is subtracted both from initial soil salinity (EC_o) and salinity of soil after application of specified leaching depth (EC), the relationship becomes independent of salinity of irrigation water and evaporation conditions (Gharaibeh *et al.*, 2012). The ECrel will take values from 1.0, for the untreated soil (EC= EC_0) to 0.0, when the soil EC reaches that of applied water. Similarly, soil pH and desodification curves were constructed by plotting relative changes in soil pH (pH_{rel}) and ESP (ESP_{rel}) on the ordinate and PV on the abscissa.

Statistical analysis

The two-way completely randomized design of the applied treatments was used to carry out the statistical analysis of the obtained data to test significance of the effects of water application rates and the leaching method on the calculated parameters (EC_{rel}, pH_{rel} and ESP_{rel}).

Results and Discussion

Leaching experiments in the field is not feasible to carry out since they are known to be time-consuming and expensive. Therefore, column leaching experiments were used for this purpose. Leaching curves are useful tools to determine the efficiency of amendments and the required amount of water needed for successful reclamation.

Leaching curves that describes the relationship between the number of PV of applied water and the resulted reduction in soil salinity (desalinization) are shown in Fig. 1. Reduction in EC_{rel} values of the soil columns were increased with increasing the water application rates. EC_{rel} values were reduced from 1.0 in the control to 0.076 and 0.033 after adding 12 PV of leaching water for the continuous leaching (CL) and discontinuous leaching (DL) methods, respectively. This means that the average EC of the soil was reduced from 36.76 dS m^{-1} in the control to 4.15 and 2.61 dS m^{-1}, for these two methods respectively. It seems that the DL method was more efficient than the CL method in reducing the soil salinity to an acceptable level for cultivation (<4 dS m^{-1}). The ECrel values under the CL method were initially lower than those of the DL method (PV= 4). After that, the ECrel values of the DL method tend to be lower than those of the CL method. This may be attributed to the very high initial soil salinity of the soil columns which facilitated the removal of larger amounts of soluble salts with the continuous flowing leaching water along the soil macro pores (Gupta and Gupta, 1987). As the soil salinity is further decreased, more time was needed to dissolve and remove soluble salts from the smaller soil pores. Keren and Miyamoto (1990) and Gharaibeh *et al*. (2012) stated that continuous ponding (carried out under near saturated soil-water conditions) usually required more water than intermittent ponding (carried out under unsaturated conditions). Thus, the efficiency of leaching increased as the contents of the soil water decreased during leaching and the range of soil pore size distribution also affected salt leaching.

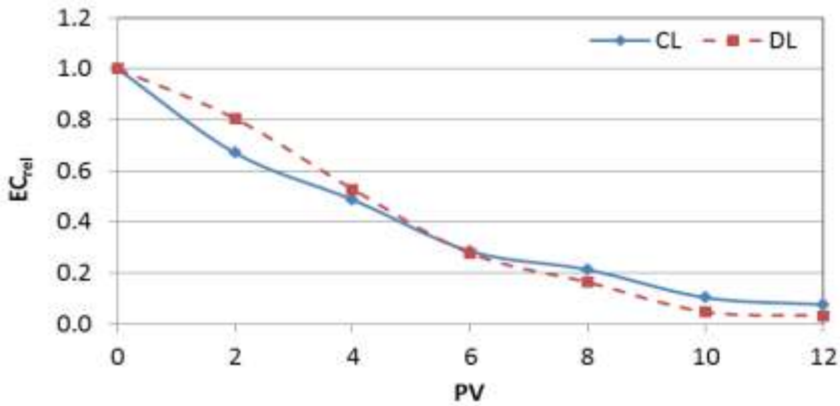

Fig. 1. Relative changes in soil salinity (EC_{rel}) as affected by water application rate expressed as PV and the continuous (CL) and discontinuous (DL) leaching methods.

Statistical analysis of the obtained data (Table 2) revealed that there were significant differences between the number of PV of applied water and the reduction of EC_{rel} of the leached soil columns under the two leaching methods. In addition, the DL leaching method resulted in significantly lower EC_{rel} (higher leaching efficiency) than those for the CL method under all water application rates.

TABLE 2. Significant differences between means of the tested water application rates and leaching methods treatments.

Treatments	Means Values		
	EC_{rel}	**ESP_{rel}**	**pH_{rel}**
Water Appl. Rate (PV)			
0	1.000 a	1.000 a	1.000 a
2	0.739 b	0.853 b	0.913 b
4	0.507 c	0.677 c	0.770 c
6	0.282 d	0.485 d	0.586 d
8	0.188 e	0.357 e	0.298 e
10	0.065 f	0.141 f	0.260 f
12	0.059 f	0.138 f	0.253 f
LSD.05(n= 6)	0.0069	0.0095	0.0078
Sign. Degree	***	***	***
Leaching Method			
CL	0.408 a	0.559 a	0.593 a
DL	0.404 b	0.485 b	0.571 b
LSD.05(n= 21)	0.0029	0.0035	0.0042
Sign. Degree	**	**	*
Appl. Rate x Leach. Method	***	**	ns

Desodification curves (ESP_{rel} vs. PV), illustrated in Fig. 2, showed that the progressive decreases of ESP_{rel} by increasing the amount of applied leaching water were recorded under the two leaching methods. The ESP_{rel} of the control soil was reduced to 0.183 and 0.064 for CL and DL leaching methods, respectively. This means that the soil ESP was reduced from 23.8% to 7.05 and 4.62%, respectively. However, increasing the amount of applied water from 10 to 12 PV had not any significant effect on decreasing the EC_{rel}. Both application rate of water and method of leaching had significant effects on reducing the ESP_{rel} (Table 2). The DL method was found to be significantly more efficient than the CL method in reclaiming the sodicity of the soil. The longer time period needed in the DL method facilitated conditions for better dissolution of gypsum and increase the replacement of Ca ions with the soil exchangeable Na.

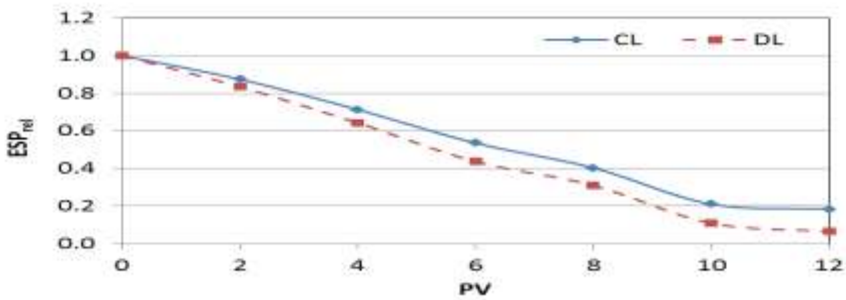

Fig. 2. Relative changes in soil sodicity (ESP_{rel}) as affected by water application rate (PV) and the CL and DL methods.

Reductions in the soil pH due to the tested leaching treatments followed the same trends of the desalinization and desodification curves previously described. However, increasing the amount of applied water from 10 to 12 PV did have significant effect on decreasing the pH_{rel}. The pH_{rel} of the control soil was reduced from 1.00 to 0.181 and 0.180 for the CL and DL leaching methods, respectively. This means that the soil pH was reduced from 8.38 to 7.79 and 7.78, respectively. Similarly, the efficiency of the DL leaching method was significantly more efficient than the CL method in reducing the soil pH (Table 2) (Fig. 3).

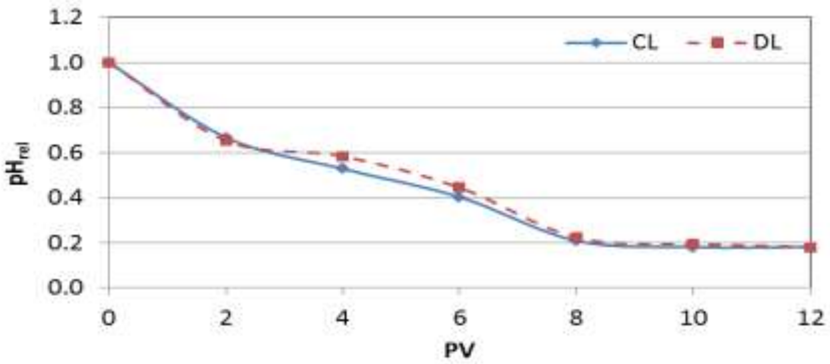

Fig. 3. Relative changes in soil acidity (pH_{rel}) as affected by water application rate (PV) and the CL and DL methods.

From all the aforementioned findings, the DL leaching proved to be significantly more efficient in eliminating salinity and sodicity of the tested soil to acceptable levels compared with the CL method. The amount of leaching water equivalent 12 PV was calculated to be about 18471 m^3 ha^{-1}. For field applications, evaporative conditions, efficiency of the applied irrigation system and spatial soil variability should be considered.

Conclusion

The efficiency of the optimum depth of leaching water and the method of leaching can be evaluated using the leaching curves as a tool for successful reclamation. The depth of water needed to reduce the salt content for a given application rate can be calculated from desalination graphs. Desalinization and desodification leaching curves showed that the Harawah calcareous saline-sodic soil could be reclaimed efficiently using the Man-made River water. The application of 50 kg ha-1 gypsum and an equivalent of 12 PV leaching water using the discontinuous leaching method substantially reduced soil salinity and sodicity to acceptable levels. The amount of water required for leaching salts from soil columns can be minimized by discontinuous method but with longer time period needed for reclamation compared with the continuous method.

However, further field experimentation is required before any certain recommendation is drawn to account for field evaporative conditions, efficiency of irrigation systems and field spatial variability of soil properties.

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تأثيـر مـعدل إضافـة الماء وطـريقـة الغـسيل علـى استـصلاح تربة ساحـلية متأثـرة بالأمـلاح في منطقة هـراوة – ليبيا

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يعتمد استصلاح الأراضي المتأثرة بالأملاح على العديد من العوامل المتعلقة بخواص التربة، واتاحية المياه ونوعيتها، وطريقة الغسيل، ونظم الري، وطبيعة المحصول والظروف المناخية السائدة. وتهدف هذه الدراسة إلى بحث تأثير كل من معدل إضافة المياه وطريقة الغسيل على استصلاح تربة ساحلية جيرية متأثرة بالأملاح لمنطقة هراوة - ليبيا (EC=36.76 dS m-1 ESP=23.8% pH 8.38) وذلك باستخدام مياه النهر الصناعي (EC= 1.48 dS m-1 and SAR= 3.71). حيث تم تجميع عينات تربة سطحية مفككة من منطقة الدراسة إلى عمق 50 سم ، وتم تعبئتها في اسطوانات بلاستيكية (PVC) (بطول 60 سم وقطر 10 سم). وقد تكونت التجربة من سبع مستويات من إضافة مياه الغسيل معبرا عنها بمتوسط حجم المسام لأعمدة التربة (0, 2, 4, 6, 8, 10 and 12 PV) وطريقتين من طرق الغسيل: طريقة الغسيل المستمر (CL) والطريقة المتقطعة (DL)، وذلك طبقا للتصميم العاملي كامل العشوائية (CRD)، مع توفر ثلاث مكررات لكل معاملة. وقد تم تقدير ملوحة التربة عن طريق قياس كل من التوصيل الكهربي (EC, dSm-1)، وقياس درجة حموضة التربة (pH)، وتركيز أيونات الكالسيوم والماغنسيوم والصوديوم في مستخلص عجينة التربة المشبعة و حساب نسبة الصوديوم المتبادل (ESP, %) من قيم (SAR) المحسوبة. ولتقييم عملية الغسيل تم رسم منحنيات الغسيل والتي تمثل العلاقة البيانية بين التغير النسبي للصفات المدروسة (EC_{rel}, ESP_{rel} and pH_{rel}) ومعدل إضافة مياه الغسيل معبرا عنها بمضاعفات (PV). وقد أوضحت النتائج وجود تأثير معنوي لزيادة معدل إضافة مياه الغسيل على خفض التغير النسبي ملوحة وصودية التربة ورقم الحموضة لها. وأظهرت طريقة الغسيل المتقطع زيادة معنوية في كفاءة الغسيل وخفض خصائص ملوحة وقلوية التربة المدروسة لمستويات مقبولة (EC= 2.61 dS m^{-1}, ESP= 4.61% and pH= 7.78) بالمقارنة بطريقة الغسيل المستمر. فإذا تم اتباع الطريقة المتقطعة للغسيل، هذا يعني استهلاك كميات أقل من مياه الغسيل ولكن تحتاج عملية الغسيل لوقت أطول . وهناك حاجة إلى إجراء المزيد من التجارب الحقلية للأخذ في الاعتبار تأثير الاختلافات المكانية لخواص التربة، وكفاءة نظم الري، وظروف المناخ والمحصول المنزرع.