Rehabilitation of Salt-Affected Land

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Soil salinity is a major threat to the sustainability of agricultural production systems and has defeated civilisations whenever the cost of remediation exceeded the benefits. Among the reasons for this is the complexity of the plant-water-soil nexus and that the causes of salinity are often separated from the damage in time and space. a more concerted effort, perhaps initiated by a philanthropist, is needed to show merchants and agencies how a range of payments for ecosystem services can be turned into true markets in an aggregate way so the 'knowledge of what can be done can be transformed into benefit'.

Keywords: salinity ; natural resource management ; ecosystem services ; halophyte agriculture

1. Soil Salinity and Plant Productivity

The absolute majority of staple crops are classified as glycophytes and show a very significant growth reduction when grown in the presence of salt in the root zone [1]. This is specifically true for wheat, rice, and maize—three cereal crops that are responsible for over 50% of calory intake by humans. For example, a 50% reduction in yield has been measured for rice at 80 mM NaCl, while for durum wheat this threshold is ~100 mM [1]. Salt tolerance was present in wild crop relatives but then lost during domestication process [2][3][4], alongside with tolerance to other abiotic stresses. This is hardly surprising, as human selection targeted mostly agronomical traits such as reduced seed shattering, absence of the secondary dormancy, and fewer and more upright tillers (in cereals) or fruit size, shape, and an ease of harvesting and/or transportation (in horticultural crops) [5][6]. Moreover, a human-driven selection of crop species for the Na+ exclusion trait (the mainstream trend in breeding over the last several decades) has come with a high carbon (ATP) cost for osmotic adjustment [7], thus imposing significant penalties on production.

While the need to improve salinity stress tolerance in staple crops is now recognised as one of the key priorities [8], the progress in a field is much slower than required, due to highly complex physiological and genetic nature of this trait. In this context, there is no single gene that can be targeted by molecular editing to improve salinity tolerance, and assembling a dozen of complementary mechanisms in one ideotype via marker-assisted selection is also not practical. The most promising approach would be to re-domesticate current crops for the lost halophytism [9]. However, this requires a major shift in the breeding paradigms and takes time.

2. Halophytes as Cash Species

A small group of terrestrial plants can not only tolerate substantial amounts of NaCl in soil solution but also benefit from its presence [10][11][12]. These plants are termed halophytes and represent a valuable resource for both using salt-affected lands and utilizing low-quality saline water [13].

Halophytes have long been advocated for use as forage, fodder, oil seeds, and pharmaceuticals [13][14][15][16]. The use of halophytes as salad vegetables have commanded a high price [17], although, the choice of species is quite limited. This is hardly surprising as according to eHaloph, a registry of all halophyte species [18]: out of some 351,000 species adapted to fresh water, only 1386 are listed as salt tolerant, and only 525 can tolerate 70% of seawater. Thus, only about 0.15% of all flowering plants may be classified as true halophytes. As a result of this, the use of halophytes in conventional agriculture is extremely limited, with the notable exception of quinoa. Quinoa (Chenopodium quinoa) is an annual pseudo-cereal crop originating from the Andes that possesses exceptional nutritional qualities and a superior salinity stress tolerance [4][19][20]. Compared to conventional grains, quinoa seeds lack gluten, have a superior ratio of proteins, lipids, and carbohydrates, a higher content of essential amino acids, and are rich in minerals and vitamins [4], and its cultivation is expanding globally [21]. However, a broad application of quinoa as an alternative pseudo-cereal crop in Australia is limited by the fact that most quinoa cultivars have short-day requirements [4], and this species also does not possess sufficient heat tolerance (being originated from high-altitude regions in South America). Thus, the future of quinoa as a crop in Australia requires its further domestication for the above traits [4][22].

Halophytes may also represent a highly valuable resource for desalination and phytoremediation of degraded lands [13][23]. The studies of soil–plant relationships are amongst the oldest in science, beginning at least with Aristotle. The technology of irrigation arose even earlier along with practices to leach the damaging salts. However, long term irrigation in dryer regions usually led to substantial salt build up in the soil, impacting its structure and chemical properties, and eventually its sustainability as an agricultural system. Efforts to delay or ameliorate these effects through leaching these salts differs between soils and the science of irrigation hydraulics and soil treatments continues to evolve with new materials, irrigation technologies and markets. Pasture improvement programs in salt-affected regions throughout the world have used halophytes and salt tolerant shrubs and grass species [14][24]. Trees and shrubs can be valuable complements to grasslands because, being perennial deep-rooted species, they can significantly reduce saline shallow groundwater tables.

3. Towards a Systems Approach to Halophyte Agriculture

The parsimonious course for land managers is to address only the needs of their location and to consider their situation as a new system rather than a particular problem such as the wrong plant or soil treatment [25]. This may result in learning to live with and to take advantage of salinity where it cannot be removed or sequestered away from 'productive' plants and land.

Halophytes utilise a broad range of physiological and anatomical mechanisms assisting their adaptation to saline environments [26]. This includes using Na^+ and Cl^- as 'cheap osmotica' to maintain cell turgor [7][11][27], as well as operate their stomata [28], pronounced tissue succulence that allows more efficient vacuolar salt sequestration [29][30], the presence of highly specialised structures such as salt glands or epidermal bladder cells, [31][32][33], more efficient redox homeostasis, and more efficient chloroplast operation [34][35][36]. These adaptations are individual genetic traits, usually not dependent on each other as assemblages and no halophytes possess all of them. Some of them may be required for conditions of extreme salinities, while others may be more essential for less severe environments. The selection of halophyte plant species is thus context and system specific, of which the degree of salt tolerance may not be as significant as some other factor, such as tolerance of waterlogging [37][38], or a high value product type. In many circumstances a combination of halophytes may be the best low risk approach to ameliorating the salinised situation. Many saline areas are a mosaic of still productive and degrading regions, usually for topographic reasons so the selection of plants may include trees, conventional glycophytes and a range of halophytes such that they reinforce each other bio-physically across a landscape [39][40]. A very promising technique here is companion cropping, or intercropping, where the obligate halophyte thrives in saline conditions, uses some of the saline water, and can remove some soil salt through its salt glands [26] and benefits the growth and production of the associate usual crop, for example tomatoes, [41].

Soil conditions can vary significantly over short distances and assessing and planning for these can be costly [42]. In many circumstances a cost-effective means to map these is required for efficient establishment and to monitor differences over time if the associated ecosystem services are to be marketed [43][44].

Very often the cost, time, and this complexity defeats individual farmers or land managers, although, they may prefer to address the problem if they perceive a solution to be possible, even if the return is lower. This may be for aesthetic reasons, or to avoid the problem spreading to other areas if not addressed [45]. The answer pursued under many officially supported programs to address land degradation is to fund projects justified by the ecosystem or public good values of the investment, but these interventions may not persist unless the actions are seen by the farmer or land manager to be profitable and largely conform with their experience and values.

4. Economic Rationale and Decision Making

Most investigators researching ways to deal with salinity provide some economic justification for their suggestions. This is true for both agricultural, livestock, and aquaculture production [46][47][48][49], as well as remediation of mined, contaminated, or desert soils [50], including reducing saline water tables [51][52][53]. A similar analysis has been conducted for the use of halophytes in carbon sequestration [50][54][55][56][57], and for the overall role in landscape management [23][58][59][60][61]. However, the net effect is to miss the effect of multiple benefits (except for the landscape view), and importantly, not to view their idea from the perspective of the farmer or land manager whose agency is essential if the suggestions are to be taken up in the real world [44].

Astute choice of halophyte(s) can be used to reverse these impacts by improving biodiversity, biomass production above and below ground, soil structure, water holding and cation exchange capacity, and to sequester carbon. Yet, only the above ground gain in biomass can be easily monetised by the land manager and this is often insufficient incentive. Some farmers also invest to address salinity for aesthetic reasons; land conservation ethics are important where there is community support to address social decline in degrading landscapes but are not necessarily applicable in all landscapes and not sufficient in themselves [62]. Public or other external investment support is necessary to generate the ecosystem, public good, aspects of rehabilitating saline land and water, considered externalities.

5. An Essential Role of the Land User

The difficult task for the land manager is to decide what is possible and profitable, particularly considering the scale and technical complexity. The difficult task for the external financier is to make a cost effective and accountable connection with land managers who can deliver the desired ecosystem services.

Much institutional attention in planning is directed towards stakeholder consultation, 'learning from the farmer', and in supporting direct investment to demonstrate successful technology and approaches to restoring saline lands. However, Australian, US, and other international experience has been that official support is costly and the activity ceases once the official support ends [63]. This problem can only be solved by the additional activity, be it payment for ecosystem services or some novel use of degraded water or land, becoming a real market seen of value to the land manager. This in turn will require a transformational change in how natural resources are managed and this requires a much more sustained approach.

Putting these two world views together, that of the farmer or land manager on one hand and the investor in ecosystem services on the other, is the desired outcome of this transformation and for this to occur some mechanism, is required to cross this divide, to 'bridge the gap' [44].

A key element of this system is the focus on finding and supporting an adequate source of income for the farmer and other land manager's investment in these activities, as their agency is essential if the knowledge about what can be done is to be transformed into benefits. This approach shifts the context of land use planning and management towards the land manager while retaining something of the benefits of scale, technology, markets, and availability of finance inherent in official schemes. It gains in appreciation of local variations that occur in many landscapes, particularly saline ones, and in the sense of ownership that results from participatory approaches. It rests on experience with NRM in Australia and elsewhere [64][65], and in small holder extension [66] and might operate as an 'exchange' at a regional level, much as with commodity futures.

6. Valuing Water

Degraded water comes in many forms and can be considered to have a negative value, providing a clear income objective, increasing its value from negative to whatever other use it may be applied [67]. Many of these forms of degradation are also accompanied by salinity, which is a significant and under-appreciated factor in treatment or in utilizing the resource. In the case of a plant-based solution, for example to strip nutrients from an effluent stream, salinity seriously reduces the range of plants that can be used [68]. Globally, some 80% of wastewater is discharged into rivers [69].

Addressing degraded water problems may occur in one of three directions or as a combination: (i) activities to reduce or eliminate the damage in return for payment for the service; (ii) activities to substitute for or 'stretch' fresh water by mixing the waters; and (iii) activities towards some production that makes use of the water, and/or the nutrients it contains and is rewarded in the normal way through the sale of products.

The representative board or committee has the task of addressing this issue of negotiating locally relevant value in collaboration with relevant officials, and then in brokering sales and finance with interested parties. For this, they require a typology of mapping tools able to economically describe the ecological situation at the appropriate scale to support the mobilisation of payments for environmental services (PES) in a useful way [70]. Such tools are vital in capturing the linkages between investments in salinity with relevant infrastructure, to mobilise the different types of finance available for linked investments. This is increasingly possible in an era of heightened awareness of climate impacts on water, which emphasizes the integrated nature of most investments in NRM issues and the linked co-benefits [67].

7. Investment Sources

Investment in salinity mitigation has normally come through official channels and are directed towards research or ground mitigation, augmented by farmer input with the benefits being seen only in salinity terms, usually expressed in increased production. The linkages between the co-benefits of this investment with other aspects of natural resources management have seldom, until recently, been visible to the land manager or financiers. More and more of these linkages are becoming evident so that investments directed towards a particular outcome, for example biodiversity conservation, climate mitigation or water quality is seen to generate others as co-benefits. In this new environment, it behoves investors in NRM, as farmers or land managers, to quantify and articulate these linkages. In this way, more funding can be directed towards integrated activities, which will have a significant impact on the amount a land manager can apply to each situation and so possibly reach a threshold for investment.

Investment sources that might be applied in these ways include (i) usual official investments, but aggregated where possible to achieve co-benefits, (ii) institutions interested in each specific benefit, and (iii) international and Ethical Investment Funds, mediated by a regional or local collaborative body.

The challenge for supporters of the idea of creating a real market for more of the benefits that accrue from successful rehabilitation of salt-affected soils and water is to find a way to fund the process long enough to demonstrate how they can be captured, to merchants, PES traders, and development institutions. For the initial step, an interested philanthropist, or farsighted merchant, might be needed.

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