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HALOPHYTES AND SALT-TOLERANT GLYCOPHYTES A POTENTIAL RESOURCE

V. Sardo

Department of Agricultural Engineering, University of Catania
Via Santa Sofia, 100 – 95123 Catania, Italy - email sardov@unict.it

SUMMARY - Water of good quality for agricultural uses is becoming ever more limited in regions where irrigation is necessary, due to increasing requirements for domestic and industrial uses. This makes exploration of using “non conventional” waters mandatory. Seawater or saline water may be used to irrigate a variety of plants, both halophytes and glycophytes, however their use entails a number of problems. A review is given of the halophytes most commonly grown and of their various uses, of the response of some glycophytes when irrigated with saline water and of the possible levels of production. A brief account is given of researches addressing plant tolerance to various salinity levels; salt balance in the soil as affected by leaching fractions and precipitations; soil physical conditions as affected by irrigation systems.

Keywords: halophytes, seawater, brackish water, non-conventional irrigation

INTRODUCTION

The rapidly increasing world population puts ever more pressure on land and water resources: it becomes therefore imperative to undertake a serious effort not only to train advisers and irrigators to better use available freshwater (thereby reducing the rate of water and land loss) but also to expand agricultural crops in those vast unused areas that are an enormous potential resource. Under those extreme conditions of soil or water salinity where no crop of agricultural interest can be grown it is possible to imagine dedicated halophyte plantations for forage production, soil rehabilitation, bioenergy generation, landscaping, carbon dioxide sequestering, and a number of other useful purposes at no cost in terms of good quality water and soil. Worldwide, there are vast surfaces of barren and abandoned marginal lands that are commonly believed useless: on the contrary a huge research and demonstration activity in the last decades has demonstrated their unsuspected value.

Mankind today is not in a position to overlook such untapped resources.

HALOPHYTES

Various attempts to classify halophytes have been proposed, however the simplest and clearest definition is probably that of Aronson and Le Floch (1996), stating that “halophyte species are those occurring in naturally saline conditions only”.

It is difficult to precisely define halophytes, as opposed to glycophytes, due to the variability of plant responses in dependence of a number of factors, including climatic conditions and plant phenophases: for instance a plant may be sensitive during, say, the germination or seedling phase while it is tolerant during the other phases or may suffer salinity under dry climatic conditions while easily overcoming it under a moist climate (an interesting new “dynamic” salinity stress index linked also to temperature and solar radiation has been worked out by Dalton, Maggio and Piccinni, 1997, 2000 and 2001). In conclusion there is a wide and uncertain frontier between halophytes and tolerant glycophytes.

Those plants growing best under a certain level of salinity are called “euhalophytes”; a further distinction is that between xerohalophytes, thriving under saline, arid conditions, and hydrohalophytes, thriving under saline, moist conditions.

According to Le Houérou (1996) “there are as many as 6000 species of terrestrial and tidal halophytes in the world” and by far the largest proportion is that belonging to Chenopodiaceae,

followed by Poaceae; the Mediterranean flora includes about 700 species of halophytes, some 70% perennials and 30% annuals. In China, Kefu *et al.* (2002) identified 430 halophyte species.

Halophytes can tolerate high salinity levels in irrigation water, in some cases even higher than those in seawater (which typically has an EC, electrical conductivity, of about 45-50 dS/m) by enacting several different mechanisms of defence which include exclusion, compartmentation or excretion of noxious ions.

HALOPHYTES AND SALINE LANDS

The wide variety of halophytes and of their characters permits to envision a profitable use of vast barren extensions of saline lands by selecting the appropriate species best fitting local conditions. Possible actions in dependence of peculiar soil and water conditions are synthetically shown in the following table.

| Case | Soil | Main Water Source | Principal possible actions |
|------|---------------------------------|-----------------------|---|
| 1 | Coastal lands | Seawater | Fixing dunes, landscaping, growing mangroves, fodder production |
| 2 | Inland saline areas (irrigated) | Brackish/saline water | Various scopes |
| 3 | Inland saline areas (dry) | Rain | Erosion control, fodder production |
| 4 | Salinized agricultural lands | Fresh/brackish water | Soil rehabilitation, agricultural production |
| 5 | Endangered agricultural lands | Fresh/brackish water | Soil protection, agricultural production |

All the possible actions listed in the table can be easily undertaken after an appropriate plant selection but of course also a preliminary analysis assessing their environmental, economic and social feasibility is in all cases required.

The principal experiences on halophyte uses in the various conditions listed in the table are briefly illustrated below.

Case 1 - Coastal lands

One of the main problems in sandy coastal lands is their vulnerability to wind erosion and dunes shifting, possibly combined with sea eroding action. Under such conditions it is obvious to think of a soil cover with halophytes to be irrigated with seawater, without any risk of damage to the soil and the aquifer, since the soil is typically a-structural, with no colloidal fraction to be protected, and the aquifer is the seawater itself.

Experiences conducted within a European Commission-funded Concerted Action have shown the amazing performance of seawater-irrigated *Sesuvium portulacastrum*, able to rapidly spread to form a thick cover, perfectly tolerant to a wide range of temperatures (- 2°C to 46°C) and drought stresses, apparently free of diseases and natural enemies (Sardo and Merlo, 2002).

Sesuvium grew very well when subsurface irrigated, but tolerated well enough sprinkler irrigation, even when seawater was daily applied in the warmest hours of the day.

The action of sprinkler-applied seawater on the soil was dramatic, since an evident decay was detected in the sprinkled coarse sand, as opposed to a subsurface irrigated plot: in the former case, after two campaigns' daily application at the precipitation rate of about 6 mm/h during two hours, a surface crust was formed in the sand which reduced infiltration rate from the initial 1400 mm/h to only 22 mm/h, whereas in the adjacent subsurface-irrigated plot the infiltration rate showed a limited reduction, to 954 mm/h (Sardo, unpublished work). It has been proposed to plant protective strips of *Sesuvium* along the sandy shorelines, to be automatically irrigated through the use of solar-powered pumps at the cost of about US \$ 2 per square meter (Sardo and Merlo, 2002).

In those coastal areas where tourist development is planned it is also possible to select particular halophytes for embellishment and landscaping, thus saving precious freshwater.

As early as 1985 Gallagher reported the results of his interesting researches on seawater-irrigated plants potentially useful for forage (*Spartina alterniflora* and *S. patens*, *Distichlis spicata*, *Sporobolus virginicus*), as vegetables (*Atriplex triangularis*) and as grain producers (*Kosteletzkya virginica*), with promising results (Gallagher, 1985).

Forage production in seawater-irrigated fields (*Salicornia bigelovii*, *Batis maritima*, *Suaeda esteroa*, *Sesuvium portulacastrum*, *Atriplex barklayana*) has been obtained in Mexico and the Arabian Gulf, and appropriate irrigation systems have been developed (UNEP, 1993; Glenn *et al.*, 1996; ICBA, 2003).

Challenges for restoring vegetation on tidal, hypersaline substrates have been illustrated by Zedler *et al.* (2003), who point out the importance of the many factors affecting plant mortality upon transplanting.

A typical solution for coastal areas protection in the warmest regions is that of mangrove plantations, which create a rich ecosystem in addition to protecting the coast and supplying fodder and wood (Lieth, 1999).

Examples of production with full strength seawater irrigated halophytes

mangroves: in excess of 8 tons/ha (fresh biomass)

Batis: almost 34 tons/ha (dry matter)

Atriplex: 24 tons/ha (dry matter)

Sesuvium: almost 17 tons/ha (dry matter)

Salicornia: 2 tons/ha (oilseeds)

Distichlis: 1 ton/ha (grain)

Aster: 40-80 tons/ha (fresh biomass)

Case 2 - Inland saline areas (irrigated)

The most evident beneficial uses of halophytes in irrigated inland areas are forage production and soil rehabilitation (some other uses will be examined later).

Forage production in saline-sodic or sodic soils, when brackish or saline water is available for irrigation, has been extensively studied, with very encouraging results (e.g. Pasternak and Nerd, 1996; ICBA, 2003; Qadir and Oster, 2004), since water availability permits to simultaneously achieve an appreciable forage yield and a significant action in soil rehabilitation.

The reuse of drainage water for irrigation is useful to conveniently dispose of an otherwise dangerous salt load, provided that long-term sustainability is secured. It is recommended to prepare seedbeds ripping the soil to the depth of some 50 cm in case of an existing hardpan, following with a shallow cultivation.

Grieve and Suarez conducted a research on purslane (*Portulaca oleracea* L.) as a candidate crop to be irrigated with selenium-rich, highly saline drainage water in San Joaquin Valley of California, concluding that "Purslane appears ideal as a salt-tolerant crop to be used at the end of a drainage

reuse system to reduce drainage water volume” and noting that purslane is “highly tolerant of both chloride- and sulphate- dominated salinities; a moderate selenium accumulator in the sulphate-system, and a valuable, nutritive vegetable crop for human consumption and for livestock forage (Grieve and Suarez, 1997).

Forage production is frequently obtained by adopting appropriate intercroppings or rotations; among the most used species are Kallar grass (*Leptochloa fusca*) and old man saltbush (*Atriplex nummularia*). Kallar grass is a perennial extensively used in Pakistan with excellent results both in forage production and soil reclamation, but it dries up during the winter season (Aslam *et al.*, 1991); for this reason it has been suggested to substitute it with saltbush which is more salt tolerant and produces green forage throughout the year (Hanjra and Rasool, 1991). It has also been suggested to integrate it with *Aster tripolium* which is cold-tolerant and able to vegetate during the winter. *Aster tripolium* is also marketed as an edible delicacy in the Netherlands (Lieth, 1999).

In Australia, saltbush (five species of *Atriplex*) when irrigated with water containing up to 10.000 ppm dissolved solids averaged a fresh biomass yield of over 20 tons per hectare in the second year of saline irrigation as opposed to a production of 17,4 tons when freshwater-irrigated (Schulz and West, 2002).

A synthesis of experiments conducted in Sicily during several years and covering several aspects of plant tolerance to various abiotic stresses is reported in the table below.

| Genus | growth rate & soil cover | "hedge" action | fire resistance | tolerance to | | |
|----------------------------|-----------------------------|-------------------|--------------------|--------------|------|------|
| | | | | drought | cold | salt |
| <i>Chamaerops</i> | - | ++ | ++ | +++ | +++ | ++ |
| <i>Nicotiana glauc</i> | + + | - | ? | +++ | + | + |
| <i>Arundo</i> | +++ | ++ | ++ | -- | ++ | ++ |
| <i>Portulaca</i> | + + * | - | + | - | - | ++ |
| <i>Lippia</i> | + | - | + | -- | + | + |
| <i>Atriplex</i> | + | - | + | +++ | + | ++ |
| <i>Cynodon</i> | + + | - | + | + | ++ | ++ |
| <i>Phragmites</i> | + | + | ? | --- | +++ | ++ |
| <i>Typha</i> | + | - | ? | --- | +++ | - |
| <i>Sesuvium</i> | + + | - | + | - | + | +++ |
| <i>Spartina</i> | + + | + | ? | - | + | +++ |

* seasonal cover

Case 3 - Saline drylands

Problems with halophytes growing in saline rainfed areas refer mainly to the germination phase; to the scope special techniques have been devised, including the formation of “niches” where rainfall water is collected and seeds are protected with a mulch to reduce evaporation (Malcolm, 1981; Malcolm *et al.*, 2003).

A rather simple mechanical equipment permitting a fast soil preparation (from 2 to 14 ha /day) at the cost of US\$ 20 to 60 per hectare has been developed and successfully used on a relatively large scale (over 100.000 ha) by Vallerani (Vallerani, 2002), which combines pit digging to seeding in a single passage. Such a system is particularly useful in rainfed areas during the crop cycle and not only in the establishment phase since it has the advantage of harvesting rainwater conveying it to the plants.

In rainfed areas the soil rehabilitation action is typically slower than in the irrigated ones due to the lower amount of incoming water while fodder production is less, however it can reach appreciable

levels provided that the right species are selected. For instance Greig (1994) reported the results of an interesting trial with 72 different halophytic species in an area in Australia receiving an average of 425 mm rainfall and rated their performance according to salt tolerance, palatability, productivity, persistence and ability to spread.

Of a particular interest in arid saline soils is the “old man saltbush” (*Atriplex nummularia*), reportedly able to grow with only 150-200 mm of rainfall per year, and able to survive for a year with only 50 mm (Aganga *et al.*, 2003).

Moselhy and El-Hakeem (2002) report the results of an interesting experiment conducted in Egypt during three years, combining in an “alley cropping system” rows of *Atriplex nummularia* with barley; in a loamy sand under a yearly average precipitation of about 144 mm they obtained the best results when barley was grown in alleys 10 metres wide (i.e. saltbush rows were spaced 10 metres) and saltbush was planted at the distance of 3 metres along the row. Results were less positive when rows were 15 and 20 metres apart: the authors explain this with a less effective wind protection.

An overlooked crop, certainly deserving more attention, is quinoa (*Chenopodium quinoa* Willd). Quinoa, a pseudocereal, is one of the three big staple crops existing in South America at the time of Spanish invasion (the other two being potato and maize), but its use was discouraged by the Spaniards who saw it linked to pagan practices and later by middle classes who considered it a food for the poor. Nowadays it is being explored with ever increasing interest due to its vast nourishing potential (Oelke *et al.*, 1992) and its amazing ability to adapt to extreme conditions (it is tolerant to drought, salinity, frost, submersion: Jacobsen and Mujica, 2001) provided that the right cultivar is selected. For instance, from a research conducted in Peru by the CIP, it resulted that the highest yield was obtained with an EC of 15 dS/m in the irrigation water (Jacobsen *et al.*, 2000).

Results of experiences with diluted seawater irrigation in glycophytes

| PLANT GENUS | COMMENTS | RESULTS |
|-------------------|-----------|------------------------|
| <i>Chamaerops</i> | very good | surviving 40% dilution |
| <i>Citrus</i> | fair | surviving 16% dilution |
| <i>Elytrigia</i> | excellent | surviving 60% dilution |
| <i>Ficus</i> | good | surviving 33% dilution |
| <i>Olea</i> | very good | surviving 40% dilution |
| <i>Pistacia</i> | good | surviving 33% dilution |
| <i>Punica</i> | good | surviving 33% dilution |
| <i>Vetiveria</i> | excellent | surviving 60% dilution |

Case 4 - Salinized agricultural lands and their rehabilitation

This is the case of those barren lands affected by secondary salinization mostly dependent on irrigation mismanagement; the case, recurrent in Australia, of problems due to a shallow saline water table is rather rare in the Mediterranean region (one example in Spain is given by Moreno *et al.*, 2001; more examples for Egypt are given by Ghaffer *et al.*, 2004 and Kotb *et al.*, 2000). Compared to Australian conditions the task of reclaiming soils in the absence of a shallow water table is relatively easier since it is possible to rely on the natural drainage to leach excess salts down, if sufficient rainfall or irrigation water is available for leaching.

One additional difference between Mediterranean and Australian conditions (where problems were originated by forest clearing) is that in the Mediterranean there is a limited interest to explore the potential of tree plants such as Eucalyptus or Casuarina in soil reclamation since there is no need of applying such “biopumps”, which are useful in lowering the water table but certainly do not offer an appreciable income nor permit an intercropping.

The potential of halophytes in bioremediation is well illustrated by Qadir and Oster (2004) who compared the results from 14 experiments with gypsum application versus vegetative reclamation in sodic soils. Results were slightly in favour of chemical treatments (62% sodicity decrease versus 52%) but in the bioremediation treatments sodicity was reduced throughout the whole root zone whereas gypsum was effective only in the layer where it was applied and furthermore the plant action improved soil structure and formed macropores enhancing air and water infiltration. In an earlier work Qadir and Oster (2002) listed advantages and disadvantages of bioremediation as follows:

- advantages: low initial capital input; promotion of soil aggregate stability and creation of macropores; better plant nutrient availability; more uniform and greater zone of reclamation; financial or other benefits from crops grown during reclamation.
- disadvantages: action slower than chemical methods; limited plant tolerance to highly saline-sodic and sodic soils; essential presence of adequate CaCO_3 in the soil.

Qadir *et al.* (2001) compared bioremediation (or phytoremediation) to chemical soil or water treatment, concluding that similar results can be achieved at a lower cost with bioremediation; they attributed its action to CO_2 emission from roots, encouraging Ca^{2+} ions release from the calcareous soil.

Kirda and Hera (1997) report encouraging results in bioremediation obtained in the course of a coordinated research with a network including eleven institutions: they refer that several tree and herbaceous plants significantly decreased soil salinity and sodicity.

Other authors (Barrett-Lennard, 2002; Marui *et al.*, 2003) however caution against excessive optimism about bioremediation, showing that plant action can be very slow, particularly in low-producing rainfed areas; however vetivergrass (*Vetiveria zizanioides*) with adequate leaching has proved useful in helping to reduce saline load in lysimeter-contained sandy soils (Hamdy *et al.*, 2004).

Yunusa and Newton (2003) remark that salt damage depends not only on chemical degradation but on soil structure degradation as well and suggest the use of plants (which they call “primer plants”) capable of drilling “biopores” in the soil thus helping to restore its structure, conditioning it for the following agricultural crops.

Case 5 - Endangered agricultural lands – Sustainable saline irrigation

An integrated approach to soil, water and crop management is required to achieve irrigation sustainability in the long term and to forestall that the often quoted sentence “in irrigated arid areas salinity build up is not a question of if but of when” comes true.

Thorough reviews of irrigation management under saline conditions aimed at averting the risk of soil salinization are given by Hamdy (1996, 2001), who examines in detail the various practices for a sustainable land and water use, stating that “there is usually no single way to control salinity in irrigated land. Several practices can be combined into systems that function satisfactorily depending upon the economic, climatic, social and hydrogeological situation. Thus, management measures should not be considered in isolation but should be developed in an integrated manner to optimise water use, minimize drainage and increase crop yields within limits of the physical and social environment.”

When embarking in an action of soil rehabilitation it is crucial to take into account the water and salt balance, securing an adequate drainage of salts; a decisive support in the planning stage can be obtained from the adoption of simulation models, permitting to explore various contrasting scenarios and to have “a glimpse into the future”; one of the best known is WATSUIT (Oster and Rhodes, 1990).

A quite useful tool in predicting the evolution of salinity in the soil as affected by soil and water quality, climate, drainage and irrigation management is the recently developed simulation model SALTMED (Flowers *et al.*, 2003). It is in fact imperative to monitor salt balance in the soil, controlling rainfall and irrigation water action in order to maintain fertility in the long term (Hamdy and Ragab,

2003) and it is imperative to adopt a holistic strategy considering simultaneously in-farm and off-farm impact of irrigation and drainage, including drainage water reuse (Oster and Wichelns, 2003).

A major support to the maintenance of a favourable salt and water balance can be achieved through the adoption of water harvesting technologies, particularly when plants are grown as isolated trees or bushes, or in rows where water can be collected.

Introducing halophytes or salt tolerant crops in the rotation can significantly help in keeping a low salt level in endangered areas. Vetivergrass hedgerows can be quite useful to reduce overland flow and solid transport (to about 25 - 30% compared to unprotected lands: Hamdy and Sardo, unpublished data), thus encouraging water infiltration and salt leaching. Additionally, vetivergrass can thrive in highly saline soils and contribute to their bioremediation (Hamdy *et al.*, 2004).

Mitchell *et al.* (1999) give a very interesting report on the results obtained with 125 winter-growing potential cover crops in the Mediterranean environment of California, on moderately saline soils: the best results in terms of biomass production were achieved with some Brassica species, while with the N-fixing plants outstanding results were given by some species of Hedysarum, Trifolium, Medicago and Vicia.

SELECTING CROPS FOR SALINE ENVIRONMENTS

Frequently in the case of secondary salinization salinity levels do not reach those extreme values which make the adoption of highly salt-tolerant plants mandatory, and as a consequence two opposite courses of action can be planned, namely either selecting or “domesticating” halophytes to be used as an agricultural crop or “training” agricultural crops to thrive in the saline environment.

In all cases the first step is the formation of an extended gene pool, which is a crucial starting point due to the variability of edaphic conditions and the consequent multiplicity of plant traits required to best fit them.

Selection, hybridisation and breeding, to be conducted in the field, under specific pedo-climatic conditions, “hold tremendous promise for domesticating wild species and developing economically useful crops with higher salinity thresholds” (Biosalinity Awareness Project, 2004). The International Center for Biosaline Agriculture is conducting an excellent work in constituting a germplasm bank of halophytes and salt-tolerant species, in selecting the most promising varieties and in trying to fill the gap in the large scale halophyte use existing between Australia and the more conservative Mediterranean region (ICBA, 2003).

Breeding techniques applied to conventional crops include not only screening, selection and hybridisation, but also the more recently developed bioengineering solutions. As Flowers puts it “attempts to enhance tolerance have involved conventional breeding programmes, the use of in vitro selection, pooling physiological traits, interspecific hybridisation, using halophytes as alternative crops, the use of marker-aided selection and the development of transgenic plants. After ten years of research, the value of using transgenic plants to alter salt tolerance has yet to be tested in the field. The use of physiological traits in breeding programmes and the domestication of halophytes currently offer viable alternatives to the development of tolerance through the use of transgenic technologies” (Flowers, 2003). Such cautious statements substantiate the early sceptical previsions of Malcolm (Malcolm, 1991).

Contrary to that, an optimistic view is shared by Sharma *et al.* (2002) who presented in an interesting review the prospects of biotechnology for crop improvement and Wei *et al.* (2001) who illustrated their (only partly successful) efforts to transfer salt tolerance from a halophyte, *Aeluropus litoralis*, to wheat via asymmetric somatic hybridisation. Suiyun *et al.* (2004) report some promising results obtained applying asymmetric somatic hybridisation to *Triticum aestivum* and *Thinopyrum ponticum* (*Agropyron elongatum*).

Also López-Bucio *et al.* (2000) are optimistic about the possibility of obtaining transgenic varieties able to elaborate and excrete organic acids permitting plants to thrive in “extreme soils”.

Munns *et al.* (2002) illustrate the "avenues" for increasing crop salt tolerance, highlighting the potential of molecular markers to solve the problem of the diffuse rejection of genetic engineering and concluding that "possibly a combination of all approaches, old and new, will be the most productive".

HALOPHYTES AND CO₂ EMISSION MITIGATION

The rapid increase in atmospheric CO₂ content in the last decades has aroused concern about its impact on the greenhouse effect (e.g. Lal, 2000). In principle, agriculture can help to contrast CO₂ increase in two ways: by reducing emissions from fossil fuels through the production of renewable biofuels and/or by sequestering it in the biomass; however, although repeatedly demonstrated technically feasible, such solutions have not been adopted due to economical reasons. It has been in fact suggested (UNEP, 1993; Glenn *et al.*, 1993; Lal, 2000) to use halophytes or anyway plants able to thrive in severely degraded soils for capturing and long-term sequestering atmospheric CO₂ in order to alleviate the greenhouse effect. UNEP (1993) estimated in fact that in world dry lands 0.5 to 1.0 gigatons of carbon per year over 100 years can be sequestered at a cost of 10-20 US \$/ton of carbon: a significant part of the desert land needed for sequestration could be irrigated with seawater or brackish water to enhance biomass production.

Mean carbon storage in forest biomass (including above ground and below ground parts) in dry areas of low latitudes has been estimated in the range of 33 to 124 tons/ha (Winjum and Schroeder, 1997) but such figures are quite distant from those given by Douglas for seawater- irrigated halophytes in Mexico, of about 4 to 8 metric tons per hectare (Douglas, 1994).

One interesting feature of halophytic biomass behaviour in drylands is its slow decomposition rate, a sort of "salami effect", favouring the long term sequestration of the captured carbon; however such effect has been questioned, at least for specific environmental conditions (Goodfriend *et al.*, 1998).

It has also been proposed (e.g. Douglas, 1994) to use halophytes to produce bioenergy, since annual dry biomass yields in the range of 17 to 34 metric tons per hectare have been reported for seawater irrigated plants in an experimental Mexican farm (from researches conducted in Sicily by the authors a biomass yield in the order of 10 to 15 metric tons appears more probable, however). The solution is certainly attractive, since almost no fossil fuel would be used to add CO₂ to the already overburdened atmosphere, but the problem has been overlooked of the high ash and salt content in such biomass, which can be detrimental in the process of bioelectricity production with the current technologies.

ECONOMIC AND SOCIAL CONSIDERATIONS

Until today the possible agricultural utilization of saline lands has been overlooked, in the belief that it would be un-economic. But if worthless, saline lands and waters are used to grow dedicated halophytes, able to produce some useful yield, albeit at a lower level than in good arable lands, then the economic framework can be totally different, particularly if externalities are taken into account.

Externalities can include social benefits depending on soil protection against water or wind erosion (and hence reductions in-site and off-site damages), biodiversity enhancement, the creation of shelters for wildlife, the protection of atmosphere quality through the production of biofuels, the mitigation of the greenhouse effect through the capture of CO₂. The attribution of a monetary value to such items (their "internalisation") would give to the biosaline agriculture the right to claim a financial support to integrate the limited direct farm income; a significant step in this direction has been taken with the approval of the Kyoto protocol fining those nations which exceed the fixed emissions and permitting the trade of CO₂.

The economic and social aspects of salinity management were analysed in some detail by Feinerman, who quite aptly maintained that "the best way to promote effective water management is via collaboration among economists and soil, water and plant scientists" and clearly focused the conflict between the viewpoints of farmers "who may believe that they should be compensated for respecting environmental rules, and environmental activists, who may believe farmers should bear

responsibility for on-farm pollution. The latter group adheres to the principle that the "Polluter Pays" (Feinerman, appendix to Hillel, 2000). It can be commented that 1) the "Polluter Pays" principle is only acceptable if a reasonable threshold value of pollution is defined (which is not the case at present) and 2) that automatically a reward must be granted to farmers for the positive impact of some activities on the environment, such as CO₂ capturing, wastewater disposal, land protection, landscape embellishment.

The extensive, large-scale adoption of halophyte and salt-tolerant crops in marginal lands, to be irrigated with marginal waters can be determinant in enhancing the production of food, forage and fibres and more in general human well being, contributing also to alleviate the problem of unemployment. As Khan and Duke write, "saline agriculture, however, must fulfil two conditions to be cost-effective" namely, first must produce yields reasonably high and second, must be sustainable (Khan and Duke, 2001).

Furthermore growing crops and achieving significant productions without putting any more pressure on limited good quality land and water resources would contribute to mitigate social strains and litigations, inside and outside national boundaries.

Through such possible pathways agriculture can abandon its present uncomfortable position of defendant as an environmental polluter to assume instead that of the environment defender.

CONCLUSIONS

"The development of mankind has reached the point that a variety of new resources need to be tapped in order to fill our basic needs for food, feed and freshwater": in this statement of Lieth (1999) lies the basic reason for the interest in halophyte research.

A vast, very promising field is now facing the research on halophytes, where only part of the "conventional" knowledge of those previously engaged in research with saline water and soils can be used. Paradoxically, it can be argued that those approaching such researches without the support of the classic background are under some respects in a position of privilege: evidence is in fact accumulating of the need of adopting new agronomic approaches and revising currently accepted guidelines for water quality evaluation and recommendations for irrigation with saline waters.

Undeniably the problems to be overcome for an environmentally safe and economically convenient use of saline lands and waters are still formidable and their solution requires a coordinated effort of a vast number of experts in various domains. However, though challenging the task may appear, it is exciting and stimulating to participate in an undertaking which can lead to enormous strides towards mankind's well being and environmental protection.

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