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in

Hamdy A. (ed.), Trisorio-Liuzzi G. (ed.).
Water management for drought mitigation in the Mediterranean

Bari : CIHEAM
Options Méditerranéennes : Série B. Etudes et Recherches; n. 47

2004
pages 205-218

Drought Mitigation: the Sustainable Use of Saline Water for Irrigation in the Mediterranean Region

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Abstract

The increasing constraint to adopt saline waters imperils soil fertility and as a consequence immediate and practical solutions are needed to secure the sustainability of the practice with an appropriate management. The principles to maintain a correct salt balance in the soils are reviewed and the need to jointly consider irrigation and drainage management as a single system is highlighted, emphasizing the role of rainwater in maintaining a favourable water and salt balance.

Examples are given of sustainable management under different representative conditions.

Introduction

The climatic changes which are taking place and the consequently increasing demand for irrigation water with the concurrent growing needs for domestic and industrial uses oblige farmers to employ ever more frequently waters of poor quality, well below the standards recommended when water was abundant.

The adoption of saline waters raises problems of agronomic, economic and environmental order, impacting the reduction in crop yields, soil fertility conservation and the protection of the aquifer: to find appropriate solutions to such complex problems scientists and researchers worldwide are engaged in investigations spanning from the chemistry of waters and soils to plant genetics, to soil and crops management, economics etc.

The challenge is not only to explore in depth every single aspect, but also to combine all such composite aspects into one single framework, in a system approach permitting a synthesis of the great advances of the last decades: a notable example is the model SALTMED worked out by a team of scientists and presented in a workshop in Cairo last

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December (Flowers *et al*., 2003; Ragab, 2003), combining in a holistic vision soil, crop and water management.

In order to obtain reliable results, as remarked in the course of that workshop, it is imperative that reliable inputs be supplied to the model and unfortunately this is not always the case: it has been demonstrated for instance that the so-called "threshold values" and the slopes of diminishing crop productivity with increasing salinity are a rough approximation at best (Continella *et al*., 2002) and that the so-called "crop coefficients" used to estimate water requirements in orange trees can be largely improved (Germana and Sardo, 2003), while researches are being conducted to better define the rather nebulous concept of the "permissible" electrical conductivity (EC) in drained water when determining the leaching requirement (Belligno, pers. com., 2004).

Furthermore, some practices suggested when using saline waters are intended to protect crops but fail to protect soil fertility in the long term and therefore they cannot be considered sustainable.

In the light of the above considerations it seems appropriate to give a close look to the principles underlying the sustainability of irrigation with saline water and review those agronomic practices which can safely and promptly be adopted for an immediate protection: in spite of the impressive progresses in the theory achieved in the last decades, in fact, "in many if not most developing countries the area adversely affected by salinity still increases faster than the rate at which affected land is being reclaimed" (Kijne *et al*., 1998) and it is important to avoid that in this case the popular sentence "while the doctor studies the patient passes away" be substantiated.

An Integrated Approach

It is well known that salinity build-up can depend (the cases of primary salinization are not considered here) on the use of saline waters, on seawater intrusion due to an excessively lowered water table or on too shallow water tables, as a consequence of poor irrigation/drainage management: it can be stated therefore that it depends in general on a mismanagement of the circulatory system in the soil body.

A really sustainable water management of irrigation and drainage must jointly consider in an integrated approach water and salt balance, taking the necessary steps to avoid any unbalance.

The well known equation for water balance is

$$P + I = O + D + E + T \pm \Delta\theta \qquad (1)$$

Where

P = precipitation

I = irrigation

O = overland flow

D = drainage (normally a loss, but can be a gain from upward flow)

E = evaporation

T = transpiration

$\Delta\theta$ = change in soil water content

Within the present context it is of interest to emphasize that when a fraction of D is a gain in the rootzone (this fraction of D will be symbolized as G in equation (2)), the value of I in equation (1) is proportionally reduced, P being constant. The units used can be various, but generally are mm month-1 or mm season-1.

The equation for salt balance, linked to equation (1), is

$$IC_i + PC_p + GC_g = DC_d \pm \Delta S \qquad (2)$$

Where

C = salt concentration

G = capillary flow from groundwater to the rootzone

D = deep percolation from the rootzone

ΔS = change in salt content in the rootzone

Subscripts *i*, *p*, *g*, *d* refer to salt concentration in irrigation, precipitation, drainage, deep infiltrated water, respectively; normally the value of C_p is extremely low.

Equation (2) neglects the amounts of salt absorbed by biomass (which often are not negligible, as we shall see later) as well as the impact of fertilizers, and although it is perhaps not always correct to assume that salt uptake by plants is more or less balanced by fertilizers, we can accept this assumption here as a first approximation.

In order to maintain conditions of equilibrium it is desirable to maximize the impact of P in equation (1), thus reducing the amount of I and consequently that of ICi in equation (2); one additional advantage of enhancing the value of P in equation (1) is that the contribution of rainfall to soil leaching is precious since it has a value not only depending on its volume but also on its low salt content and its relatively uniform distribution. In fact equation (3) commonly used for determining leaching requirement, LR, should be actually modified into equation (3 bis)

$$LR = \frac{EC_i}{EC_d} \tag{3}$$

$$LR = \frac{EC_{wa}}{EC_d} \times \frac{1}{\eta_{wa}} \tag{3 bis}$$

where EC_{wa} is the weighted average of electrical conductivity of irrigation water (EC_i) and rainwater and η_{wa} is the weighted average of the efficiency of both waters in leaching, normally very high in the case of rainfall with the exception of intense precipitations (EC_d symbolizes an ill defined value of drainage water electric conductivity and is not of interest here). The indications of equation (3 bis) confirm that rainfall water helps to reduce the value of LR acting in two senses, namely by reducing EC_{wa} and, particularly when water harvesting practices are adopted, also by enhancing η_{wa}.

It is interesting to note that the above equations implicitly assume steady state conditions in uniform, homogeneous soils, which is actually far from the reality, due both to the well known, high spatial variability of soils and to the variations in time of moisture and salt content, as depicted by figure 1, confirming that moisture and salinity must be jointly considered.

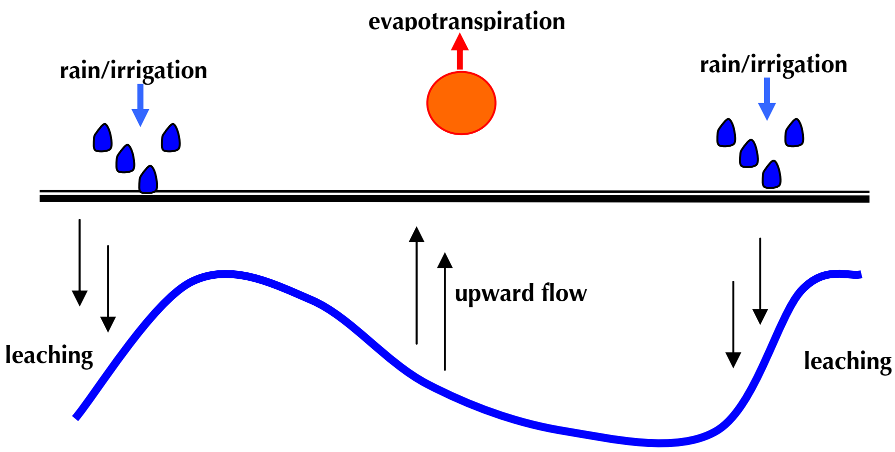

Fig. 1. Seasonal variations in water table level and salinity

Striving for Sustainability

From the discussion above it is apparent that the single major factor to achieve sustainability when adopting saline waters is the enhancement of rainfall contribution to water and salt balance: of course this conclusion does not fit those Mediterranean environments where annual precipitations are negligible, but it can apply wherever rainfall exceeds the amount of approximately 150 mm per year.

It is also evident that an appropriate draining system, either natural or artificial, is necessary to dispose of leached salts, otherwise the addition of water in excess for leaching would ultimately increase the amount of salts and maybe even raise the water table to a dangerous level.

Some practices recommended when applying saline waters have actually a limited or only indirect value in reducing the risk of soil salinization: this is the case of shaping seed beds in irrigation furrows for permitting plants to escape salt accumulation zones, or that of selecting salt tolerant cultivars; appropriately blending or alternating saline water with freshwater is a means to improve plant agronomic response but the problems to soil fertility are only postponed in time.

Reclamation through the plantation of appropriate crops to remove salt is rather problematic: Rengasamy and Olson (1993) estimated that pasture and cereal crops can remove 0.1 –0.5 metric tons of Na^+ per hectare per year and halophytes not more than 1 metric ton Na^+ per hectare per year: such data match those recently obtained by Belligno *et al*. with vetivergrass (Belligno *et al*., 2004) and demonstrate the inadequacy of the solution, considering that the application of just 2000 m^3 /ha of water with a salt content of just 1 ‰ adds two tons of salt.

Also the improvement in water distribution and application efficiency, so often advocated, is just a means to mitigate and delay salinity build-up, but it cannot be seen as a tool for its prevention: van Schilfgaarde stated that in irrigated agriculture of the semiarid zones the question is not "if" but "when" salinity problems show up (van Schilfgaarde, pers. comm., 1992).

Appropriate, effective solutions can be found in the control of water and salt balance only by adequately integrating the water management system, combining the irrigation and drainage subsystems (Ayars *et al*., 2003). In fact drainage, either natural or artificial, must not be considered exclusively a tool for disposing of excess water in humid areas, since it can be a key factor to maintain fertility in arid and semiarid areas by controlling both water and salt balance.

To better illustrate the concept, three different conditions will be separately considered.

Sloping Lands

The principal problem when dealing with water and salt balance in sloping lands is the control of overland flow, which in single, high intensity events can exceed 50% of rainfall.

Structures and practices for water harvesting have been actively investigated in the last years and several solutions have been proposed. While large dams construction is opposed by environmentalists because of their social and environmental implications, simple structures for water harvesting, either removable or not, are quite acceptable.

Water harvesting is an age-old practice which has been rediscovered in the last decades (Evenari *et al.*, 1962-1967) and has been the object of intense research in order to determine the parameters for a correct design (Shanan and Tadmor, 1979; Ben Asher *et al.*,1984). This technique is based on the combination of a large runoff contributing area and a small water collecting basin, in a ratio depending on precipitations, on the amount of water needed in the collecting basin and on the degree of drought risk which is accepted. One major drawback of this solution is the large proportion of area normally devoted to convey runoff.

Among the semi-permanent solutions one is very promising, already implemented on the surface of about 75000 ha by Vallerani (Vallerani, 2001), based on a series of contiguous deep furrows interrupted by crescent-shaped pits where rain water is collected.

In this solution plants grow along the furrows or into the pits, taking advantage of the runoff which flows between them and is stored in depth. The solution is fast to implement, efficient and rather cheap (costs range from 20 to 60 US $/ha) and the structures are expected to last some 5 years.

One alternative, cheaper solution, lasting one single season, is that of the microbasins, otherwise called diked furrows or tied ridges (Jones and Stewart, 1990), whereby usual furrows are dammed in a very simple way in the fall, after the harvest time when no cultural practice is needed (they are mainly suited for vineyards, fruit orchards, olive crops but can also be applied to some field crops). The microbasins capture the rainfall during the winter season and if adequately sized avoid any overland flow, thus conveying all the precipitation water into the soil, with the exception of evapotranspiration losses, usually low at that time of the year. Subsequently, at springtime, they can be easily removed with the first soil cultivation.

Microbasins are very useful in enhancing salt leaching, since experiments have demonstrated that runoff can be reduced to zero, provided that they are correctly sized (Rizzo *et al*, 1993); the risk of collected water overtopping and destroying them in a sort of "domino effect" must be not overlooked, however.

Other benefits linked to microbasins implementation are aquifer enrichment, overland flow elimination and consequently erosion control.

A totally different, more expensive solution which has been demonstrated effective (Sardo and Parlascino, 1992) consists in coupling shallow subsurface drains to open ditches spaced widely apart: this solution permits to reduce the disturbance to mechanical operations by open ditches, spacing them much wider, because the overland flow is largely reduced thanks to the action of the drains, which encourage infiltration. The subsurface drain system not only enhances water infiltration into the soil but also helps to dispose of the leached salts.

The wide-spaced open ditches can be used as tracks, thus facilitating rather than hindering farm mechanization, in an integrated approach to the design of farm structures (Sardo, 1992).

Whatever the solution, a key point is a close monitoring of soil salinity in order to avoid salt accumulation to dangerous levels, by suspending the application of saline waters for some time, according to need, until acceptable conditions are restored through leaching.

Flatlands With a Deep Water Table

Some solutions typically elaborated in the US for managing irrigation, such as surge flow (Stringham an Keller, 1979) and LEPA (Low Energy Precision Application, Lyle and Bordovsky, 1981), although useful in principle to reduce energy input, improve uniformity and encourage infiltration, can hardly be transferred to the Mediterranean agriculture without the necessary modifications, however one new and more sophisticated solution, the so called "precision farming" system, based on a combination of the Global Positioning System (GPS), the Geographic Information System (GIS) and an advanced electronic technology, is more promising.

Although still far from immediate application, its potential for soil protection and runoff reduction, implying soil enrichment in water and salt leaching, with huge potential savings in energy and chemical inputs (e.g. Schueller, 1997; Whitney *et al.*, 1999) in fact deserves a close attention. Precision farming is also useful in limiting the soil compaction to those narrow lanes where machinery wheels are supposed to pass.

The Vallerani system described above can be applied also to flatlands thanks to a blade which creates an artificial slope between the furrows, thus conveying water into them and acting therefore as a simple water harvesting tool: like in sloping lands, of course, the best strategy for a sustainable use of saline waters is to take advantage to the possible extent of precipitations in order to maintain a sufficiently low level of salinity while monitoring accurately salinity fluctuation in the soil.

Flatlands With a Shallow Water Table

In this particular case the risk of salt accumulation due to water evaporation from soil surface compounds the risk saline water application; it is therefore imperative to control water table level in order to permit salt leaching and avoid capillary rise to the surface.

In spite of such limitations, the presence of a shallow water table can be a blessing to the farm, provided that water is not too saline, because through an appropriate control a regulated water table can be an efficient resource to subirrigate the plants.

The principles underlying the subirrigation and drainage management result from the sketch in figure 2 showing an ideal crop response to a varying water table depth.

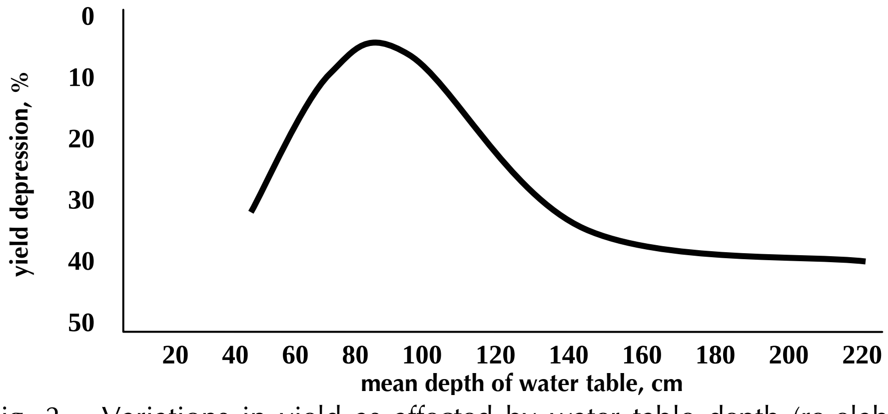

Fig. 2 – Variations in yield as affected by water table depth (re-elaborated from Visser, 1958)

The figure shows that yield is reduced at a shallow water table depth, rises to a maximum at a depth of approximately 75 cm, then is reduced again when an excessive depth prevents capillary rise contribution to crop water requirements (of course the curve is crop and soil- specific): such is the principle underlying subirrigation, as shown in figure 3, based on the hypothesis of a subsurface horizontal drainage.

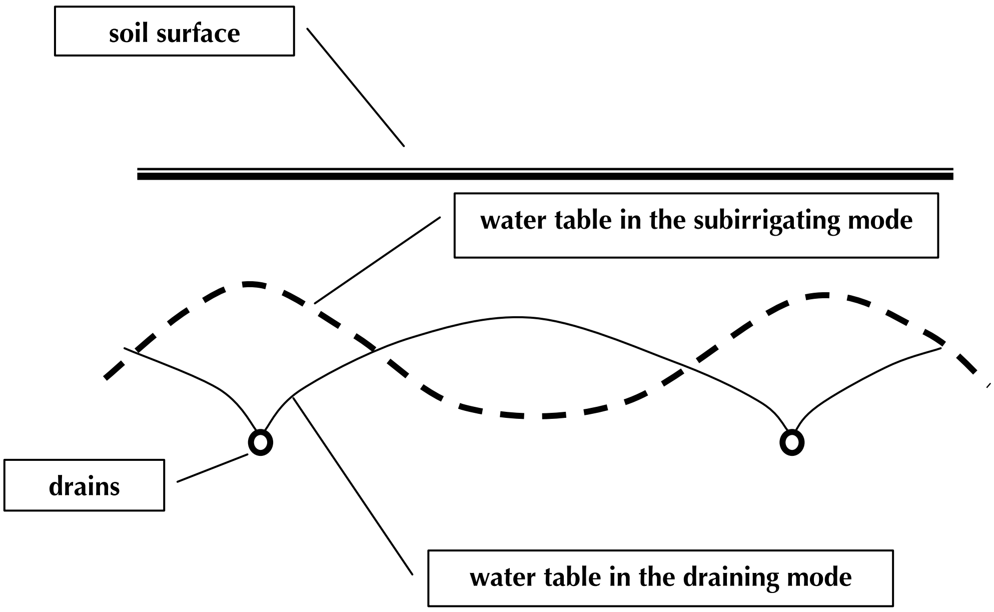

Fig. 3. Different water table shape in the draining and the subirrigating modes

Besides presenting the well known advantages of energy saving and no need for filtration, subirrigation with its dual mode of operation gives a good example of the integrated irrigation-drainage management, permitting to leach during the draining phase the salts accumulated when irrigating.

Water table can also be controlled by means of vertical drainage, by appropriately combining a number of wells, at a distance depending on soil hydraulic conductivity; vertical drainage is cheaper and easier to implement than horizontal drainage, but in this case the control is not as accurate as with horizontal drains and energy is required to lift water (fig. 4).

Of course there are some limitations to the applicability of subirrigation: the main limits are that irrigated areas should be uniformly flat and large enough, with rather homogeneous soils, and water table should be sufficiently shallow to moisten the root zone when needed.

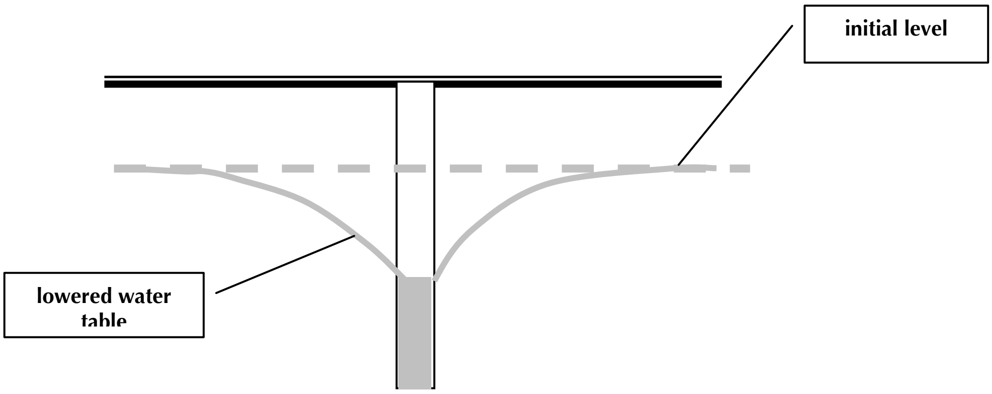

Fig. 4 – Action of vertical drainage in lowering water table

Ancillary Practices

Besides those listed above, other well-known practices exist to help in achieving the goal of sustainability, which are briefly reviewed and for convenience have been grouped under two headings below: the point is emphasized however that they must be considered auxiliary, inserted into the general framework of the control of the water and salt balance through the integrated water management system.

Soil amendments

Organic matter is notoriously a powerful agent in the improvement and maintenance of soil structure and macroporosity, that are conditioning water infiltration rates; it can be added to the soils under various forms, i.e. as organic (green or animal) manure, compost or plant wastes and residues and according to its origin and composition it can have a more or less pronounced effect and a more or less extended duration.

Besides improving soil structure and permeability, organic matter has been reported to enhance plant tolerance to salinity (e.g. Chaudry and Rafique, 1992) through a still not well clear mechanism.

It is in all cases of interest to select the appropriate source and amount of organic matter to be added in order to avoid possible harmful effects depending on the unbalanced C/N ratio (e.g. when adding wheat straw) or –when operating on heavy soils- on the increased permeability that, coupled to the increased moisture capacity, can encourage the formation of a perched water table or at least of anoxic conditions at root zone level.

In addition to organic matter, mineral substances can be added to contrast the permeability reduction due to Na content in the soil or in sodic waters (Oster *et al*, 1984; Hamdy, 1995): it is the case of gypsum, phosphogypsum (a by-product of fertiliser industry), or sulphur which have been demonstrated very useful in improving soil structure. When applying such amendments, however, it is necessary to secure the drainage of the displaced ions as required, otherwise their application would worsen the conditions.

Management practices

A significant support to sustainability can be obtained through the application of appropriate management practices, including:

- The adoption of conservation tillage or zero tillage
- The adoption of cover crops
- The improvement of distribution and application efficiency (it only partly true that water lost to inefficiencies is useful to leach salts and recharge the aquifer downstream)
- The reduction of kinetic energy in drops of sprinkler irrigation by reducing the nozzle size or rising the pressure
- Avoiding pulverization due to rototillage
- Avoiding trampling when soils are moist

All such ancillary factors can concur to enhance rainwater infiltration with the twin benefit of reducing irrigation water requirements and help to leach accumulated salts.

It is remarked in conclusion that almost all the reviewed practices are highly energy-efficient, since they reduce the need for water and fertilizers application, and for cultivation.

Conclusions

Using saline waters for irrigation is risky but unavoidable: the challenge is how to do so in a sustainable way.

While remarkable progresses are achieved in the solution of the multifarious theoretical aspects linked to their use and conceptual strides are assisting in the elaboration of much-needed system approaches, regrettably a widening is recorded of agricultural lands lost to salinity.

This paper is aimed to focus operators' attention on the basic principles of irrigation/drainage management when dealing with saline waters, evidencing the paramount need to take advantage to the possible extent of rainfall to maintain a favourable water and salt balance.

A system approach is therefore needed, in a vision which integrates irrigation and drainage rather than considering them as separate or even opposing entities; the commonly recommended agronomic practices should be seen as a necessary support to this fundamental, categorical principle.

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