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Leaching Potential of Sea Water in Saline Soils

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إمكانية استخدام مياه البحر لغسل التربة الملحية

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خلاصة: تعتبر ملوحة التربة من ابرز العوامل التي تقلل من الانتاجيه الزراعية في البلاد الجافة وشبه الجافة بالإضافة إلى عدم كفاءة الري و شح المياه العذبة. تركز هذه الدراسة على أحد استعمالات مياه البحر كعامل مساعد لتخفيف الملوحة العالية للتربة في عمان. هدف هذه الدراسة هو تحديد كفاءة مياه البحر في غسل الأملاح من التربة الساحلية والتي تحتوي على طبقة ملحيه في المستوى العلوي من سطح التربة. تم أعاده تعبئة التربة في أعمدة بطول ٤٣ سم وبنصف قطر ١٠ سم وريها بكميات مختلفة من ماء البحر (٤٣ سم، ٦٤,٥ سم، ٨٦ سم) وتم استخدام مياه الصنابير القليل الملوحة وذلك للمقارنه. تم تكرار نفس الدراسة على التربة الساحلية باسطوانة قطرها ٣١,٥ سم. أوضحت النتائج أن ماء البحر يقلل ملوحة التربة بنسبة ٩٠,٤ و١٧,٨% وان هذه النسبة تتفاوت باختلاف بعد العينه من السطح. كما وجد إن معظم الأملاح يمكن أزالتها بإضافة كميه من الماء تساوي عمق التربة المراد غسلها. وخلاصة الدراسة فان ماء البحر يعتبر عاملا مناسبا لغسل التربة المالحة لكنه بطبيعة الحال اقل كفاءه من ماء الصنبور.

ABSTRACT: Limited fresh water resources, inefficient irrigation and soil salinity reduce agricultural production in arid and semi-arid countries. This paper describes one of the uses of sea water to reduce salinity of an excessively saline soil in Oman. The objective of the study was to determine the efficiency of sea water to leach salt from a simulated profile of a coastal soil. The sandy soil under study contained a salt crust at the surface and was less saline in the subsurface layers. Soil was repacked in columns, 10 cm in diameter and 43 cm long, and three depths of sea water applied, i.e. 43, 64.5 and 86 cm. An additional column was leached with tap water for comparison. A leaching trial was undertaken in the field, using soil from inside cylindrical rings (D = 31.5 cm) inserted into the surface. Leaching with sea water reduced soil salinity by between 90.4 and 17.8%, depending on the depth of sampling. Salinity in the surface soil layer was reduced more than in underlying layers. Most efficient leaching occurred with the application of sea water equal in amount to the depth of soil to be leached. It was concluded that sea water is an effective leaching agent, but leached soils still contained more salt than when leached with the same amount of tap water.

Keywords: leaching, sea water, soil crust, salinity.

One of the most urgent global problems is to find enough water and land to support the world's increasing need for food (Gleen *et al.,* 1998). While fresh water resources may amount to approximately only 3% of the world's water resource, there is no shortage of sea water. People living in arid lands bordering the sea could benefit from irrigating land with sea water if the problems of using saline soil and water for crop production could be solved. Apart from selecting salt tolerant species that could be eaten by man or animals, the issues of salt accumulation, both as surface crusts and throughout the soil profile, need to be resolved.

Leaching salts from the soil profile using fresh water is the usual method of reclamation of salt affected soils (Ahmed *et al.,* 1999). However, in most arid countries, such as Oman, where exogenous supplies of fresh water are limited, a possible alternative is to leach with sea water. In Oman, approximately 5% of the coastline is dominated by sabkha (Salm, 1991). The sabkha is a low-lying area adjacent to the beach where coastal soils are frequently excessively saline and support only natural halophytic vegetation (Al-Busaidi and Cookson, 2000). If soil salinity can be reduced, following leaching with sea water, to levels that allow cultivation of more useful halophytic species, then large areas of sabkha land can be developed for bio-saline agriculture.

Many studies have been undertaken on salt flushing from agricultural soils. Boyko (1967) found that, if soil

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has a good drainage system, salts can be leached even with the same water that was used for irrigation. Salts have been successfully leached with saline water and the same can be done with sea water if the right conditions are available (Keren, 1996). Unfortunately, little information is available in Oman regarding the use of sea water for leaching. This paper examines the effectiveness of leaching sandy coastal soils with sea water in laboratory studies as compared to the field.

Materials and Methods

Leaching experiments were performed under both laboratory and field conditions. Soils for the laboratory study were randomly selected (December, 2002) from a coastal location in A'Sawadi area of the Batinah region of Oman (22° 30' N 53° 30' E). Soil samples from three depths (i.e. 0 - 3, 3 - 23 and 23 - 43 cm) were collected to reflect the salinity distribution found in the profile. The soil samples were moist when collected and were not allowed to dry during the course of the study. The soils under investigation were classified as a sandy, mixed, hyperthermic Typic Aquisalids.

Soil was re-packed (with bulk densities of between 1.2 and 1.4 $Mg.m^{-3}$) into plastic cylinders, 10 cm in diameter, ensuring that each layer was in the same sequence and thickness as in the field. Each soil column was 43 cm in length. Electrical conductivity in 1:1 soil:water suspensions (EC_b) and percentage moisture content [by gravimetric method (% MC_b)] of the samples were measured before water was applied in the columns.

Soil in three columns was leached continuously by applying a head of 43 cm, 64.5 cm, or 86 cm of sea water (designated T1, T2 and T3, respectively), and a fourth column was leached continuously with 43 cm of tap water (designated T4). The amounts of water applied were chosen so that the ratios of depth of water applied (D_w) to soil column depths (D_s) were 1, 1.5, 2 and 1 for treatments T1, T2, T3 and T4 respectively. Once drainage had stopped completely, soil samples were collected from different depths (D_s) of the column. Electrical conductivity in 1:1 soil water suspensions (EC_a) and percentage moisture content by gravimetric method (% MC_a) were measured. The electrical conductivities of sea water and tap water used in this study were 69.1 and 0.41 $dS.m^{-1}$, respectively.

Leaching experiments were performed in the field (February 2003) at the same soil collection site. Cylindrical rings (D = 31.5 cm) were inserted into the soil to a depth of 20 cm. Treatments No. 1, 2 and 4 were applied to soil in separate rings. Soil samples were taken before and after leaching from depths 0 - 2, 2 - 11 and 11 - 20 cm.

The percentage reduction in soil salinity due to each leaching treatment was calculated using the following equation: $[(EC_b - EC_a) / (EC_b)]* 100$ where conductivity before (EC_b) and after (EC_a) treatment was measured in dSm^{-1}.

Results and Discussion

LABORATORY STUDY: Table 1 details the properties of the soil studied, including depth of sampling, average initial electrical conductivity, pH, $CaCO_3$ content, and particle size distribution. The surface horizon was more saline than others due to the presence of a surface salt crust. Soils at all depths of sampling were alkaline, calcareous, and sandy.

The contributions of different sand fractions to the total content in each layer are given in Table 2. The surface layer contained a higher proportion of coarser sand than in underlying layers. The subsurface layers were dominated by fine and very fine sand. The occurrence of coarser sand in the surface was probably due to removal of finer materials by wind action and occasion flooding by sea water.

Table 3 reports the percentage moisture content of each horizon before (MC_b) and after (MC_a) leaching. Soils were moist when initially collected and were kept moist before being leached to avoid any redistribution of salt during drying.

Table 4 shows the salinities of soil before and after leaching for the different additions of sea water and tap water. Soil salinities at all depths were reduced following leaching. However, as was expected, addition of tap water (T4) reduced salinity more than did application of sea water (T1).

TABLE 1

Physical and chemical properties of the soil used.

Depth (cm)	EC ($dS.m^{-1}$)	pH	$CaCO_3$ ($g.g^{-1}$)	Texture
0 - 3	176.50	8.36	0.28	Sand
3 - 23	18.03	8.01	0.36	Sand
23 - 43	24.80	7.67	0.38	Sand

TABLE 2

Particle size analysis results.

Soil Horizons	Percentage of particles retained by sieve sizes						
	2 (mm)	1 (mm)	0.5 (mm)	0.25 (mm)	0.106 (mm)	0.053 (mm)	Less than 0.053 (mm)
1	13.72	5.48	54.44	19.69	6.64	0.03	0.00
2	0.36	0.56	3.16	7.83	83.01	4.57	0.51
3	0.52	1.89	4.55	11.38	78.38	3.01	0.27

TABLE 3

Depth and mean percentage moisture content (MC) of soil samples before (b) and after treatment (a).

Soil Horizon	Depth (cm)	% MC_b	% MC_a
1	0 - 3	5.53	32.54
2	3 - 23	12.46	32.29
3	23 - 43	19.79	31.82

TABLE 4

Soil salinity in the laboratory before and after leaching.

Sampling depth (cm)	Soil salinity ($dS.m^{-1}$) before leaching	Soil salinity ($dS.m^{-1}$) after leaching treatment & its percentage reduction (% R)			
		T1-% R	T2-% R	T3-% R	T4-% R
0 - 3	176.50	19.26- 89.09	17.03- 90.35	16.92- 90.41	2.44- 98.62
3 - 23	18.03	14.83- 17.75	14.83- 17.75	14.44- 19.91	0.70- 96.12
23 - 43	24.80	15.4- 37.90	14.57- 41.73	14.17- 42.86	0.73- 97.06

T1 = 43 cm of water head T3 = 86 cm of water head
T2 = 64.5 cm of water head T4 = 43 cm fresh water head

The relative efficiency of leaching salts from soil can be assessed by comparing the percentage reduction in salinity due to each treatment, as shown in Table 4. The efficiency of leaching was little affected by increasing the ratio of D_w/D_s from 1, 1.5 or 2. Addition of water at rates higher than $D_w/D_s = 1$, appeared to remove very little extra salt from the soil column. This result supports the finding of other researchers who recommend leaching soils with an amount of water equal to the soil depth to be leached. Ahmed *et al.* (1999) reported that 50 - 90% of salt in agricultural soils from Oman was removed from the profile by the application of fresh water equal in amount to the depth of soil to be leached. Moreover, applying less water than $D_w/D_s = 1$, appeared to not achieve the purposes of leaching, ie. dissolving and removing salts from the leaching zone (Hoffman, 1980).

A comparison of the percentage salinity reductions between different soil depths is shown in Table 4. Sea water was more effective in reducing salinity at the 0 - 3 cm depth than below this. In contrast, leaching with tap water was equally effective at reducing salinity in all soil depths. Ahmed *et al.* (1999) reported that 60% of salt can be leached by fresh water from sandy soils of 3.04 $dS.m^{-1}$ initial salinity and that the percentage was increased up to 90% when the initial salinity was higher.

The presence of salt crust material in the 0 - 3 cm layer probably reduced the efficiency of the leaching process by redistributing salts to other horizons. The efficiency of the leaching process would presumably be improved if the salt crust could be removed by some other method, perhaps mechanical. Workers reclaiming saline clay soil in Egypt also found that soil salinity could be markedly reduced by using brackish water but for greatest effect, removal of the surface salt crust at the outset was recommended (Abdel-Dayem *et al.,* 2000).

It is important to note that leaching with sea water was more effective in soil with initially higher rather than lower salinity. Sea water leaching appeared to leave soil with a final salinity of no lower than 14.17 $dS.m^{-1}$. It is recommended that plant species selected for cultivation on similar soils after reclamation with sea water should be able to tolerate a soil salinity of, at least, 15 $dS.m^{-1}$.

TABLE 5

Soil salinity in the field before and after leaching.

Sampling depth (cm)	Soil salinity ($dS.m^{-1}$) before leaching	Soil salinity ($dS.m^{-1}$) after leaching treatment		
		T1	T2	T4
0-2	179.70	12.57	13.40	2.71
2-11	8.41	10.26	10.51	0.83
11-20	8.26	10.00	10.11	0.16

FIELD STUDY: Table 5 shows the salinities of soil in the field before and after leaching for the different additions of sea water and tap water. As expected, soil salinity was highly reduced in the first horizon and the addition of tap water (T4) reduced salinity more than addition of the same amount of sea water (T1).

As shown in the Table 5, there was a substantial reduction in soil salinity after leaching, in the upper-most horizon. However, there was no reduction in salinity in the second and third horizons due to the initial soil salinities being below the 'after leaching' average residual salinity range of 14.7 dSm^{-1} as revealed by the laboratory study. The low initial salinity of field soils was probably a result of leaching by natural rainfall and salt uptake by active halophytic plants during the interval between soil collection and inception of the field study. In either case, soil salinity in the lower horizons was substantially lower at the time of the field study, than when soils were initially collected. This indicates that salinities in sabkha soils can change markedly over time and this should be taken into account if the area is to be developed for bio-saline agriculture. Since the second and third horizons in the field were of equivalent depth to only the second horizon in the laboratory study, it is probable that, as found in the laboratory, leached salts would accumulate in field in horizons deeper than those investigated. However, over time, excessive evaporation will lead to upward migration of these salts, aggravating soil salinity in all horizons. For field application, we would recommend repeated additions of sea water in order to achieve the same degree of success in leaching as obtained in the laboratory.

Conclusions

The results from this study suggest that it is feasible to leach salts from a sandy soil by using sea water if a good drainage system is present. Sea water was most effective at reducing soil salinity when applied at an amount equal to the depth of soil to be leached. This is in line with the general recommendation that 70 - 80% of salts can be removed by a similar amount of fresh water. The main difference between leaching with sea water, as compared to fresh water, was that residual soil salinity after using sea water was around 14.7 $dS.m^{-1}$, whereas fresh water leached virtually all salt. Bio-saline agriculture should aim to cultivate crops that can tolerate soil salinities of at least 15 $dS.m^{-1}$. The results also show that the salty surface crust required the addition of more water than subsurface horizons to attain similar final salinities. The field study showed that soil salinities, after leaching, tend to converge on a value between 10 and 13 $dS.m^{-1}$, regardless of whether initial soil salinities are higher or lower than this range. In addition, the field study confirmed the laboratory results, indicating that the head of sea water applied should be equal to the depth of soil being leached.

It is concluded that sea water is a potential source of water for reclamation of salty coastal soils. Further research is needed to investigate sea water leaching under different conditions and to greater depths, using a wider range of soil types and sea waters of different salinity before reclamation guidelines for Omani farmers can be established.

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