

eip-agri
AGRICULTURE & INNOVATION



EIP-AGRI Focus Group

Water & agriculture: adaptive strategies at farm level

MINIPAPER: WATER QUALITY AND SALINITY 15 10 2015

Diego S. Intrigliolo, Marek krysztoforski, Marcello Mastroilli, Bence Fulop, Agatha Agudelo

1. INTRODUCTION AND RATIONALE

Water contamination and soil salinity are major risks for ensuring sustainable agriculture worldwide. In the Mediterranean basin, most fresh water resources are over-exploited while the population food requirements and climate pressure are still growing. The use of saline water resources constitutes already a remedy to face the current water scarcity. As a consequence, growers need to adopt solutions to reduce the risk of soil salinization and to alleviate the detrimental effects of salt stress on crop performance.

The general term «saline soil» mainly refers to two conditions:

- The first one is related to the huge increase in irrigated areas over the last century. In hot-arid climate regions, where this growth is associated with overestimation of crop water requirements and the absence of a drainage system, irrigation might result in the long-term in soluble salt accumulation in the soil layers explored by roots. About one third of agricultural soils in arid and semi-arid regions are currently salt-affected. The surface area out of cultivation each year because of excessive salinization is reported to vary from 10 to 20 million hectares. No salt-affected country can claim to have solved this problem regardless of their extension services.
- The second one relates to the use of saline water in agriculture on soils previously affected, at varying degree, by salinity. This mainly occurs in countries with limited water resources, as it is particularly the case in the southern Mediterranean countries. In these countries, most fresh water resources are over-exploited but the demand for water keeps increasing. Using saline waters helps to face the current water scarcity. Accordingly, should the assumed climate change occur, whereby climate in the southern Mediterranean countries is going to be more arid and in the future the situation is expected to become even more serious.

Practicing environmentally-friendly and economically sound agriculture in the above situations is a challenge the farmers should take. Successful practices are only possible if adequate saline water irrigation management policies are performed. A number of options that come into play in such policies are currently practiced. However, the selection of appropriate species and varieties capable of producing under saline conditions is a crucial one, particularly when a long-lasting positive impact is needed. This is the case of water basins with chronic fresh water scarcity and already salinized water resources.

The effects of soil salinity on plant functioning are similar to those caused by soil drought. As soil salinity increases, soil water available to the plants decreases as a result of the reduction in osmotic potential. Accordingly, this may cause short-term disturbance in plant water status and gas exchanges and long-term disturbance in growth and productivity.

2. SOLUTIONS TO MANAGE SALINITY IN IRRIGATION WATER

Management practices can often be modified to obtain a more favourable distribution of salts in the profile and therefore better crop yields, water quality remaining the same. Management practices that can help to overcome a high salinity problem of the irrigation water are discussed below. Desalinization of water to remove soluble salts has often been referred to as a technical possibility but at the present stage of available technologies it is doubtful if this method can have any large-scale application in the utilization of saline water for irrigation of most agricultural crops, at least in the near future.

2.1 Minimise application of salts

An option to minimise the effects of salinity is to minimise irrigation applications and the subsequent accumulation of salts in the field. This can be accomplished through converting to a rainfed production system; maximizing effectiveness of precipitation to reduce the amount of irrigation required; adopting highly efficient irrigation and tillage practices to reduce irrigation applications required; and/or using a higher quality irrigation water source (if available). Since some salts are added through fertilisers or as components (or contaminants) of other soil additives, soil fertility testing is warranted to refine nutrient management programmes.

2.2 More frequent irrigation

The adverse effects of the high salinity of irrigation water on the crops can be minimized by irrigating them frequently preferably with good-medium quality water. But even with scarce water quality, more frequent irrigations maintain higher soil water contents in the upper parts of the root zone while reducing the concentration of soluble salts. Both these factors result in reduced effect of high salts on the availability of water to plants and therefore promote better crop growth. The sprinkler and particularly the drip method of irrigation are generally more amenable to increased frequency of water applications. In surface irrigation methods however, more frequent irrigations almost invariably result in an appreciable increase in water use.

2.3 Selection of highly productive crops and varieties under salinity conditions

There is a wide range in the relative tolerance of agricultural crops to soil salinity (see summary in Table 1). Proper choice of crops can result in high yield and good economic returns even when using high salinity water, whereas use of such water for growing a relatively salt-sensitive crop may be questionable. Currently crop breeding programmes are addressing salt tolerance for several crops, including small grains and forages. But the focus should not only be directed towards obtaining highly resistance genotypes but also in obtaining more productive species and varieties. Often the increased crop performance character is maintained under salt stress conditions. In this sense, plant emergence is the most critical phase as salts are generally accumulated in the soil surface where the root system is first exploring. In the case of woody perennial crops, rootstock choice can play a major role for salt tolerance since there are some chlorides excluding rootstocks that do not accumulate toxic chloride ions in the rootstocks. This is for instance the case of the Cleopatra Mandarin for citrus trees (Syvertsen and Levy 2005) or the Virginiana rootstock to be employed for Kaki cultivars (Besada et al. 2016).

Some field crops are particularly susceptible to particular salts or specific elements or to foliar injury if saline water is applied through sprinkler irrigation methods. Similarly, selection and breeding of salt-resistant crop varieties offer tremendous possibilities of utilizing saline water resources for crop production.

Table 1. Summary of several crop tolerance to salinity. Adapted from information reported in Bernstein 1980 and Hill and Koenig 1999.

Crop type	Tolerance to salinity	Notes
Date palm, Pomegranate	Very high	
Barley, Sugar Beet, Wildrye, Asparagus	High	
Citrus	Moderate	High when Rangpur lime or Cleopatra mandarin rootstocks are employed. Low when sweet orange or Citrange are used
Stone fruit	Moderate	High when Marianna rootstocks are employed. Low when Yunnan is used
Grapevine	Moderate	High for Thompson varieties. Low for Cardinal and Black-Rose cultivars
Wheat, Wheat Grass, Zucchini, Beet	Moderate	
Tomato, Cucumber, Alfalfa, Clover, Corn, Muskmellon, Potato	Low	
Onion, Carrot, Bean, Cherry, Raspberry, Strawberry, Avocado	Very low	

2.4 Use of extra water for leaching

To prevent excessive salt accumulation in the soil, it is necessary to remove salts periodically by application of water in excess of the consumptive use. The excess water applied will remove salts from the root zone provided the soil has adequate internal drainage. This concept is quantified in the term 'leaching requirement' often referred to by the abbreviation, LR. By definition, leaching requirement (LR) is the fraction of total water applied that must drain below the root zone to restrict salinity to a specified level according to the level of tolerance of the crop.

Application of excess water, above that needed for meeting the evapotranspirational needs, though useful for salinity control, puts a high demand on the water resources on the one hand and increases the salt load of the drainage water on the other. It therefore appears that controlling the interval between irrigations is the most important management practice for obtaining higher yields with high salinity water and this could be achieved by the sprinkler, drip or the surface irrigation methods.

2.5 Conjunctive use of fresh and saline waters

There are situations where good quality water is available for irrigation but not in adequate quantities to meet the evapotranspiration needs of crops. Under these conditions, the strategies for obtaining maximum crop production could include mixing of high salinity water with good quality water to obtain irrigation water of medium salinity for use throughout the cropping season. Alternatively, good quality water could be used for irrigation at the more critical stages of growth, e.g. germination, and the saline water at the stages where the crop has relatively more tolerance. Research is in due course to define the best options considering the tolerance of crops at different growth stages, critical stages of growth vis-a-vis soil salinity.

2.6. General management practices to reduce the impact of soil salinity on crop performance:

In addition to the management practices mentioned above, the following approaches may help reduce salinity impacts.

Mulching: Mulching with crop residue, such as straw, reduces evaporation from the soil surface which in turn reduces the upward movement of salts. Reduced evaporation also reduces the need to irrigate. Consequently fewer salts accumulate.

Deep Tillage: Accumulation of salts closer to the surface is a typical feature of saline soils. Deep tillage would mix the salts present in the surface zone into a much larger volume of soil and hence reduce its concentration and impact. Many soils have an impervious hard pan which hinders in the salt leaching process. Under such circumstances "chiseling" would improve water infiltration and hence downward movement of salts.

Incorporation of Organic matter: Incorporating crop residues or green-manure crops improves soil tilth, structure, and improves water infiltration which provides safeguard against adverse effects of salinity. In order for this to be effective, regular additions of organic matter (crop residue, manure, sludge, compost) must be made.

Fallow and alternating rain-fed and irrigation cultivation systems. By leaving uncultivated soils during some growing seasons, the salt leaching due to rainfall is enhanced. Similarly, in case of irrigation applications with salty water, alternating rain-fed cultivation with irrigation might reduce the long-term soil salt accumulation.

3. Measures to reduce water contamination

Contamination of rivers and seas fertilizer components is a growing problem, mainly concerning catchment seas (the Baltic Sea, Mediterranean Sea, Black Sea, Adriatic Sea). The main nutrients, called "biogens" causing eutrophication are nitrogen and phosphorus. Some measures involve the precise dosing of fertilizers so that they can be retrieved by the plant as a whole and not be washed off / rinsed into flowing water or groundwater. Measures which limit contamination of the main biogens (N and P), very often give the added effect of efficient water use. It should realize that escape the components of the field is often the most commonly in the form of a solution or any water retention on the surface of the field or in the root zone of plants will work positively not only on water quality but also cost-effective water management.

Below follows a list of agri-environmental measures that can be used to reduce nutrient leaching from the soil to the water.

3.1 Treating and spreading the manure

Composting: stabilizing manure as a nutrient source (tube composting, drum composting).

Take manure samples to determine how much nutrients the manure contains.

Fertiliser plans should be made before spreading. Mulch dry manure and broadcast slurry as soon as possible. Slurry injection or hose as spreading is preferable to spreading. Avoid spreading in autumn if there is no growing crop. Manure heaps on fields: nutrient losses to watercourses, groundwater and air need to be avoided (compact base with collection of liquids, or a layer of material that collect liquids plus a cover in both cases). Manure also has an after-effect a nutrient source; take it into account in the planning of fertilization. Remember co-operation between crop and animal farms if the manure produced is surplus to on-farm requirements.

3.2 Nutrient plan

The use of nutrients should be planned well, parcel by parcel, in order to minimize harmful environmental effects while optimizing plant growth, production and farm profits. Soil quality, e.g. nutrient and organic matter content, structure, soil type, and other site specific properties such as erosion risk, steepness, risk of flooding, closeness to watercourses, as well as the crop specific need of nutrients have to be taken into account. Also experiences from previous years are useful.

When the work is done all management such as nutrient sources, application dates, rates, and methods as well as yield level and quality should be documented.

There are 16 elements that are necessary for plants. Nitrogen, phosphorus and potassium are major nutrients because these are required by plants in large or moderate amounts, and they are often so-called minimum factors for plant growth. On the other hand, a shortage of any nutrient can restrict growth.

Results of the soil fertility analysis are used to determine the requirement of many macronutrients such as P, K, Mg, Ca, S, as well as micronutrients (Fe, Cu, Mn, Zn, B, Mo, Cl). P-index calculation methods also helpful to estimate the need for phosphorus

3.3 Plant cover

Catch crops

Catch crops are effective in reducing nitrate leaching, because they grow and take up nitrogen from the soil before and during the period when leaching takes place.

Catch crops are mainly used before spring-sown crops. The effect of catch crops is dependent on the date of sowing and successful establishment. Cruciferous crops in particular require care at establishment after the main crop, while grasses, e.g. perennial ryegrass, are easily undersown in spring. The roots of cruciferous species extend to greater depth than those of ryegrass, so they have greater potential to absorb nitrogen if they are well-established.

A buffer zone

A buffer zone is a 6-20 m wide vegetated zone, located on an arable field next to a watercourse (stream, river or lake). The risk of surface run-off and soil erosion, and therefore also the need for a buffer zone, is greatest on sloping fields with low infiltration capacity and/or during times of heavy rain. The risk is especially high when there is no crop growing on the field or when the crop is poorly developed, since crop roots are important for stabilising the soil. Water uptake by a crop also reduces the risk of surface run-off. The buffer zone will not prevent leaching via from sub-surface run-off (through drainage pipes). Losses from sub-surface run-off require

other mitigation measures. For phosphorus, improved soil structure has proven to be important for reducing both surface and subsurface run-off.

The buffer zones should not be fertilised and they need to be managed by mowing or grazing. If they are managed by mowing, the plant material should preferably be harvested, since this prevents the nutrients that have been taken up by the plants being released again.

3.4 Treatment of run-off waters

Constructed wetland

Suitable locations for a wetland include for example natural hollows and depressions, water meadows susceptible to flooding, and terraced drainage areas. Old drained wetlands can also be restored.

Larger wetlands capture nutrients efficiently. In Sweden, it is recommended that the catchment area of the wetland (with the focus on nitrogen retention) be large (>100 ha) and comprised of mostly field area (~70%). Small wetlands can improve biodiversity but their efficiency in reducing nutrient loads is questionable. Relatively shallow wetlands are best for both nutrient retention and improving biodiversity.

If the wetland is meant to attract birds, a good rule of thumb is that 50% of its surface should be open water area and 50% should be covered with vegetation.

In a Swedish study, the capacity of wetlands to retain nutrients was estimated based on water samples and modelling. The 50 wetlands in the study retained on average 59-105 kg of nitrogen and 1.7-5.3 kg of phosphorus per hectare of wetland surface per year.

Phosphorus dam

A phosphorus dam is a small wetland specially designed for facilitating sedimentation of soil particles and particle-bound phosphorus. It can also be combined with ditch filters, for improved retention. A phosphorus dam is elongated in shape and comprises both a deep sedimentation part and a shallow vegetated part. A dam can be placed in or in connection with a ditch. The dam should be placed near fields that have high phosphorus erosion losses.

Control well

Controlled sub-surface drainage is a drainage system in which the drainage efficiency can be adjusted with a control mechanism. The water control mechanism is usually located in a control well installed in the collector ditch (Figure 1). If there is a dry season, the control mechanism is closed so that the water stays in the drainage system and soaks into the soil so that the plants can use it. In times of heavy rain, the control mechanism is kept open in order to direct water away from the field. During tillage, drilling and harvesting, the groundwater level should be kept low enough so that it is possible to move on the field with heavy vehicles without soil compaction.

The humidity of the soil can be monitored in observation pipes installed in the field. A general rule is that the groundwater level should be at least 0.5 meters below the surface of the field. Controlled drainage is best suited to soils that conduct water well. The slope of the field should preferably not exceed 2%. Extra slope adds to the building and maintenance costs, because more control wells need to be installed. On a flat field, one control well is needed every approximately 1.5 hectares. The regulating system can be installed when building a new subsurface drainage system but also retrofitted to existing subsurface drainage.

Controlled drainage has a reduced water outflow compared with traditional sub-surface drainage in the most of trials reviewed. The total nitrogen content in drainage water is not affected by controlled drainage, but in some cases it can reduce $\text{NO}_3\text{-N}$ concentrations by around 10-20%. Controlled drainage has only minor effects on total phosphorus concentrations in drainage water. Leaching is decreased mainly because of the smaller outflow of water

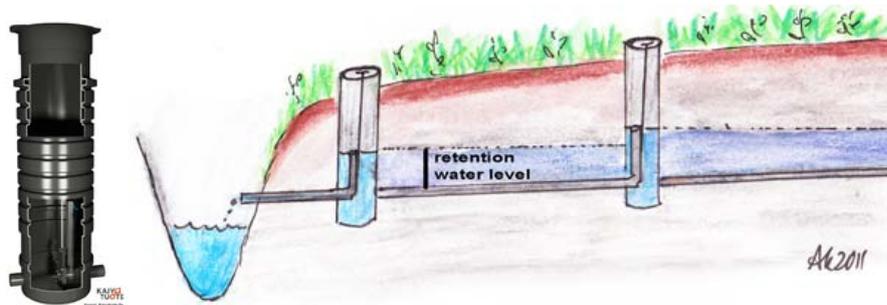


Figure 1. Left: Example of a commercial control well. Photo: Kaivotuote. Right: Water level is controlled by adjustable control wells installed in the drainage pipe. Illustration: Airi Kulmala

3.5 Phytoremediation

Phytoremediation is a biological method for remediation of soil and groundwater by using plants (Figure 2). By planting trees such as willows or poplars along streams, it is likely that significant nitrogen removal from drainage water can be achieved, while the biomass can be exploited for energy purposes. This allows better use of constructed wetlands, while also allowing for increased biodiversity. Phytoremediation occurs when the plants change the chemical, physical and biological conditions in the root zone, so substances are retained or removed from the system. For nitrogen in particular, significant removal occurs by denitrification, whereby nitrogen disappears in the form of gaseous losses.



Figure 2. Method of phytoremediation water from farmyard. Institut of Technology and Life Sciences in Falenty, Poland. Photo: L. Rossa

3.6 Liming

The availability of most nutrients is best around pH 6.5. If the pH of the soil is lower, liming makes many nutrients more available to plants by increasing the pH of the soil. Liming also prevents other harmful effects of acid soils, e.g. the increased availability of many harmful substances in the soil. Another effect of liming is that it improves soil physical structure and increases biological activity. Soil acidity is described with a pH value which tells how many free hydrogen (H⁺) ions there are in the soil solution. The need for liming and the amount that needs to be spread is dependent on the field's soil type, soil organic matter content, pH and which crops are being grown, and it should always be based on recent soil fertility analysis.

Liming affects very favorably on soil structure. For light sandy soils, generates better cohesion and water retention, while heavy soils, where water percolation is difficult, are loosened. The positive impact on soil biology causes an increase in the content of soil organic matter that collects water supplies.

4. Research needs

Growers need new solutions for improving crop performance under salt stress and for decreasing soil salt accumulations in the root-zone. In terms of crop tolerance, breeding programs are needed to obtain and identify new rootstocks for both woody and vegetable crops able to reduce Cl⁻ accumulation in leaves tissues. More at the basic research level, the plant physiology mechanisms involved in the root system Cl⁻ exclusion capacity should be defined.

In order to decreasing soil salt accumulation, new cropping systems mixing traditional crops with halophyte plants should be tested. Species able to accumulate salts and particularly Cl⁻ in their tissues should be used as soil phytoremediation plants. Finally, hydroponic systems should be investigated in order to be able to design new culture practices under near-soilless systems even in woody crops where the salinized soil orchard floor might be replaced with the external use of substrates with high water hydraulic conductivity.

5. References

- Bernstein, L. 1980. Salt tolerance of fruit crops. USDA, Agriculture information bulletin. 292:1-8.
- Besada, C., Gil, R., Bonet, L., Quiñones, A., Intrigliolo, D.S., Salvador, A. 2016. Chloride stress triggers maturation and negatively affects the postharvest quality of persimmon fruit. Involvement of calyx ethylene production. *Plant Physiology and Biochemistry* 100:105-112.
- Hill, R., Koenig, R.T. 1999. Water salinity and crop yield. *Utah Water Quality*. Ag-452.3:1-6.
- Syvertsen, J., Levy, T. 2005. Salinity interactions with other abiotic and biotic stresses in citrus. *HortTechnology* 15:100-103.