Importance of Leaching in Irrigated Vegetable and Plant Production in Saline Soils Under Arid Conditions

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Introduction

In Yemen a dry, arid climate prevails in the delta region of the Wadi Hajr. The yearly precipitation of 50-60 mm is due in the period of summer monsoons when the maximum temperature often reaches 45 °C. The potential evapotranspiration is 1800-2000 mm. Agricultural production is only possible under irrigation from September to the end of December and from February to the end of May, respectively.

The soil is a typical variation of high moor fresh river silt and sand dunes of coastal alluvial or wind-blown origin. The wadi, which transports the irrigation water, has formed its bed between mountains of carbonaceous rocks of volcanic origin. The high temperature accelerates the decomposition of organic matters.

In non-irrigated areas there is a considerable salt accumulation from the saline subsurface waters by the intense capillary salt transport to the surface soil horizons due to the high rate of evaporation.

Material and Methods

For an efficient control of moisture and salt regimes, adequate technologies are required for leaching and irrigation. Proper methods – based on long-term field experiments can serve as a scientific basis for the application of up-to-date advisory services for vegetation and plant production.

In the present study the adaptability of various crops and possibilities of territorial development were investigated; and soil texture (particle size distribution) and water soluble salt content criteria of leaching requirement were analyzed.

Leaching studies could only be performed in 6 plots – 8000 m^2 each – where drain spacing was 30 and 50 m. Salt content was determined from representative soil and water samples. Soil samples were collected from various characteristic soil horizons.

For studying changes in the salt content of the upper, arable soil layers samples were taken from the 0-20 cm layer in 8 places from the 8000 m^2 plots, before the first and after the second flooding.

EC was determined from well homogenized soil samples and drain waters from the three blocks of the 8000 m^2 test area where different water application rates were used.

EC was measured in 1:2 soil–distilled water suspension by RADELKISZ Mini-digi OK-113 device. At the beginning EC values were maintained below 20 mS/cm, but later simple or multiple dilution techniques were applied for treatments with high salt concentration (EC).

For the calculation of the leaching requirement, moderately salt tolerant crops and leaching of the upper one meter soil layer were taken into consideration, with the average of 0.5% original salt content and 25, 37.5 and 50% saturation percentages (SP %), representing sand, silty sand and sandy silt textural classes.

Water doses necessary for leaching were determined according to RICHARDS (1954), Final reports of Tesco-Viziterv on Soil Survey (1984), Agro-pedology (1990) and on Soil testing for salinity (1987).

Results and Discussion

Previously the lack of drain pipes and the frequent mixing of drain water with irrigation water and its stagnation resulted in the rise of the water table and in secondary salinization.

In the soil profiles of the trial plots diagnostic genetic soil horizons were not distinguishable. Changes in soil texture, however, could be followed in the profiles. Silt and gravel deposited in the wadi alternated with fine wind-blown or coarse maritime sand.

The salt content in the soils varied according to the particle size distribution and textural class of the soil and the frequency of irrigation and floods, respectively. Layers composed of fine sand and coarse sand had lower, while silty sand and sandy silt had higher EC values. This also indicated the former use of the area: insufficient water in the upper silty sand layers resulted in higher EC values.

Identical salt concentration of soil solutions in soils of different texture indicates different water soluble salt percentages. The saturation of sand requires less water than that of silty sand or sandy silt. In case of identical EC values the total salt percent of sand is lower than that of silty sand or sandy silt.

Former laboratory studies revealed considerable differences in EC values in settled and ultrafiltered 1:2 soil extracts composed of heavy loam, clay of soils rich in organic matter. In these soils considerable force is needed to remove the water bound to the surface of clay and colloid particles (VÁRALLYAY, 1987) as ions are closely bound to fine particles. They can only be separated by ultrafiltration.

Table 1 presents water doses and EC results in the 0-20 cm soil layer before the first and after the first and second flooding.

Table 1

Water doses applied and electrical conductivity in the upper soil layer (0-20 cm) during leaching

Plot	Water doses, mm	Electrical conductivity, mS/cm		
	At the first and second leaching	Prior to leaching	After the first leaching	After the second leaching
R_1	500+300	11.16	7.96	7.89
R_2	500+300	13.42	11.93	6.02
R_3	300	10.04	9.62	-
L_1	500+(500+200)	28.06	19.24	2.83
L_2	500 -	12.78	6.97	-
L_3	300 -	8.06	6.71	-

The usual 300 mm irrigation water reduced the salt content insufficiently (plots R_3 and L_3). Despite of this, Tourkestan watermelon grew, flowered and set satisfactorily in plot R_3. The second 300 mm leaching water doses, after the first 500 mm dose, decreased EC values by half (R_1 and R_2). Similar results were obtained where the planned 500 mm water could only be applied on the first occasion (plot L_2). Salt reduction was the highest in plot L_1 using a total of 1200 mm leaching water. Leaching results call attention to the following:

– Insufficient irrigation water doses (300 mm) hardly affect changes in the salt content, especially, if given in one dose.

– Salt content can considerably be reduced by the planned quantity of leaching water even if the water in the wadi has high EC values (6.00 mS/cm).

In uncovered soils water loss due to evaporation is very high. Saline water rises to the surface by capillarity where it precipitates and increases the salt content. Insufficient water quantities can even induce salt accumulation in the root zone.

Testing soil profiles

Changes in salt content were studied in 2 soil profiles before and after leaching (Figure 1). In both profiles (L and R) the decrease in salt content was the highest in layer A (silty sand), which was exposed to the highest leaching water dose. Considerable decrease in salt content was also found in layers B and D,

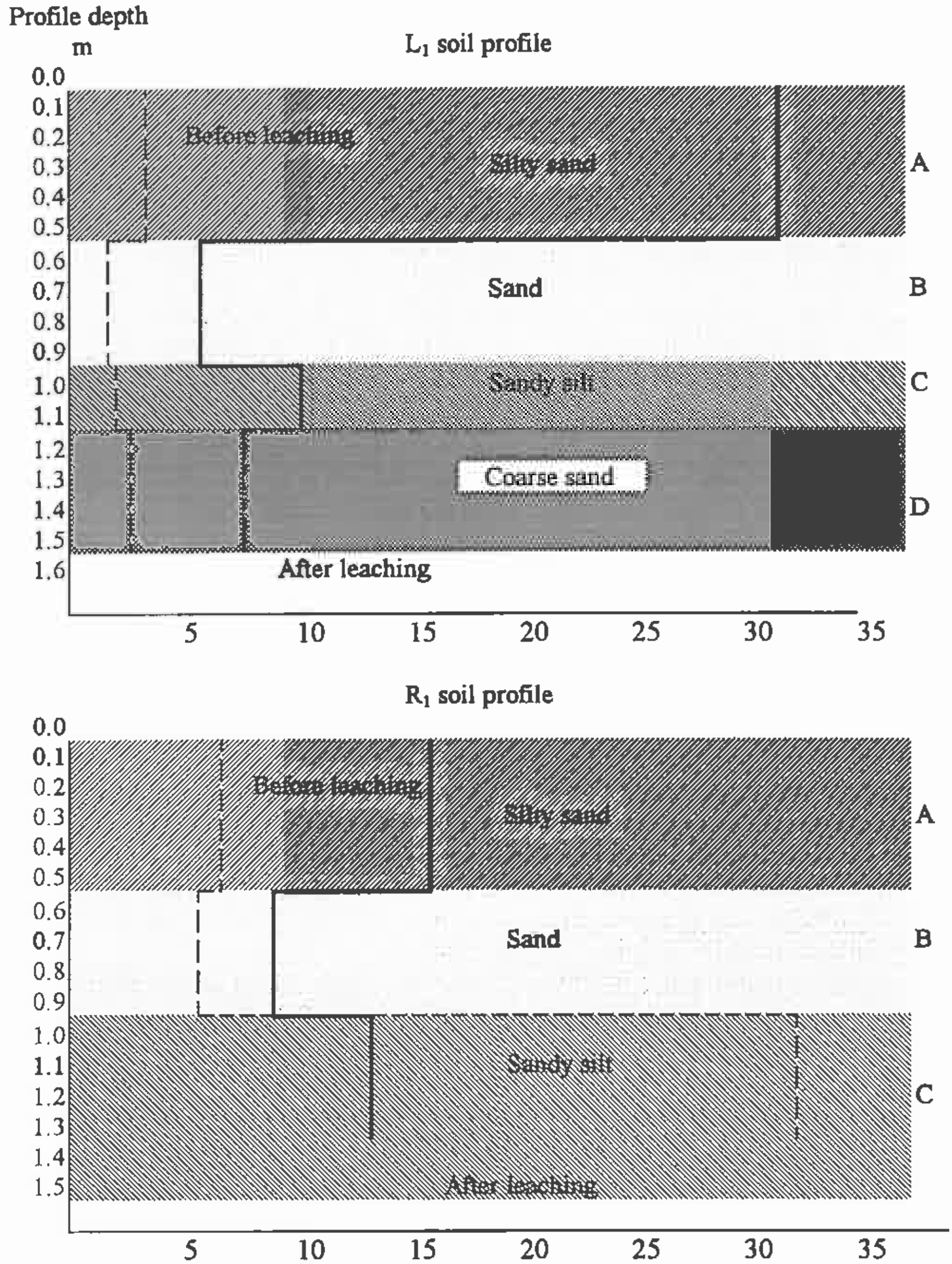

Figure 1

Changes in salt content in the different soil texture layers of L_1 and R_1 soil profiles before and after leaching

composed of fine or coarse sand, respectively. Soils of such texture have the highest water conductivity capacity and, thus, despite their high EC and salt content they can easily be leached with sufficient irrigation water.

In plot L the water dose of 500+500+200 mm was applied in such a way that the soil was not allowed to dry out after the infiltration of the first dose, to increase the efficiency of leaching. In this soil profile (L) salt content decreased more significantly within the whole profile, than in profile R. In layer C of the latter, salt accumulated instead of being leached: 800 mm water was insufficient to leach the whole profile and, thus, the salt content increased in layer C with a sandy silt texture. In addition, layer C of profile R was 0.6 m thick as compared to profile L in which it was only 0.2 m. In this plot the planned irrigation water quantity (200 mm) was increased by 20%, following calculations in Final report on Soil Survey (1984). As a consequence, the salt content dropped to 0.01-0.05% in the whole profile.

In plot R the 800 mm water dose was only effective in the upper 0.9 m layer. The planned water quantity should be given, completed with 20% of the calculated dose, so as to ensure the downward movement of the solution during flooding.

Water infiltration was prevented/limited in the upper layers containing a higher amount of finer particles. Water conductivity was also decreased in layer C of buried sandy silt, probably as a result of the peptization effect of Na^+ ions in the profile. Therefore, in soils with high salt contents (EC 10-15 mS/cm or higher values) or with silty sand, sandy silt or finer clay fractions, the impermeable layers must be broken up or loosened mechanically.

It should be mentioned that the 4 drain pipes placed 30 m apart in plot L proved to be more efficient than the drain spacing of 50 m in plot R, and layer D had, due to its coarse sand content, a very high hydraulic conductivity. This fact, however, makes the use of drain pipes questionable. About one quarter of the applied water quantity flowed through the drain pipes and the other part through the coarse sand texture of layer D.

Desalinization was performed before the flood of the wadi when its EC varied between 6.01 and 6.21 mS/cm. The wadi contained 600-800 ppm soluble salts of chloride sulphate composition In the course of leaching there was a three-fold increase in the salt content of the drained water (Final Reports on Soil Survey (1984) and on Agro-pedology, (1990)). The salt content of the wadi decreased to 25% of the original during the flood period (EC = 1.48 mS/cm) and increased again to 6.00 mS/cm later.

Table 2 shows the chemical analysis of irrigation water samples. The HCO_3^- content was negligible, but Na^+ and Cl^- contents were very high.

It can be said that the water in the wadi is favourable for desalinization and drainage (Final Reports on Soil Survey (1984) and Agro-pedology (1990)) as well as for irrigation especially at the time of floods or shortly after. The cultivation of salt sensitive crops is, however, not recommended as the water is only adapted to irrigation for 1-2 days.

Table 2
Data for calculating leaching requirement

Required depth of desalinization (m)	Original soil salt content (%)	EC in saturation extract (mS/cm)								
		4			8			12		
		Saturation percentage (SP %)								
		25	37.5	50	25	37.5	50	25	37.5	50
		Required salt content (%)								
		0.08	0.11	0.15	0.15	0.22	0.31	0.23	0.33	0.46
0.30	0.1-0.5	350	300	250	250	200	150	200	100	-
	0.5-1.0	450	400	350	350	300	250	300	250	200
	>1.0	600	550	500	450	400	350	450	350	300
0.50	0.1-0.5	600	500	400	400	300	200	300	200	-
	0.5-1.0	800	700	600	600	500	400	500	400	300
	>1.0	1000	900	800	800	700	600	700	600	500
0.6-1.00 m ≥ 0.1		600	600	500	500	400	300	400	300	250
1.00	0.1-0.5	1200	1000	800	800	600	400	600	500	400
	0.5-1.0	1500	1400	1200	1200	1000	800	1000	800	600
	>1.0	1900	1800	1600	1600	1400	1200	1400	1200	1000

Fertilization and production systems

Climatic conditions, the production level, the nutrient requirement of crops, yield, properties and nutrient supply of the saline soil were considered.

Irrigation can affect cultivation both positively and negatively. Desalinization succeeded by intensive irrigation can promote degradation of the soil aggravated by the fact that a regulated wadi will not deposit silt fractions rich in fine particles. The production level can only be increased by proper crop rotation and cropping pattern, adequate nutrient supply and regular irrigation.

Several production systems could be introduced at the same time.

Intensive vegetable growing

Intensive growing can be recommended in areas where vegetables (such as okra, watermelon) used to be grown, mostly on fluvisols with good drainage and close to the wadi where fine silt particles are mixed with sand. Their salt content and water retention capacity are favourable.

On test areas with drainage, where leaching can easily be performed, fruits (lemon) can also be grown. Tomato, local pointed hot peppers, onions, eggplants, sweet potatoes, okra and sesame can be cultivated successfully.

Traditional cultivation

In traditional cultivation of sweet melon and watermelon the area is flooded with 250-300 mm water. After infiltration, seeds are sown by hand on the properly wet surface and are poorly covered. The soil surface is left unsmoothed to prevent wind erosion. Watermelon has a 8-10 t/ha potential yield, however, only 4-5 t/ha are harvested. Yield is reduced by the high salt content of the soils and by virus diseases due to the neglect of rotation and other circumstances.

In watermelon cultivation the salt content of soils was frequently as high as EC 2-4 mS/cm (1:2) 25 °C; actually, EC of 11.31 and higher values were also found where crop development was poor but still acceptable.

On areas under cultivation 300 mm irrigation water was applied, which is only sufficient to leach the arable upper 30 cm layer. If no further irrigation is applied the capillary transport of water that satisfies the water requirement of watermelons – taking 10 t/ha average yield – during the vegetation period will also transport considerable amounts of soluble salts to the upper soil horizon. So it is easy to understand that traditional cultivation methods are not harmful, they can even be economic under given conditions. Even after one flooding saline soils are capable of storing sufficient water for several growing cycles. They used to be supplied with silt by the wadi and with salt by the sea. During floods the water in the wadi becomes 2-4 times more diluted than the 6.04-6.21 mS/cm EC value which is ideal for leaching.

The traditional methods are acceptable in the cultivation of sweet melon and watermelon, which are the most reliable horticultural crops. In intensive sweet melon and watermelon cultivation the nutrient supply must be guaranteed. The variety Charleston – tolerant to Anthracnose and Fusarium – is recommended with sowing at the end of August, beginning of September or February.

Spate irrigation method

In this irrigation method water is led from one plot to the other by means of level differences. Sorghum, Sudan grass, millet, cotton, Alexandria clover seem to be economic as they can be flooded even during their growing periods. This is not possible in the case of melon.

Fertilization

Data from the Final Report on Soil Survey (1984) and own research were used to calculate soil nutrient supplies of the soils with low humus content and moderate P_2O_5 and K_2O contents.

The available nutrient content of the soil and the expected yield helped us to determine the nutrient requirement of crops. Generally, one third of K and P quantities are incorporated and two thirds of N are applied as topdressing.

In traditional watermelon and sweet melon production with no irrigation during the growing period, N is spread after leaching on the wet surface and is incorporated with the seed.

In flooded horticultural crop production one or two topdressings are given. N is easily leached by irrigation water. Okra developed more vigorously in flooded plots at the foot of ridges (EC 3.27 mS/cm) than in the center of the plot (EC 1.75 mS/cm), as less leaching of nutrients was observed on ridges (CSERNI, 1991).

In light textured saline soil yield is limited – in addition to water – by extreme N deficiency. A higher yield level requires nutrient supplies because leaching decreases not only the harmful salt content but the amount of useful nutrient elements as well. In sandy soils poor in nutrients and colloids, P migrates even without irrigation (CSERNI, 1984). In irrigated cultivation P movement must also be considered in addition to K and N. N supply (besides K and P) is necessary, depending on the available nutrient content of the soil, the nutrient requirement of crop and expected yield.

Economic cultivation is aimed at, which motivates traditional production completed with legume fodder plants, like Alexandria clover and alfalfa. In this way the N balance, the structure and water storing capacity of the soil can be improved and legumes rich in proteins can increase the number of livestock which, in turn, results in more milk and meat. The stable manure obtained by this means would also favour intensive horticultural production by improving the nutrient content, structure and regime of saline sandy soils.

Summary

The efficiency of leaching was studied under arid conditions in Yemen in 1990 in order to promote irrigated vegetable and plant production.

In the tested saline sandy soils leaching efficiency depended on the salt distribution in soil layers of different texture, on the quantity and quality of leaching water, on the hydraulic conductivity of the soil and on the depth of the water table.

In areas not irrigated previously a single irrigation water dose of 300 mm decreased EC values slightly in the upper soil layer. The salt content, however, decreased by half if leaching water was applied in two doses (800 mm). Leaching efficiency was increased by applying the second dose on a wet surface.

The calculated water quantity (500 mm + 500 mm + 200 mm) was sufficient to leach to a 1 m depth.

Subsoil drain pipes increased leaching efficiency, but drainage seemed to be the most sufficient when drain spacing was 50 m.

It is advisable to execute leaching at flood times when abundant, diluted water of good quality (EC = 1.48–2.94 mS/cm) is available. The water in the wadi can be used for leaching and salt transport as well.

The leaching, draining of irrigation water into canals and regulation of the water table decrease the risk of secondary salinization.

Intensive vegetable production of okra, eggplant and onion is only recommended in leached fluvisols. Leek, tomato, sweet potato, local pointed hot pepper, watermelon, sweet melon and in rotation, sesame, Egyptian clover and alfalfa could be grown. Vegetable crops which are sensitive to salts (cucumber, sweet pepper) are not recommended because of the high salt content of the soil and water.

Traditional water and sweet melon production must not be neglected as no drastic salt content decrease can be expected in the upper layers in spate irrigated areas. The higher salt concentration is also to store and bind moisture during the growing period.

Soil conservation would require special agrotechnics for sandy soils. The stubble and root residues of melilot should be ploughed in and the green parts used for fodder. In this way the N balance, the structure and water storing capacity of the soil can be improved and legumes rich in proteins (melilot, Egyptian clover, alfalfa) can increase the number of livestock which, in turn, result in more milk and meat. The stable manure obtained in this way, would also favour intensive horticultural production by improving the nutrient content, structure and water regime of saline sandy soils.

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