

Designing the Path for Soil Salinity Management: Lessons Learned and Future Perspectives in Morocco [†]

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Abstract: Soil salinity is a significant threat to crop sustainability and food security. This review aims to provide the basis for effective soil salinity management by examining the different solutions to develop scientifically sound guidelines for farmers, maintain profitable agricultural production in saline farmland irrigated possibly with saline groundwater, and alleviate agricultural land degradation. A lesson learned from the Moroccan experience in tackling salinity is needed for integrating soil and water management and appropriate salt-tolerant crops with innovative agricultural practices as a package of saline agriculture. Moreover, regional and global cooperation to exchange emerging challenges, successful rehabilitation studies, and innovative solutions should be considered. This review concludes that no single parameter could be suggested as the only possible way for soil salinity rehabilitation.

Keywords: salt-affected soil; climate change; strategies; water resources



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1. Introduction

Under the pressure of global climate change and anthropogenic activity, salinization has been a worldwide issue that reduce severely soil quality and crop productivity and gradually reducing the cultivated area. Additionally, the salt-affected area is increasing at a rate of 10% yearly because of high evaporation, low rainfall, inadequate irrigation, and other irrational anthropogenic activities [1]. By 2050, the salinized area will exceed 50% of global arable land [2]. Researchers have identified several plant responses due to soil salinity and recommended different approaches to address the problem. However, there is a lack of coordination between the plants' physiological and biochemical responses and possible management strategies. This paper aims to provide the basis for effective soil salinity management by examining the different solutions to develop scientifically sound guidelines for farmers, maintain profitable agricultural production in saline farmland irrigated possibly with saline groundwater, and combat agricultural land degradation.

2. Material and methods

2.1. Soil Salinity Situation in Morocco

Morocco is a semi-arid Mediterranean country with scarce and irregular precipitation. Most soil and groundwater salinity problems in irrigated areas result directly from poor drainage, the rise of the saline water table, high evapotranspiration, and irrigation with water with increased risk of salinization and sodification [3]. In coastal areas, groundwater alteration is due to seawater intrusion because of over-pumping and pollution by the

irrational use of fertilizers and pesticides in agriculture [4]. The areas most affected by salinity are located in the irrigated areas of Ouarzazate, Tafilalet, Haouz, Basse Moulouya, Tadla, Souss-Massa, and Gharb (Figure 1).

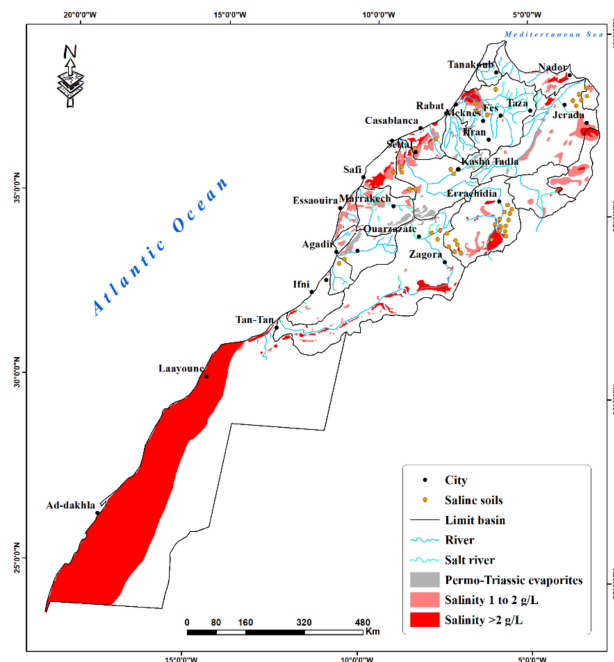


Figure 1. Spatial distribution of saline soil, aquifers and rivers in Morocco, modified from [4].

2.2. Study Approach

Many published works ($n = 300$) covering salt-affected soils and related salinity issues were collected to make an initial assessment. After a systematic literature review and content analysis (Figure 2), we identified the key management strategies and practices.

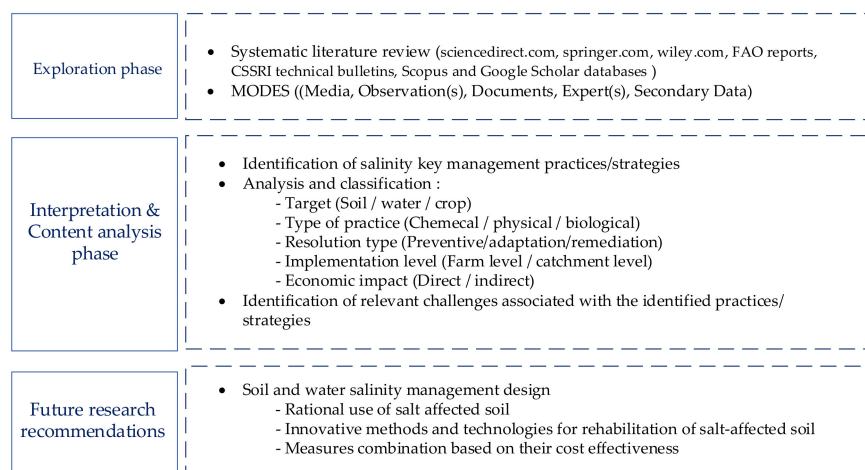


Figure 2. Methodology scheme.

3. Results and Discussion

3.1. Findings on Soil Salinity Rehabilitation in Morocco

The analysis of Moroccan regulations has shown that several actions aimed at protecting soils and combating land degradation are based on three components: (1) a better knowledge of Moroccan soils; (2) a better exploitation of soils; (3) the fight against soil degradation. In addition, the Green Generation strategy, launched in February 2020, aims to consolidate the achievements of the Green Morocco Plan, in particular through the

continuation of programs to control and enhance water use and availability, which go hand-in-hand with soil preservation. This orientation would make it possible to develop and adopt a Code of Sustainable Land Management (according to the vocation), which sets the regulatory aspects, the standards, and the good practices of management, exploitation of soils, and adaptation to climate change.

Several options for managing salt-affected catchments are available. Table 1 provides a non-exhaustive list of selected examples from genetic improvement for salt-tolerance, agronomic practices and irrigation management.

Table 1. Practices and strategies adopted at the farm and territorial levels to tackle soil salinization in Morocco.

Strategies or Management Practice	Target ¹	Type ²	Resolution ³	Level ⁴	Type of Coast ⁵
Inorganic amendment (gypsum, phosphogypsum)	S	C	R	F	D
Organic amendment (Compost, humic acids, etc.)	S	B	R	F	I
Development and use of salt-tolerant cultivar	C	B	A	C	D
Introduction of alternative crops (e.g., Quinoa, Blue panicum, etc.)	CSW	B	A	F	I
Use of plant growth-promoting bacteria (PGPB) (e.g., <i>Robinia pseudoacacia</i> , <i>Phaseolus vulgaris</i> L., etc.)	S	B	A	F	D
Remote sensing and GIS in salinity mapping	S	P	R	C	D
Electromagnetic and tomographic technique in soil salinity	S	P	A	C	I
Genetic engineering (e.g., Exogenous application of compatible solutes such as proline)	C	B	A	C	I
Leaching, implementation of subsurface drainage Systems	W	P	PAR	F	D
Use of brackish water	W	P	A	C	D
Mixing saline and freshwater	W	C	A	C	D
Alternative water sources, e.g., Seawater desalination, Desalination of Irrigation water	W	C	A	C	D
Plant halophytes in high salinity areas	C	B	R	C	D
Inoculation with mycorrhizal associations	C	B	A	F	I
Incorporate agroforestry into management	S	B	A	C	D
Apply biological agents to increase crop resistance to salinity or plant growth under saline conditions (Example: <i>Ulva lactuca</i> extract)	C	B	A	F	I
Use halophilic green algaeto counter salinisation effects on the crop (e.g., <i>Dunaliella salina</i>)	C	B	A	F	I
Intervention in the nutrition of plants (e.g., <i>Phosphorus fertilization</i>)	S	C	A	F	I

¹ W: Water-based practice; C: crop-based practice; S: soil-based practice. ² C: Chemical approach; P: physical practice; B: biological practice. ³ P: Preventive resolution; A: adaptation resolution; R: remediation resolution. ⁴ F: farm level; C: catchment level. ⁵ D: direct coast; I: indirect coast.

Under water scarcity conditions, a trade-off exists between allocating water for salinity management and production [5]. Thus, leaching practices are not relevant option in arid and semi-arid areas. El Hasini et al. [6] recommended the compost application as an amendment to alleviate soil salinity. However, compost quality needs to be very carefully checked to prevent pathogenic organisms or pollutants. Gypsum application, the most recommended amendment for alleviating sodicity stress, is available in a finite amount. In recent decades, constraints such as decreased availability of mined gypsum, deterioration

in product quality, and high market prices have increasingly made gypsum use a costly and less efficient proposition in sodic land reclamation.

3.2. How to Go Forward

Tackling salinity requires a more scientific approach to integrate soil and water management and appropriate crop tolerance to salinity with new agricultural practices as a package of ‘saline agriculture.’ In addition, regional and global cooperation is of utmost importance to exchange emerging new challenges and innovative solutions.

Three considerations are necessary to improve existing farming practices and provide a solid foundation for the successful implementation of sustainable crop production intensification: (1) rational use of salt-affected soils, (2) innovative methods and technologies for the amelioration of salt-affected soils, (3) cost-effectiveness of combined measures. Combined measures for managing saline soils may be based on the following principles: (1) selection of salt-tolerant crops, (2) dilution of salts in the root zone, (3) improving soil structure with organic and biological amendments, (4) improving leaching of salts by irrigation and drainage, (5) reducing surface evaporation with mulch and/or cover crops, (6) maintaining the groundwater table at a safe depth below the root zone and (7) maintaining the crop while reclamation is underway.

4. Conclusions and Perspectives

Morocco faces enormous challenges related to the extent of salt-induced land and water degradation. Despite concerted efforts made to combat soil and water salinity, the problem persists and remains unresolved. Concepts related to the management of soils affected by salinity must be at the heart of water-saving strategies. Therefore, we suggest that all researchers and managers adopt multidisciplinary and integrated approaches to deal with the problem of soil and water salinity. These research approaches must be cost-effective and acceptable to farmers. We recommend through this attempt the creation of national regulations that would govern sustainable agriculture and encourage farmers to adopt sustainable systems based on soil health as well as capacity building to allow decision makers to explore new approaches. The Moroccan experience with salinity highlights the critical importance of high-quality scientific information to guide policy design. It also reinforces the importance of bringing together the perspectives of different disciplines to adequately address such a complex and multifaceted problem. This will require government support, particularly programs for introducing modern technologies to protect the agriculture sector, restore saline soils, and increase their fertility.

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