Hydro-salinity balance to monitor soil salinity at field scale due to brackish irrigation water

Libutti A., Florio M., Monteleone M., Disciglio G., Tarantino E.

in

Santini A. (ed.), Lamaddalena N. (ed.), Severino G. (ed.), Palladino M. (ed.).
Irrigation in Mediterranean agriculture: challenges and innovation for the next decades

Bari : CIHEAM
Options Méditerranéennes : Série A. Séminaires Méditerranéens; n. 84

2008
pages 301-310

Hydro-salinity balance to monitor soil salinity at field scale due to brackish irrigation water

A. Libutti, M. Florio, M. Monteleone, G. Disciglio, E. Tarantino

Department of Agro-Environmental Science, Chemistry and Plant Protection
Agriculture University of Foggia, Italy

Abstract. A "hydro-salinity balance" could be considered as an objective method to detect salt increase into the root soil layer due to brackish water irrigation.

A permanent experimental field-unit was established in autumn 2006; three plots of 100 m^2 each (6.4 x 15.6 m) were delimited; at the center of each plot an artificial draining basin was arranged digging the soil out of a trench, 3.2 m wide, along the entire plot length; the bottom of each trench was covered with a plastic sheet in order to prevent water percolation; a set of drains (two groups per trench, three drains per group) were displaced over the plastic cover to collect the percolating water and conveying it into thanks placed at the edge of each plot (two thanks per plot). The trenches were then filled with the same soil obtained by the excavating procedure, trying to correctly reproduce the original soil stratification.

In this very first cropping season (summer 2007) the aim of the trial was to detect the risk of soil salinity build up due to the ordinary irrigation practice applied by the farmer, according to the real context of a farm of the Apulian Tavoliere, close to the coast of the Manfredonia gulf (Adriatic sea), where brackish irrigation is a diffused and frequent practice due to seawater intrusion into the groundwater.

Tomato was transplanted on 20 April and harvested on 26 July. The electrical conductivity of the irrigation water (ECi) increased from 4.7 to 5.3 dS m^{-1} along the crop cycle. Soil ECe (electrical conductivity of soil saturated water extract) was periodically measured (approximately every 10 days) by soil samplings.

Seasonal farmer irrigation was 544 mm while rain amounts were equal to 117 mm; thus the total water supply was 661 mm. Along the crop cycle, an increasing soil salinization occurred, starting from a value of 2.4 dS m^{-1} up to a maximum value of 6.6 dS m^{-1}. Due to leaching, at harvest the soil ECe decreased to an average value of 4.8 dS m^{-1}. Approximately, a 25% of yield reduction was recorded as compared to contiguous field irrigated with good water quality. The irrigation water supplied by the farmer exceeded the plant water consumptions, particularly in the closing part of the crop cycle, thus producing drainage that, on average, was equal to 61 mm. A leaching fraction of approximately 10% resulted from the water balance while almost the 20% of salt was removed from the soil profile with respect to the salt load bring about with irrigation. That means an actual leaching efficiency of approximately 220 kg ha^{-1} per each percent point of leached water.

Keywords. Soil salinity – Salt balance – Brackish irrigation – Drainage water – Salt leaching – Tomato.

L'utilisation du bilan hydro-salin pour le contrôle de la salinité du sol dûe à l'usage de l'eau d'irrigation saumâtre

Résumé. *Le bilan hydro-salin pourrait être considéré comme une méthode directe pour détecter les conditions qui causent l'augmentation de la salinité de la zone racinaire. Un champ expérimental permanent a été établi en automne 2006; trois parcelles de 100 m^2 chacune (6.4 x 15.6 m) ont été délimitées; au centre de chaque parcelle un bassin de drainage artificiel de 3.2 m de large a été construit tout au long de la parcelle; le fond de chaque tranchée a été couvert par des feuilles de plastique pour prévenir l'infiltration de l'eau ; un ensemble d'égouts (deux groupes par tranchée, trois égouts par groupe) a été installè sur l'abri en plastique pour rassembler l'eau stagnante et la véhiculer dans des canaux placés au bord de chaque parcelle (deux canaux par parcelle). Les tranchées ont été remplies, alors, du même sol obtenu par excavation, en essayant de reproduire correctement la stratification du sol original .*

Dans cette première saison de récolte (été 2007), le but de cet essai, donc, était de détecter le risque de la formation de la salinité du sol due à l'irrigation ordinaire pratiquée par l'agriculteur et où l'usage de l'eau d'irrigation saumâtre est assez répandu et fréquent dans les domaines agricoles de la région Puglia-Tavoliere (Sud de L'Italie), près de la côte du golfe de Manfredonia (mer adriatique). Celle-ci est caracterisée par l'infiltration de l'eau de mer dans l'eau du sous-sol.

La tomate a été transplantée le 20 avril et a été recoltée le 26 juillet. La conductivité électrique (CE) de l'eau d'irrigation a augmenté de 4.7 jusqu'à 5.3 dS m^{-1}. ECe du sol a èté périodiquement mesuré (approximativement chaque 10 jours) grâce à des prélèvements d' echantillons du sol.

L'approvisionnement de l'eau d'irrigation totale était de 661 mm (544 mm d'eau d'irrigation et 117 mm d'origine pluiviale). La salinité du sol est augmentée au fur et à mesure du cycle de la culture, débutant d'un minimum de 2.4 dS m^{-1} et arrivant jusqu'à une valeur maximale de 6.6 dS m^{-1}. A cause du lessivage et pendant la récolte, la Ece du sol, a diminué pour une valeur moyenne de 4.8 dS m^{-1}. Approximativement 25% de réduction du rendement a été enregistré en comparaison avec un champ adjacent irrigué avec de l'eau de bonne qualité . L'eau d'irrigation fournie par l'agriculteur a dépassé la capacité de consommation de la plante, en particulier à la fin du cycle de la culture, en produisant un drainage équivalent à une moyenne de 61 mm. Approximativement 10% de lessivage s'est produit dû à l'equilibre hydrique tandis que 20% des sels ont été éliminés du profil du sol vis à vis du sel apporté par l'eau d'irrigation. Cela implique un lessivage réel d'approximativement de 220 kg ha^{-1}.

Mots-clé. *Drainage – Bilan hydro-salin – Irrigation saumâtre – Salinité du sol – Lessivage.*

I – Introduction

Salinity is of great concern in all the irrigated agricultural areas of arid and semi-arid climate because of the limited contribution of rainfall to soil leaching and the often poor quality of water available for irrigation. This is particularly true along the coastal areas of the Apulian region (South Italy) where shortages in water availability are often recurring and brackish water is ordinarily exploit to manage crop irrigation (Monteleone *et al*., 2006).

The risk related to a long-term use of this low quality irrigation water is extremely emphasized when an intensification in the farming systems occurs; the change from a fallow-wheat system, with an intermittently irrigated summer-crop, to a continuous sequence of irrigated horticultural crops, highly increases the overall yearly salt load on the soil and decreases the possibility to benefit of the autumn-winter rainfalls (typical of the Mediterranean kind of climate) in order to promote salt leaching from the soil.

However, in order to broaden water availability, there is today a general consensus (Rhoades *et al*., 1992; Hamdy, 1994) about the opportunity to use irrigation water of higher salinity then those which were strictly classified as suitable, for instance according to the U.S. Salinity Laboratory (1954). The re-examination of those traditional standards implies the considerations of several factors influencing soil salinity besides water quality and pertaining to soil characteristics as well as crop or variety tolerance traits and, most important, irrigation management. The combination of all such issues allows to considerably relax the conventional, too restrictive, guidelines.

Irrigation and drainage are essential to control soil salinity due to irrigated agriculture in arid and semi-arid environments. The detection of the salt amounts brought into the soil by brackish irrigation water and that removed by drainage, accurately accounts for salt loads and soil salinity build up. Therefore, a "hydro-salinity balance" could be considered as the only direct method to assess the conditions that cause salt increase into the root soil layer and check the trend of soil salinity along time. Unfortunately, the performance of this balance is not straightforward and could be out of the reach of the single farmer. Indirect and simple method to estimate soil salinity hazard and forecast soil salinization under definite cropping conditions are hence needed.

The two contrasting features of the problem are the following: irrigation is essential to reach a proper crop yield and drainage is also needed in order to leach the salts away from the crop soil profile, but leaching only occurs when extra-irrigation volumes are delivered, thus also increasing the overall salt amount brought into the soil and the threat of salt accumulation.

Soil salinity does not reduce crop yield significantly until a threshold level is exceeded; beyond this threshold, yield decreases almost linearly with respect to soil salinity (Maas and Hoffman, 1977), generally measured as electrical conductivity of the soil saturation water extract (ECe). To avoid yield loss when salt concentration exceeds the crop tolerance limit, a water leaching requirement (LR) must be applied to the ordinarily irrigation (I), approximately equal to the ratio between the electrical conductivity of the irrigation water (ECi) over the electrical conductivity of the drainage water (ECd) above which yield reduction occurs. This simple relation does not take into account the dilution effect carried out by the rain precipitations (P) eventually registered along the irrigation season; thus (assuming that ECd = 2 ECe) the complete relation is:

$$LR = \frac{I}{I+P} * \frac{ECi}{ECd} = \frac{I}{I+P} * \frac{ECi}{2ECe}$$

How to fulfil this LR during the irrigation season is a question of optimization that pertain to the irrigation scheduling. There are evidences suggesting that the best scheduling consisting in a limited number of irrigations while using larger application volumes (Crescimanno and Garofalo, 2006; Shalhevet, 1984); this criterion is in contrast with what has long been assumed: more frequent irrigations reduce the effect of salinity as a consequence of a higher soil water content that partly decreases the osmotic potential able to limit the soil water uptake by the crop. The consideration that both water soil evaporation (E) and plant transpiration (T) tend to concentrate the salts on the upper soil layer when they are frequently wetted explains why frequent irrigation may produce a negative effect.

In the frame of a long-term trial, this work is aimed to detect the build up of soil salinity along the course of the very first irrigation season carried out along a tomato crop cycle and on a soil initially affected by salinity problems to a limited degree only. The time trend of soil salinity was followed in order to detect the right time to start leaching according to the crop tolerance characteristics; the final soil salinity level was also determined in order to account the effect on the subsequent crop; moreover, the actual leaching ratio and its efficiency was calculated with respect to soil texture and irrigation frequency.

II – Materials and Methods

The experimental trial was carried out in a field 15 km apart from the coast of the Manfredonia gulf (Adriatic sea), on a loam soil (sand 45.8%; silt 34.3%; clay 19.9%), with an organic matter content equal to 1.6%; a total N content of 1.08 ‰ and a P_2O_5 content of 62.4 ppm. The field water capacity (-0.03 MPa) was equal to 29.9% d.w. and the wilting point (-1.5 MPa) equal to 17.4% d.w. Furthermore, the soil pH was of 7.6 and its ECe initial value was approximately equal to 2.45 dS m^{-1}.

In the preceding autumn 2006 a permanent experimental set-up was arranged. It consisted of three adjacent and identical plots of 100 m^2 (6.4 m wide and 15.6 m long).

At the center of each plot an artificial draining basin was arranged. It was obtained by digging the soil out of a trench of 50 m^2 (3.2 m wide and 15.6 m long), covering the bottom of each trench with a plastic sheet in order to prevent water percolation and displacing a set of drains (two groups per trench, three drains per group) over the plastic cover in order to collect the percolating water.

Each set of drain was connected to a tank placed at the edge of the plot (two tanks per plot) in order to drain away the percolating water, whenever the drainage occurred.

Finally, the trenches were filled with the same soil obtained by the excavating procedure, trying to correctly reproduce the original soil stratification.

This experimental set-up mimics the condition of a shallow water table (0.7 m of depth); in our intention, it will be used over a long period of time, allowing the performing of hydro-salinity balance over several cropping seasons, in order to check the effect of brackish water irrigation on soil salinity and outline the criteria to optimize the management of irrigation and drainage, according to the general aims of the CLIMESCO Project (*).

The seedlings of the processing tomato cultivar "*Perfect Peel*" were transplanted on 20 April 2007 and the fruits were harvested on 26 July 2007.

Prior to tomato transplanting, the soil was harrowed to a depth of 0.40 m and fertilized with 100 kg ha^{-1} of P_2O_5.

The plants were displaced in the field according to coupled-row arrangement, 1.60 m apart one to another while the distance between each single row was 0.40 m; the plants were 0.40 m apart along the row; an overall plant density of approximately 31,250 plants ha^{-1} was thus established.

All the cropping operations were carried out according to the ordinary farming techniques of the surrounding agricultural area without any significant differences with respect to what a common farmer would performed.

Fertilization and ferti-irrigations were performed during the crop cycle, according to the growth dynamic, supplying a total amount of 100 kg ha^{-1} of N; 35 kg ha^{-1} of P_2O_5 ; 50 kg ha^{-1} of K_2O; besides proper microelements amounts such as Ca and Mg.

Weeds and pest controls were performed during the cropping season according to currently management practices.

It is worth to remind that the irrigation scheduling (times and volumes of crop water supply) was entirely in charge of the farmer who had the task to perform irrigation according to his own technical decision criteria.

A drip irrigation system was set-up; every dripping line was displaced at the centre of each coupled-row with the dripping points placed 0.40 m apart along the line and a water capacity of 3 l h^{-1}. A water flow meter was placed at the head of the irrigation system to accurately measure the amount of irrigation water supplied.

A weather station was positioned in the experimental field in order to hourly record the meain meteorological variables such as air temperature (°C), relative air humidity (%), wind speed (m s^{-1}), rains amount (mm) and incident solar radiation (W m^{-2}) according to standardized criteria.

The crop growth was detected through a periodical sampling of 12 plants from each plot, approximately every 10 days; the measure of leaf area index (LAI), fresh and dry weight (g m^{-2}) of the plants, partitioned in stem, leaf and fruits, as well as of the root depth (m) was carried out.

The electrical conductivity of the soil saturation water extract (ECe – dS m^{-1}) was periodically measured through soil sampling (approximately every 10 days), at three different depth (0.20; 0.40; 0.60 m) and in four repetitions, in correspondence to two different characteristics points of the experimental plot, respectively inside and outside of the coupled row of tomato plants.

The electrical conductivities of the irrigation water (ECi – dS m^{-1}) as well as of the collected drainage water (ECd – dS m^{-1}) were periodically measured, together with their volumes.

With respect to each plot of the experimental set-up, a long-term experimental irrigation treatment was assigned, according to the following criteria:

L0 – control – brackish groundwater was supplied at each irrigation and no leaching requirements was fulfilled during the crop cycle but, eventually, only after the crop harvest, in case a critical soil ECe threshold was exceeded;

L1 – brackish leaching – brackish groundwater was supplied at each irrigation but the leaching requirements was timely fulfilled both during the crop cycle or after the crop harvest whenever a critical soil ECe threshold was exceeded;

L2 – limited fresh water availability – irrigation was ordinarily performed with brackish water but a limited amount of good quality water (200 mm as a maximum) was available in order to irrigate the crop at some critical phenological stages (establishment, flowering, fruit set-up, etc.) or eventually to perform leaching whenever a critical soil ECe threshold was exceeded both during the crop cycle or after the crop harvest.

With reference to the tomato crop, the critical ECe threshold value was fixed at 5 dS m^{-1}, corresponding to an estimated 25% of reduction in tomato yield according to the model of Mass and Hoffman (1977); the yield reduction was determined with respect to the tomato potential yield in case a good quality water was used for irrigation.

Daily ETc was estimated according to the evapotranspiration method and the "two step approach" ($ETc = ET_0 * Kc$); reference evapotranspiration (ET_0) was calculated using the Monteith's equation (Allen *et al*., 1998) from the meteorological data collected during the trial.

The restoring of the ETc is arranged each time the depletion of the available water reached the threshold value of 40%. The water balance was daily updated in order to theoretically schedule the time and volume of irrigation and comparing them with the actual irrigation performed by the farmer.

Only the data pertaining the soil and water salinity and the water balance along the tomato crop cycle are presented and discussed in the paper.

III – Results

The actual seasonal water supply performed by the farmer was equal to 544 mm; this total water irrigation high was reached with 22 irrigations all over the crop cycle, from transplanting to harvest, corresponding to an average irrigation volume of approximately 25 mm.

Several rainfalls occurred during the tomato crop cycle even though they were gathered in the first half of the cropping season only while the second half was completely dried. The total rain amount was equal to 117 mm.

Considering altogether the artificial (irrigations) and the natural (rains) water supply, the tomato crop availed of a total water amount equal to 661 mm.

A seasonal irrigation equal to 424 mm was calculated based on the water balance book keeping, a value significant lower than the value actually supplied.

The comparison between the cumulated values of the calculated irrigation heights and those actually applied by the farmer along the crop cycle is showed in Figure 1.

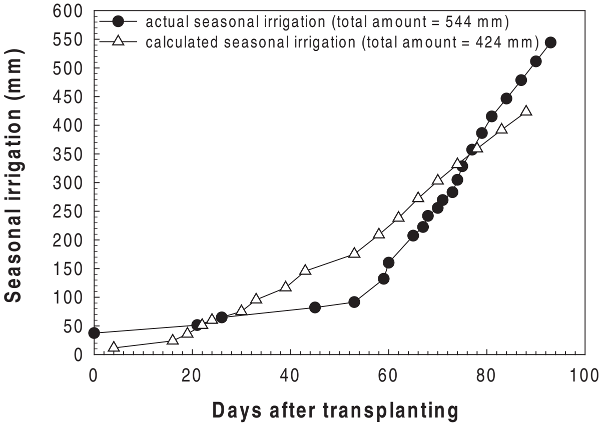

Figure 1. Calculated and actual seasonal irrigation during the tomato crop cycle.

It is easy to observe, from Figure 1, a general lower amount of the actual water availability as compared with that theoretically determined, specifically in the central part of the crop season.

It's worth to say, however, that in no way the crop experienced water stress and, according to farmer's opinion, a less frequent irrigation in the first part of the season is generally performed in order to promote root deepening and achieve a better capacity to exploit water by the crop in the deeper soil layers.

In the third part of the season the frequency of irrigations increased a lot thus exceeding the expected crop needs and generating plentiful drainage (Figure 2).

In response to brackish irrigation, soil salinity rapidly grew up (Figure 2); an increase in soil salinization was recorded during the first thirty days after transplanting, from a value of 2.4 dS m^{-1} up to a value of 3.6 dS m^{-1}.

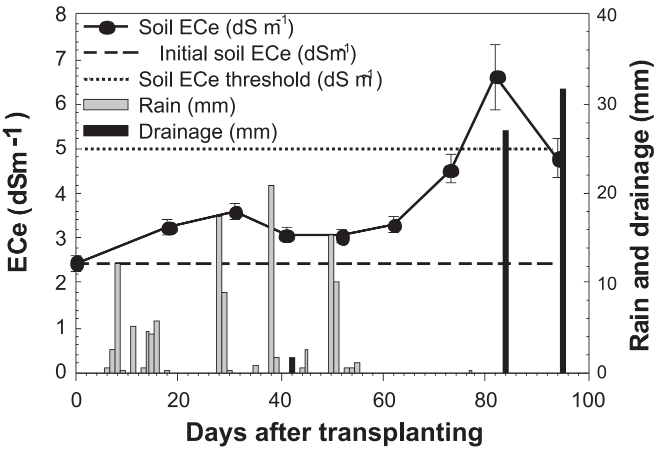

Figure 2. Average electrical conductivity of the soil saturation water extract (on the left axis), rain and irrigation water contributions to the crop (on the right axis), during the tomato cropping season

In the middle part of the cropping season frequent and abundant rains occurred determining a limited but important drainage event, on average equal to 2 mm; due to soil leaching and drainage a limited ECe decrease was observed along the active soil layer.

In the third part of the cropping season ECe rose up again, reaching the maximum value of 6.6 dS m^{-1}, thus overcoming the prefixed critical ECe threshold.

But at the end of the cropping season, approximately ten days before harvest, the frequent irrigations supplied by the farmer largely exceeded the crop water consumptions, thus producing a very copious drainage.

The drainage water was collected twice and, on average, their amounts were equal to 27 and 32 mm respectively. Due to leaching, at harvest, the soil ECe significantly and rapidly decreased to an average value of 4.8 dS m^{-1} (Figure 2).

With the increasing ECe values along the crop cycle, also their variability (standard error of the mean) increased (Figure 2); this was due to the progressively larger differences detected between the ECe value measured on the soil sampled along the dripping line as compared to the soil sampled far apart from that line; the former displayed higher salinity values while the latter significantly lower values. This remarkable spatial differences are directly related to the drip irrigation method applied.

The three irrigation experimental treatments defined for the long run were not applied during this first and short trial; this was due to the purpose to follow the farmers ordinary irrigation management but also because the fixed ECe threshold value was reached only at the end of the cropping season, when the crop was not particularly vulnerable to salinity; moreover, non-intentional leaching actually occurred due to farmers behaviour.

Approximately, a 25% of tomato yield reduction was recorded as compared to the contiguous fields of the farm which were irrigated exactly with the same amount and the same frequency but with good water quality.

In the course of the trial, the EC value of the irrigation water (ECi) progressively increased, from 4.7 to 5.3 dS m^{-1}. This was probably due to the generalized and overwhelming use of the ground-water resources to allow summer-crop irrigation and the consequent lowering of the water-table and the pumping out of the heavier and deeper salty water.

The hydro-salinity balance was performed by measuring the volume, salt concentration and salt mass of the water input (irrigation) and output (drainage). Table 1 shows the key variables, the terms of the balance and some important derived performance parameters.

Table 1. Components and derived indexes of the hydro-salinity balance

Parameters	Units	Code	Formula	Average	St. err.
Water balance					
Seasonal irrigation	$m^3\ ha^{-1}$	I	measured	5442	-
Seasonal rain amount	$m^3\ ha^{-1}$	R	measured	1166	-
Seasonal water supply	$m^3\ ha^{-1}$	W	I+R	6608	-
Seasonal drainage	$m^3\ ha^{-1}$	D	measured	605	± 10.89
Leached water fraction	%	LF_W	D/W	9.16	± 1.65
Salt balance					
Irrigation added salts	$t\ ha^{-1}$	S_I	measured	10,80	-
Drainage leached salts	$t\ ha^{-1}$	S_D	measured	1.93	± 0.37
Salt loading	$t\ ha^{-1}$	S	$S_I - S_D$	8.88	± 0.37
Leached salt fraction	%	LF_S	S_D / S_I	17.98	± 3.43
Loaded salt fraction	%	SF	S / S_I	82.02	± 3.43

The overall leached water fraction (LF_W) was the result of the ratio between seasonal drainage (D) and total seasonal water supply (I plus R); it reached approximately the value of 10%. This value can be considered relatively small compared to the high electrical conductivity of the water employed for irrigation (ECi). It must be considered, however, that the soil was almost free from salts at the beginning of the trial so that the performing of leaching would be really justified only at the end of the irrigation season.

With reference to the salt balance, the overall leached salt fraction (LF_S), resulted from the ratio between drainage leached salts (S_D) and irrigation added salts (S_I), was almost equal to 18%; it means that the 18% of the salt load bring about with brackish irrigation was removed from the active soil layer while the remaining 82% accumulated in it and gave rise to soil salinity.

The net salt loading S (t ha^{-1}) as well as the leached salt fraction LF_S (%), were linearly related to the values of leached water fraction actually registered in the three experimental plot (with two replications per each plot) as graphically reported in Figure 3.

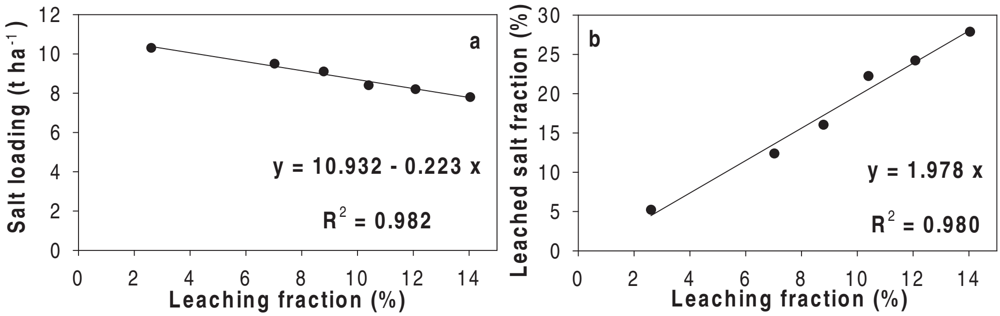

Figure 3. Salt loading (a) and leached salt fraction (b) as related to the leaching fraction with respect to the overall tomato crop cycle.

In both cases, the linear equation fitted the data very well (significantly high R^2 were obtained), pointing out the model suitability.

Quite obviously an increasing leaching fraction determined a decrease in the soil net salt loading. The intercept value of the equation line (Figure 3a) was equal to 10.9 that matched almost perfectly to the value of the irrigation added salts (S_I).

The slope of the same line equation expresses the actual leaching efficiency gained during the irrigation season; it was equal to 223 kg ha^{-1} per each percent point of leached water achieved. This value, if compared with homologous values from other experimental trials (Monteleone *et al.*, 2004; 2006) seems to be relatively lower; it must be considered, however, that this was an open field experiment while the others were all carried out in glasshouse were single tomato plants were cropped into cylindrical polyethylene containers (lysimeters); another important consideration pertain to the value of the total irrigation added salts: the higher this value the higher the value of the leaching efficiency; since the former value is quite low as compared to the preceding experimental trials, also the latter showed a lower level.

The leached salt fraction (%) showed to have almost a doubled value than the leached water fraction (%) as proved by a slope coefficient of the line equation equal to 1.98 (Figure 3b). The drainage water that leached the soil profile, therefore, was able to drag along and carry out a greater proportion of salts with respect to water; the value registered in this trial was consistently similar to those from other experiments, thus indicating that the model whose coefficients are expressed in relative terms can be of more general application.

IV – Conclusions

Based on the experimental data collected during the trial and previously outlined, it is possible to trace out some schematic remarks:

– the present work was not other than the starting trial in the frame of a long-term experiment aimed to check soil salinity with respect to farmer irrigation management and the role played by autumn-winter rains to promote salt leaching;

– soil salinity is a fast growing process and only one irrigation season could be sufficient to reach ECe value able to hamper soil productivity, taking account of the irrigation water quality and the seasonal irrigation volume (i.e. the total salt load);

– the rains eventually occurring along the season showed to be very effective in the delay of the soil salinity build up, even if of limited amounts; that was observed in the first part of the tomato cropping cycle;

– a non-intentional leaching occurred at the end of the crop cycle due to much frequent irrigations; this extra-water supply succeeded in partially removing the cumulated salts, significantly reducing the soil ECe;

– therefore, leaching showed to be effective but its efficiency increased from low to high soil salinity content; this confirms to apply leaching only when soil salinity reached a threshold level, particularly when the irrigation water quality is poor;

– the salt balance patently closed with a net salt load but without leaching the ECe end point should be very dangerous and potentially able to impair soil productivity in the succeeding cropping seasons;

– crop yield was only limited affected by the salts demonstrating the possibility to actively employ this poor quality water resource in order to broaden irrigation water availability and generally improve the productivity of a rural area, on condition that a proper technical skill is acquired by farmers.

References

Allen, G.R., Pereira, L.S., Raes, D., Smith, M., 1998. *Crop evapotranspiration. Guidelines for computing crop water requirements*. Rome, Italy: Fao. (Irrigation and drainage paper, 56). 300 p.

Crescimanno, G., Garofalo, P., 2006. Management scenario preventing salinization under irrigation with saline water. In: Ragab, R., Koo-Oshima S. (eds.). *Proceeding of the International workshop on environmental consequences of irrigation with poor quality waters*. *Kuala Lampur, Malaysia, 12 September 2006*. pp. 171-183. (ICID Publication, 86).

Hamdy, A., 1994. Saline irrigation management for a sustainable use. In: *VIII World Congress on Water Resources. Special Session: Irrigation network activities. Cairo, Egypt, November 21-25, 1994*. Valenzano: Iamb. pp. 1-45.

Maas, E.V., Hoffman, G.J., 1977. Crop salt tolerance. Current assessment. *J. Irr Drain Div*, 103, 1. pp. 115-134.

Monteleone, M., 2006. Problematiche della salinità nelle aree irrigue meridionali. *Ital J Agron*, 1. pp. 129-202.

Monteleone, M., Florio, M., de Simone, G., De Caro, A., 2006. Irrigation salinity scenario. A long term simulation on Mediterranean conditions. In: Proceedings of the IX Conference of the European Society of Agronomy. 4-7 September 2006, Warszawa (PL). *Bibliotheca Fragmenta Agronomica,* 11, 1. pp.175-176.

Monteleone, M., Gatta, G., Giuzio, L., La Rotonda, P., De Caro, A., 2004. Effect of leaching on salt accumulation in the soil under brackish water irrigation. In: Proceedings *International Workshop and Special Session on Management of poor quality waters for irrigation, Moscow, September 9-10, 2004*. ICID. pp. 102-112.

Rhoades, J.D., Kandiah, A., Mashali, A.M., 1992. *The use of saline waters for crop production*. Rome: FAO. (Irrigation and drainage paper, 49).

Shalhevet, J., 1984. Management of irrigation with brackish water. In: Shainberg, I., Shalevet, J. (eds.). *Salt salinity under irrigation. Processes and management*. New York: Springer Verlag, 298-318.

Richards, L.A. (ed.), 1954. *Diagnosis and improvement of saline and alkali soils*. Washington: USDA, Salinity Laboratory. (Agric. handbook, 60). 160 p.

(*) This work has been funded by Italian Ministry of Education, University and Research (CLIMESCO Project, D.D. 20/02/2006 n. 285)."