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Leaching Potential of Some Omani Soils: Soil Column and Drip Irrigation Studies

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قابلية بعض أنواع الترب العمانية للغسيل: دراسات على أعمدة التربة والري بالتنقيط

الملخص: تورد هذه الورقة نتائج الدراسات التي أجريت لغسيل بعض أنواع الترب العمانية من الأملاح. تم تحليل سبع عينات أخذت من موقعين في منطقة الباطنة بسلطنة عمان، ثم تعبئتها في أعمدة بطول ٣٠ سم لاستخدامها في تجارب معملية لتحديد كميات المياه الكافية لغسيل الأملاح من قطاع التربة. كما تم استقصاء أثر الغمر المتقطع والمتواصل. أوضحت النتائج أن معظم الأملاح (٥٠ - ٩٠%) يمكن إزالتها بإضافة كمية من المياه تساوي عمق التربة المراد غسلها. كما تبين النتائج أن الغمر المتقطع أكفأ في إزالة الأملاح عن الغمر المتواصل عندما تكون نسبة الأملاح عالية في التربة. كما تم أيضا جمع وتحليل عينات من التربة تحت الري بالتنقيط. ودلت النتائج على كفاءة الري بالتنقيط في إزالة الأملاح بالقرب من الناقطات وتراكمها على سطح التربة بين الناقطات.

ABSTRACT: This paper reports the findings from leaching experiments conducted on some Omani soils. Seven samples from two locations in the Batinah coastal area of Oman were analyzed. Repacked soil columns of upto 30 cm in length were used in laboratory experiments to estimate the amount of water required for adequate leaching of salts from the soil profile. Two methods of leaching: continuous ponding and intermittent ponding were investigated. Results show that most of the salt (50-90%) is removed from the soil profile by the application of water equal in amount to the depth of soil to be leached. The results also show that intermittent ponding method of leaching is more efficient than the continuous ponding method of leaching if initial salinity level is high. Soil samples were also collected to find out the salinity status under drip irrigation. It clearly demonstrates that drip irrigation is very effective in removing salts from soil near the emitters although there is a marked accumulation of salts on the soil surface between emitters.

The problem of soil salinity is an age-old problem. Human actions are mainly responsible for most of the salinity problems, causing the once productive land to become unproductive. Human actions like irrigation without adequate drainage and use of saline water for irrigation have caused huge economic losses and environmental problems. Because of over irrigation, the saline groundwater may rise close to the soil surface. Through capillary mechanism, water is evaporated from the surface leaving behind the salts in the root zone. Similarly, salts can also accumulate if saline water is used for irrigation. The accumulated salts need to be leached by the application of good quality (low salinity) water on the surface; otherwise, crop production will suffer. There is no doubt that the soil salinity is a very serious problem. Fortunately in many cases, the salinity problems associated with irrigation and drainage have simple solutions. Leaching is the preferred method of reclamation of salt-affected soils. In leaching, good quality water is used to wash away the accumulated salt from the root zone. In non-irrigated areas, rainfall is the only source of good quality water for leaching purposes.

Sultanate of Oman is an arid country with average annual rainfall of less than 100 mm. In the coastal areas, groundwater is the main source of irrigation water. Increased usage of groundwater has caused saline water intrusion resulting in higher salinity of groundwater. Use of this highly saline water for irrigation has caused serious soil salinity problems in the Batinah coast. One possible solution to this problem is the leaching of saline soil with available better quality water on a systematic basis. Very little information is available regarding the optimum water requirement for different types of soils in Oman for leaching purposes. This paper presents research findings that had the objective of estimating the amount of water required for adequate leaching. Two irrigation methods were used for leaching. Leaching experiments were conducted in the laboratory with repacked soil columns while the drip irrigation study was conducted in the landscaped area of SQU.

CONCEPTS AND PRINCIPLE: The success of irrigated agriculture depends, in the long term, on the maintenance of a salt balance in the crop root zone. Leaching is the method of choice to maintain salt balance in the root zone. Salt leaching involves the dissolution of soluble salts in the soil, the passage of water through soil profile, and the removal of salt from the root zone. The extent of leaching depends largely on initial soil salinity, the salt tolerance of the crops, and the depth of the water table (Keren, 1996). The quantity of water required to remove salts from the root zone also depends on how the leaching is done. Ponding continuously, intermittent ponding, intermittent sprinkler and drip irrigation are some of the methods of water application. When water is applied under flooded conditions, much of the water and salts in small pores can be bypassed. With intermittent ponding, there is more time for diffusion processes to transport salt from relatively immobile to more mobile regions. Experiments have shown that leaching efficiency may often be increased by reducing the soil water content in the soil profile, because the unsaturated flow conditions reduce large pore bypass (Kruse, 1996). Sprinkler and drip irrigation are more effective in salt leaching for this reason. Cropping the soil during or between leachings will also enhance the efficiency of salt removal because the soil water content is reduced by evapotranspiration.

A general rule is that with a ponded condition, 30 cm of water is required to remove 70-80 percent of the salt for each 30 cm of depth of soil to be leached (Miller and Donahue, 1990). Intermittent water applications are more efficient, it reduces the applied water to about 70 percent of that needed with continuous ponding leaching method. In terms of pore volume (PV), between 1.5 and 2.0 PV of water must pass through the soil to lower the salt concentration 70–80 percent.

Hoffman (1980) proposed the following empirical formula for the salt transport efficiency under one-dimensional leaching:

$$(C/C_o)\ (D/D_s) = k$$

where C is the salt concentration in the soil, C_o is the initial salt concentration in the soil, D is the depth of leaching water applied, D_s is the depth of the soil to be leached, and k is an empirical coefficient. He suggested a k value of 0.3 for clay, silty clay loam, silty clay and clay loam. He also found that, under intermittent ponding, the empirical coefficient is about 0.1, irrespective of the type of the soil. The salt transport efficiency decreases considerably when D to D_s ratios exceed 0.5 for sandy loam and 0.75 for clay loam to clay.

Materials and Methods

Soils for leaching experiments in the laboratory were collected from two locations in the Batinah region of Oman. Soil from seven soil profiles to depths of 20 or 30 cm were sampled in 10 cm layers. The collected soil samples were air dried and sieved to remove large particles. Three of the samples were from Barka (near the coast) and were collected from the basins around date palms. In this location, soil from the top 20 cm of the profile was sampled. For each soil profile sampled, the air-dried soil (bulk densities between 1.3 and 1.5 gm/ cm^3) was re-packed into plastic cylinders of 10 cm diameter making sure that each 10 cm layer was placed in the same sequence as in the field. Electrical Conductivity of the saturated extract of the soil samples were measured (EC_{eb}) before water was applied in the columns. The soils in the columns were leached by applying 10 and 20 cm of water (D_w). All the water (either 10 or 20 cm) was applied at one time for continuous ponding, whereas water was added in 2 equal applications with 3 to 4 days in interval between applications for intermittent applications. The EC of applied water was low (around 0.2 dS/m). The leachate was collected at the bottom of the columns. Once drainage stopped completely, soil samples were collected from different depths (D_s) of the column. Electrical Conductivity of saturated extract of the soil samples was measured (EC_{ea}) after water application. To investigate the long-term effect of drip irrigation on soil salinity, samples were collected from a plot in the SQU campus. This plot of land was under drip irrigation for the previous 3 years. Ornamental plants are grown on this plot. The soil is clay loam (16% sand, 50% silt and 34% clay). Irrigation is done all year round with treated wastewater. Electrical Conductivity of water is around 0.3 dS/m. The irrigation emitters are 60 cm apart. Soil samples were collected from 5, 10, 15, 20, 30 cm from the emitter and at depths of 5, 10, 15, 20, 25, 30 cm. Soils around 6 emitters were sampled. A total of 174 samples were collected. Electrical conductivity of 1: 2 soil:water extracts of samples was measured.

Results and Discussions

SOIL COLUMN STUDY: Table 1 provides information on the location of sampling, depth of sampling, land use, average initial electrical conductivity, particle size

TABLE 1

Physical and chemical properties of the soil samples used in soil column study.

Soil sample	Location	Land use	Depth of soil sample (cm)	Mean initial EC of profile (dS/m)	% sand	% silt	% clay	classification	pH
1	Barka	Date palm	20	85.20	32	60	8	Silty loam	7.27
2	Barka	Date palm	20	17.97	38	38	24	Loam	7.07
3	Barka	Date palm	20	3.04	96	2	2	Sand	7.70
4	AES, Al Khod	Vegetable	30	1.98	80	14	6	Loamy sand	8.05
5	AES, Al Khod	Vegetable	30	3.71	59	34	12	Sandy loam	7.63
6	AES, Al Khod	Vegetable	30	8.99	46	43	10	Loam	7.65
7	AES, Al Khod	Vegetable	30	5.00	58	26	16	Sandy loam	7.28

distribution, pH and soil classification. Samples nos. 4-7 were collected from the Agricultural Experimentation Station (AES) of Sultan Qaboos University, AL-Khod. These soils were transported to this location few years ago when the station was established. Salinity levels of the samples varied from non-saline (sample nos. 3,4,5) to extremely saline (sample no.1). The fraction of salt remaining, f, determined as EC_{ea}/EC_{eb} at depth $D_s = D_w$ was used as the indicator of leaching efficiency and results are given in Table 2. The salt transport efficiency coefficient, k, as suggested by Hoffman (1980), was also determined for each soil profile sampled as the average of the product $(D_w/D_s)(EC_{ea}/EC_{eb})$ for all values of D_s. Average values for k were also calculated for depths where D_s was greater than D_w. Lower values for k and f indicates higher efficiency (Table 2).

Figures 1 - 4 show that in most of the samples, for both continuous ponding and intermittent ponding, lowering of soil salinity (as expressed by the ratio EC_{ea}/EC_{eb}) is moderate beyond $D_w/D_s=1$. It shows that addition of more water beyond $D_w/D_s=1$ would be a wastage. Figure 5 also shows that intermittent ponding will be a more efficient method especially if the initial salinity is high. There is no difference between the continuous and intermittent ponding methods if the initial soil salinity is low (Figure 5). Figure 5 also shows that fraction of initial salt concentration remaining at $D_w/D_s=1$ drops significantly upto initial EC value of 10 dS/m. Average salt concentration coefficient, k, is dependent both on the ratio D_w to D_s and initial EC. Considering that the number of samples from different soil groups were very small, it would not be proper to accept any particular k value for Omani soils, although calculated values are comparable to those obtained by Hoffman (1980). Another factor to consider is that field conditions are likely to be different from the repacked soil columns. Presence of large particles, pebbles, cracks and macropores all will affect the leaching process. Water is likely to move faster bypassing smaller pores, which will decrease leaching efficiency.

Sample 1: This soil had the highest initial soil salinity (EC_{eb} of 85.2 dS/m). Figure 1 clearly shows that at $D_w/D_s=1$, the fraction of salt removal is nearly 80% for continuous ponding and nearly 90% for

TABLE 2

Fraction of salt remaining at Dw/Ds = 1 and average salt transport efficiency coefficient for the soil samples used in soil column study.

Soil Sample	Fraction of salt remaining, f, at $D_w = D_s$		Average salt transport efficiency coefficient, $k = (D_w/D_s)(EC_{ea}/EC_{eb})$		Average salt transport efficiency coefficient, k, for $D_s \geq D_w$	
	Continuous ponding	Intermittent ponding	Continuous ponding	Intermittent ponding	Continuous ponding	Intermittent ponding
1	0.18	0.09	0.24	0.15	0.46	0.11
2	0.14	0.16	0.27	0.34	0.60	0.52
3	0.38	0.38	0.96	0.63	0.33	0.33
4	0.51	0.47	1.21	1.47	0.45	0.47
5	0.20	0.15	0.45	0.32	0.40	0.14
6	0.09	0.08	0.22	0.12	0.26	0.08
7	0.29	0.29	0.40	0.40	0.22	0.27

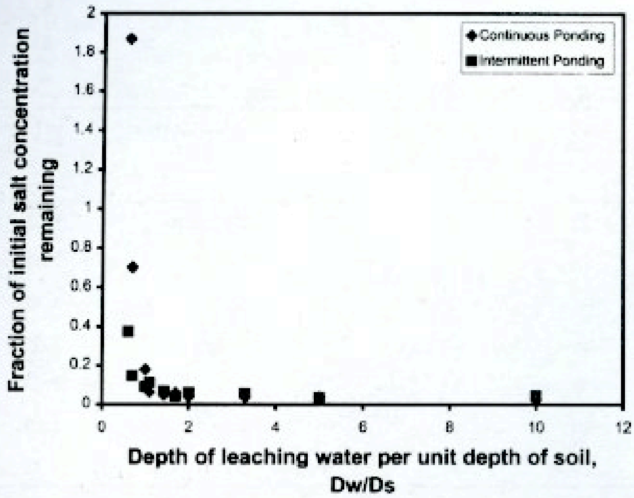

Figure 1. Relationship between fraction of initial salt concentration remaining and depth of leaching water per unit depth of soil, D_w/D_s for silty loam soil (Sample 1).

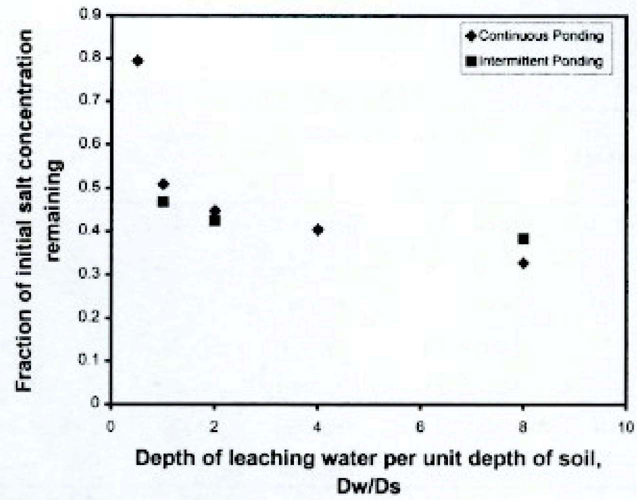

Figure 3. Relationship between fraction of initial salt concentration remaining and depth of leaching water per unit depth of soil, D_w/D_s for loamy sand (Sample 4).

intermittent ponding condition. However, to make this soil suitable for crop production, more than 95% of the salt has to be removed by applying more water.

Sample 2: This soil was loam with initial salinity of 17.97 dS/m. Fig 2 shows that at $D_w/D_s=1$, the fraction of salt removed is nearly 85% under both conditions of ponding. Also clear is that by application of water beyond $D_w/D_s=1$, very little extra salt will be removed.

Sample 3:The soil was sandy with initial salinity level of 3.04 dS/m. Results show that at $D_w/D_s=1$, the fraction of salt removed was nearly 60% under both conditions. It also shows that further application of water failed to leach significantly more salt from the profile.

Sample 4: The plot from where this sample was collected had center pivot irrigation system growing Rhode grass. Salinity was low (initial EC of 1.98 dS/m). The fraction of salt removed at $D_w/D_s=1$ was roughly 50% for both conditions of ponding (Fig. 3). It also shows that as the initial salinity level decreases the fraction of salt removed at $D_w/D_s=1$ also decreases.

Sample 5: This sample was collected from a plot that is cultivated once every year using drip irrigation system. The soil sample was collected from between emitters. The initial salinity was 3.71 dS/m. At $D_w/D_s=1$, the fraction of salt removed is about 80% for ponding condition and 85% for intermittent ponding condition (Fig. 4). The comparative advantage of intermittent leaching is evident.

Sample 6: The sample was from a saline soil (initial EC of 8.99 dS/m). Efficiency of salt removal was very high. At $D_w/D_s=1$, salt removal was more than 90% for both conditions.

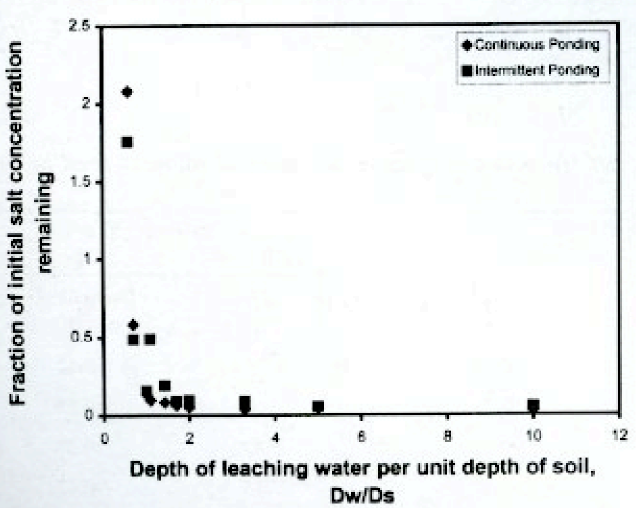

Figure 2. Relationship between fraction of initial salt concentration remaining and depth of leaching water per unit depth of soil, D_w/D_s for loamy soil (Sample 2).

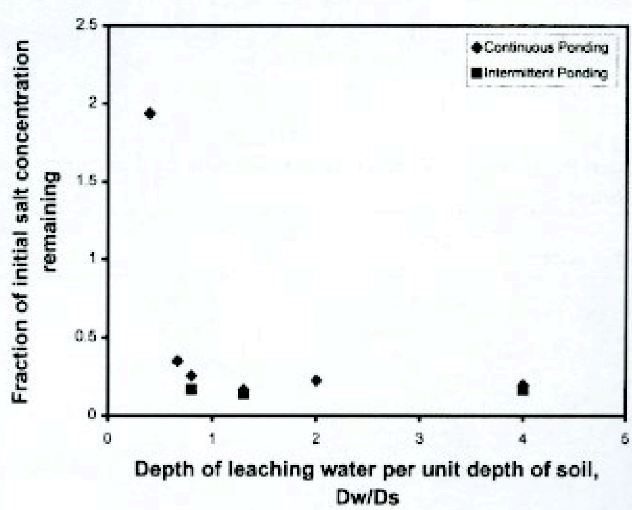

Figure 4. Relationship between fraction of initial salt concentration remaining and depth of leaching water per unit depth of soil, D_w/D_s for sandy loamy (Sample 5).

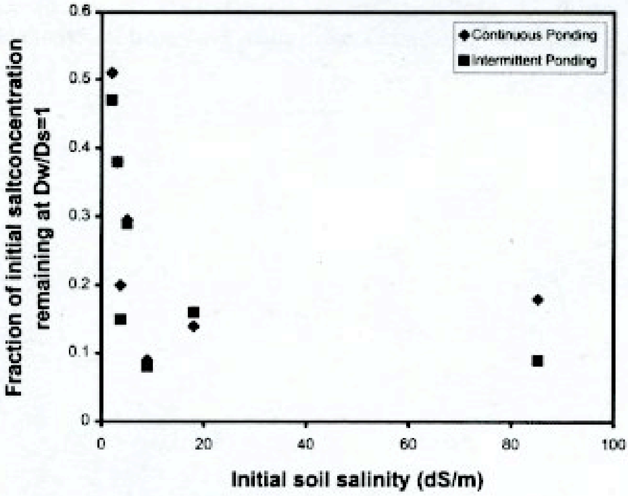

Figure 5. Relationship between initial soil salinity and fraction of initial salt concentration remaining at $D_w/D_s=1$.

Sample 7: Initial EC was 5 dS/m and at $D_w/D_s=1$, salt removal was 70% for both continuous ponding and intermittent ponding methods.

DRIP IRRIGATION STUDY: Drip (trickle) system is now widely used in Oman particularly among farmers, who get it installed at a highly subsidized rate by the Ministry of Agriculture and Fisheries as an incentive to conserve water. As water comes from the drip emitters, it spreads laterally and vertically by soil capillary forces and vertically by gravity. The area wetted depends upon the flow rate, soil type, soil moisture, and vertical and horizontal hydraulic conductivities of the soil. Salt distribution in the drip irrigation forms a typical pattern of low salt accumulation under the drippers due to high leaching and marked accumulation of salt at the wetting front and the soil surface between the drip laterals (Yarn *et al.*,1973). Comparative studies have shown that drip irrigation method provides the best condition for crop growth from salinity and water requirement viewpoints under a given quality of irrigation of water. The results from SQU drip study are summarized in Table 3. It clearly demonstrates that drip irrigation is very effective in removing salt from soil within 10 cm of the emitters. The accumulation of salt between emitters may cause a problem if emitter locations are changed or during rainfall salts from the middle region may wash down into root zone. It is advisable to irrigate soon after rainfall events to avoid such problems.

Conclusions

The results from this study show that for Omani soils the general guide for saline soil reclamation as proposed by Miler and Donahue (1990) is applicable.

TABLE 3

Mean values of soil salinity ($EC_{1:2}$ in dS/m) around emitters under drip irrigation.

Depth cm	5 cm from emitter	10 cm from emitter	15 cm from emitter	20 cm from emitter	30 cm from emitter
5	0.77	0.64	3.13	7.3	6.05
10	0.41	0.41	1.22	1.08	2.59
15	0.36	0.43	0.82	2.37	2.9
20	0.43	0.43	0.41	1.28	1.33
25	0.38	0.44	0.63	1.44	1.58
30	0.39	0.45	0.41	1.66	1.62

The general guide, as stated earlier, recommends the use of water equal in amount to the depth of soil to be leached for 70-80 percent removal of salt. Application of water beyond this guideline value will be using water ineffectively in terms of salt removal from the soil. The results also show that intermittent ponding method is more efficient compared to continuous ponding method of leaching if initial salinity level is high. Intermittent method of leaching can also be achieved by drip or sprinkler irrigation. The effectiveness of drip method within 10 cm of the emitters has been proved from field trials. Further research should be conducted under field conditions to cover broader range of soil types, salinity levels and irrigation and land use practices for formulating guidelines for Omani farmers for reclamation of saline soils.

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