Management of Salt-Affected Soils: A Photographic Mini-Review

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Soil is the main source of human food, feed for our animals, fiber, and a major source of fuel. The ability of soil to supply life essentials can be impacted by several obstacles that reduce or prevent plant production. Salt-affected soils are common under arid and semi-arid climates, which often produce soils that have salinity and/or alkalinity problems. Salinity and alkalinity are important stresses, mainly including oxidative and osmotic stress, which threaten crop productivity under such soil conditions and can cause significant yield reductions. Successful production in such soils needs a deep understanding of their formation and productivity challenges. Due to the increased areas of salt-affected soils in the world, the management of these soils is a crucial global issue. This paper is a mini-review on salt-affected soils, which include their characterization and suitable management approaches. Nano-management of salt-affected soils as a promising approach will also be discussed and new perspectives and challenges in reclamation of salt-affected soils will be highlighted.

Keywords: Saline soils, alkaline soils, nanofertilizers, nanomaterials, water table.

1. Introduction

Soil is the unconsolidated organic matter and mineral material on the surface of the Earth that formed under different genetic and environmental factors including macro- and micro-organisms, climate, and topography acting on parent materials over a period of time (Brevik and Arnold 2015; Dazzi and Lo Papa 2022). The parent material controls many soil chemical, physical, and morphological characteristics. Soil also consists of horizons that differ in their chemical, physical, biological, and morphological properties. Several threats have been identified to soil and its productivity including erosion (Lei 2022), pollution (Riveros et al. 2022), salinization and alkalinity (Imran et al. 2021), climate change (Brevik 2012; Yang et al. 2022), and degradation (Sharma and Singh 2017; Salnikov et al. 2022) (Fig. 1). The management of salt-affected soils is a crucial issue, and often involves amendments such as gypsum, press mud (Imran et al. 2021), compost (El-Sharkawy et al. 2021), potassium humate (Yao et al. 2022), biochar (Yao et al. 2022), and nanomaterials (El-Sharkawy et al. 2021), as well as microbial approaches (Arora 2021) and Geographic Information System (GIS) techniques (Shaddad et al. 2019; Barman et al. 2021). This work highlights the problems of salt-affected soils, their properties, and their management using photographic evidence. The nano-management of salt-affected soils and other new approaches will also be discussed.
Fig. 1. Several threats cause soil degradation and reduce its productivity, including water logging (the 2 upper photos), pollution (the middle photos), and urban sprawl (lower photos). Photos by El-Ramady.

2. Important soil properties and issues

Soil is considered a non-renewable natural resource due to its very slow formation rate compared to the human lifetime (Stockman et al. 2014; Dazzi and Lo Papa 2022). Soil is crucial to life on earth and plays a central role in several environmental challenges that face humanity today (Weil and Brady 2017; Brevik et al. 2019). Soil suffers from several degradation problems due to human activities that decrease their ability to produce services and goods (Fig. 2) (Amundson et al. 2015). Many soil properties are considered in the classification of soils, including texture, climatic parameters, colour, organic matter content, and more (Bockheim et al. 2014) (Fig. 3).
Fig. 2. Horizons differentiate the pedogenesis that results in soils from geologic weathering (Simson, 1959).

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Several soil forming factors (parent material, time, topography, organisms and climate) and soil forming processes (carboxylation, hydration, leaching, etc.) are well known (Fig. 4). Soil is important to many human activities such as the foundation for transportation infrastructure, houses, and commercial buildings, establishment of public gardens, parks and recreational areas, (Fig. 5), producing ornamentals and rare plants (Fig. 6), and the production of food, feed, and fiber (Fig. 7).

Fig. 3. Soils have a variety of properties that influence their productivity including the non-saline productive clay-derived soil in Giza, Egypt (upper lift photo), saline clay-derived soil in Kafrelsheikh, Egypt (upper right photo), sandy soil in Behera, Egypt (middle lift photo), waterlogged saline soil in Karcag, Hungary (the middle right photo) soils formed in the temperate climate near München, Germany (lower lift photo), and arid saline soil in Siwa, Egypt (the lower right photo) (Photos by El-Ramady).
Fig. 4. Examples of soil forming factors. The upper photos show clay-rich glaciolacustrine (left) and sandy glaciofluvial (right) deposits in the Red River Valley of North Dakota and Minnesota, USA. Even though both were deposited in the same ancient glacial lake at about the same time, the differences in their textures and related properties lead to very different soil properties and different cropping systems in the soils formed in them. The middle photos show the flat Red River Valley in Minnesota, USA (left) and the Cascade Mountains of Washington, USA (right). Subtle changes in topography of only a meter, known as microtopography, are very important in creating different soils in the Red River Valley, while topographic changes important to pedogenesis tend to occur over larger changes in elevation in the Cascades. The lower photos show a desert area that averages about 200 mm of rainfall per year (left) and temperate rain forest that averages about 3,050 mm per year (right) in Washington, USA. Even though they are separated by only about 200 km, the climate soil forming factor is very different. Photos by Brevik.
3. Main functions of soil

Soil has 11 main functions: (1) provision of food, fiber, and fuel, (2) carbon sequestration, (3) water purification and soil contaminant reduction, (4) climate, (5) nutrient cycling, (6) habitat for organisms, (7) flood regulation, (8) source of pharmaceuticals and genetic material, (9) foundation for human infrastructure, (10) provision of construction materials, and (11) cultural heritage (FAO 2015) (Fig. 8).
Fig. 6. Producing ornamental and rare plants is a common agricultural activity that generally needs non-saline soil. All photos from the botanical garden, Debrecen except the upper left which is from Keszthely, Hungary. Photos by El-Ramady.
Fig. 7. Soils are important in the production of food, feed, fiber, and fuel. Upper left – cauliflower in Brazil. Upper right – harvesting potatoes in Minnesota, USA. Middle left – cattle grazing in Austria. Middle right – baling hay in Iceland. Lower left – trees are an important source of fiber, fuel, and building materials (Washington, USA). Lower right – stack of firewood in Germany. Photos by Brevik.
4. Soil obstacles to crop production

Crop productivity can face many stresses, including biotic (soil borne diseases and phytopathogens) and abiotic (drought, salinity, waterlogging, pollution, etc.) stresses that decrease production (Fig. 9). Salinity, drought, and stresses caused by changing climate are particular problems for crop production (García-Sánchez et al. 2020; Koriem et al. 2022; Shalaby et al. 2022). Continuous cultivation in greenhouses is common in arid regions because the greenhouses can provide controlled conditions that are optimal for plant production (Mahmood and Al-Ansari, 2021) (Fig. 10). However, greenhouses may cause problems for cultivated plants due to altered soil bacterial community structure, especially in arid regions (Liu et al. 2020; Gao et al. 2021).
Fig. 9. Several stressors can impact soil productivity, including alkalinity and high shrink-swell clay content (due to high smectite clay content) in Kafr El-Sheikh, Egypt (top photos), salinity as evidenced by salts on the surface of soils in Kafr El-Sheikh (middle photos), waterlogging in Debrecen Hungary and pollution stress in Rome, Italy (lower photos). Photos by El-Ramady.
5. Characterization of salt-affected soils

The main properties used to determine salt-affected soils include electrical conductivity (EC), pH, and soluble ions, particularly sodium, calcium, and magnesium, which are used to calculate exchangeable sodium percent (ESP) and sodium adsorption ratio (SAR). The values of these parameters (EC, pH, and SAR or ESP) are used to determine whether a soil is saline, sodic, saline-sodic, or not affected by salts (Mohamed 2017). The pedogenesis of salt-affected soil is a slow and continuous process with features such as those shown in Fig. 11. The global area of salt-affected soils may be as high as 1125 million hectares (Hossain 2019) (Fig. 12). Several books have recently been published on salt-affected soils and their management (e.g., Abou-Baker & El-Dardiry 2015; Ouda et al. 2018; Chhabra 2021; Pandey et al. 2021). For the 2021 World Soil Day (12 May 2021), the official celebration was organized by the Global Soil Partnership and FAO and was dedicated to the theme "Halt soil salinization, boost soil productivity". FAO stated “Salt affected soils by salinity and sodicity undergo a rapid decline of health, losing their capacity to grow healthy plants, filter water, store carbon in the soil (and take carbon dioxide out of the atmosphere), and other necessary ecosystem functions” (Fig. 13).
Fig. 11. The main characterization of salt-affected soils includes salts on the soil surface as shown in the upper and middle photos in Kafr El-Sheikh region, whereas the lower photos show waterlogged saline soils in Karcag region, Hungary. Soils with high sodium content can hold water because they lose their structure, making it difficult for water to pass through the soil. Photos by El-Ramady).
Fig. 12. A global map of soil stressors. Areas in pink are affected by salinity or alkalinity. Map courtesy of USDA-NRCS.
6. Management of salt-affected soils

Several reports have been published on salt-affected soils and their management from different regions such as Argentina (Imbellone et al. 2021; Taboada et al. 2021), China (Wang et al. 2022), India (Dagar et al. 2019; Thimmappa et al. 2019; Mahajan et al. 2020; Barman et al. 2021), Hungary (Gangwar et al. 2021), Bangladesh (Islam et al. 2021), Egypt (Mohamed 2017; Shaddad et al. 2019; Emran et al. 2020; Hafez et al. 2021), Pakistan (Hasan et al. 2021; Sheikh et al. 2022), Uzbekistan (Devkota et al. 2022), the United States of America (Fiedler et al. 2021), and Latin America (Taleisnik et al. 2021), as well as on the global level (Sharma and Singh 2017; Chhabra 2021). Salt-affected soils can be identified using remote sensing data through the random forest technique (Rani et al. 2022).

The main problems of salt-affected soils include salinity and/or alkalinity, which cause decline in soil productivity. Sodic soils suffer from the loss of structure, which restricts water movement and root growth. Salt-affected soils in the Nile Delta may result from low irrigation water quality, water logging, and saline water intrusion (Mohamed 2017). Due to the low rainfall and high evapotranspiration rates in such zones, there is low leaching of ions affiliated with salts. Therefore, these ions accumulate in soil layers causing soil salinization (Mohamed 2017).

The management of saline soils is mainly focused on decreasing soil salinity by leaching the affiliated ions out of the soil using materials like gypsum and high-quality water. Agricultural practices like paddy rice cultivation, soil mulching, and growing deep-rooted crops such as alfalfa to lower the local water table.
can also be used to manage and reclaim saline soils (Fig. 14). Improving drainage and proper irrigation and fertilization programs are also important management practices. Soil amendments are often used to displace sodium ions from cation exchange sites, build soil structure, and decrease soil pH. The most commonly used amendments include gypsum, sulphur, and sulfuric acid, organic amendments (mainly materials like compost), and combined chemical and organic amendments, as well as bioremediation using salt-tolerant crops like paddy rice, sugar beets, and barley (Mohamed 2017; Dagar et al. 2019). Other amendments that have been applied for management of salt-affected soils include low-cost industrial by-products like press mud (Imran et al. 2021) and zeolite or Ca-zeolite (Sharma and Singh 2017), which improve soil aggregation, increase soil hydraulic conductivity, and reduce clay dispersion in the soil, which aids in leaching undesirable ions from the soil (Sharma and Singh 2017). Microbial approaches are considered promising bioameliorators of salt-affected soils. These include arbuscular mycorrhizal fungi (AMF) and plant growth-promoting rhizobacteria (PGPR), which exhibit considerable salt tolerance and have great potential to promote plant growth in saline and sodic soils (Arora 2021). Many problems occur for cultivated plants under salinity/alkalinity, including high uptake and accumulation of Na⁺ in leaves, which increase the reactive oxygen species (ROS) and decrease the uptake of essential nutrients, which reduces plant productivity (Munir et al. 2021).

![Fig. 14. Approaches to manage salt-affected soils include zero tillage and applications of compost, growing paddy rice (upper photos), using plastic mulch in the field or greenhouse (middle photos), and using different growth media or green mulching (lower photos). The left photos are from Germany (München), Hungary (Debrecen), and Italy (Bari), respectively from top to bottom. The right photos are from Egypt. Photos by El-Ramady.](image-url)
7. Nano-Management of salt-affected soils

Recently, the application of nanomaterials (e.g., nanofertilizers) have been investigated as a way to support global food production (Fig. 15; Table 1). These nanofertilizers have important impacts under stressful conditions like those found in salt-affected soils because they are slow-release fertilizers with high nutrient use efficiency (Kheir et al. 2019). The role of nanofertilizers or nutrient nanoparticles under stresses has been investigated for crops such as rice (Kheir et al. 2019), faba bean (El-Sharkawy et al. 2021), and banana (Ding et al. 2022). In addition to nanofertilizers, halophytic-based nanoparticles have been shown to improve crop productivity under salinity stress by improving water use efficiency and enhancing the plants’ ion flux, plant photosynthesis efficiency, the production of proteins involved in oxidation-reduction reactions, detoxification of ROS, and hormonal signaling pathways (Mall et al. 2021; Munir et al. 2021).

Fig. 15. The role of nano-nutrients or nanofertilizers in supporting the growth of cultivated plants under abiotic and/or biotic stresses is important and needs more research. Studies that investigate the interplay between stressed plants and nano-nutrients is critical for human health. Red color in the figure indicates reasons that plant damage will occur, whereas the green indicates the promotion or enhancement of plant growth. Figure drawn by Y. Eid
The following strategies are proposed to develop sustainable approaches and solutions, separately and/or in combination, to improve productivity of crops and their nutrition under saline conditions (Ondrasek et al. 2022):

1- Production of genotypes or varieties tolerant to salinity or transfer genes for salinity tolerance from halophytes through breeding and genetic approaches, 2- Management of soil, water, and crops to control and avoid the detrimental effects of salinity to crops by application of specific agro/technical/technological options such as application of modern, low pressure, localized irrigation, improved drainage and tillage, grafting onto salt-tolerant rootstocks, and seed priming, 3- Application of organic and inorganic soil amendments such as organic fertilizers (compost), ZnSO₄, gypsum, lime, Si-enriched materials, phytohormones, nanomaterials like nanofertilizers and nano-based growth promoters, and 4- Detection and monitoring of soil salinity using remote sensing, salinity monitoring, ecological indicators, and mega-data analyses.

8. Conclusions

There are many potential stressors that create challenges to the production of the food, feed, fiber, and fuel that are essential to human health and well-being. One of the most important, and one that is gaining in importance under global climate change and the reliance of our modern food supply on irrigation, is soil salinization. This makes the management and remediation of salt-affected soils a very important topic. Current options to deal with these soils include the use of amendments to improve soil aggregation and enhance the leaching of salt-associated ions, careful irrigation management, lowering of the water table to reduce accumulation of salts in soil and provide for leaching, and the use of salt-tolerant crops in salt-affected soils. Future opportunities for research include the use of GIS, remote sensing, and spatial statistics to understand salt-affected soil distribution and changes in that distribution, genetics and plant breeding to improve crop resistance to salts, and the use of nanofertilizers to enhance the resistance of crops to salt stresses. Research into crop production on salt-affected soils remains an extremely important topic that needs attention and funding.

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References


Islam MA, de Bruyn LL, Warwick NWM, Koech R (2021). Salinity-affected threshold yield loss: A signal of adaptation tipping points for salinity management of dry season rice cultivation in the coastal areas of Bangla-


