Environment, Biodiversity & Soil Security

http://jenvbs.journals.ekb.eg/

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

Hassan El-Ramady [1], Salah E.-D. Faizy [1], Megahed M. Amer [2], Tamer Elsakhawy [3], Alaa El-Dein Omara [3], Yahya Eid [4], and Eric C. Brevik [5]

[1] Soil and Water Dept., Faculty of Agriculture, Kafrelsheikh University, 33516 Kafr El-Sheikh, Egypt

[2] Soil Improvement and Conservation Dept., Water and Environment Research Institute, Agricultural Research Center, Giza, Egypt

[3] Agriculture Microbiology Department, Soil, Water and Environment Research Institute (SWERI), Sakha Agricultural Research Station, Agriculture Research Center, 33717 Kafr El-Sheikh, Egypt

[4] Dean, Faculty of Agriculture, Kafrelsheikh University 33516 - Kafr El-Sheikh, EGYPT.

[5] Dean, College of Agricultural, Life, and Physical Sciences Agriculture Building, Room 200 Southern Illinois University 1205 Lincoln Drive Carbondale, IL 62901 USA

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; Saljnikov 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.

---

*Corresponding author e-mail: ramady2000@gmail.com

Received: 03/04/2022; Accepted: 25/04/2022

DOI: 10.21608/jenvbs.2022.131286.1172

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)**.

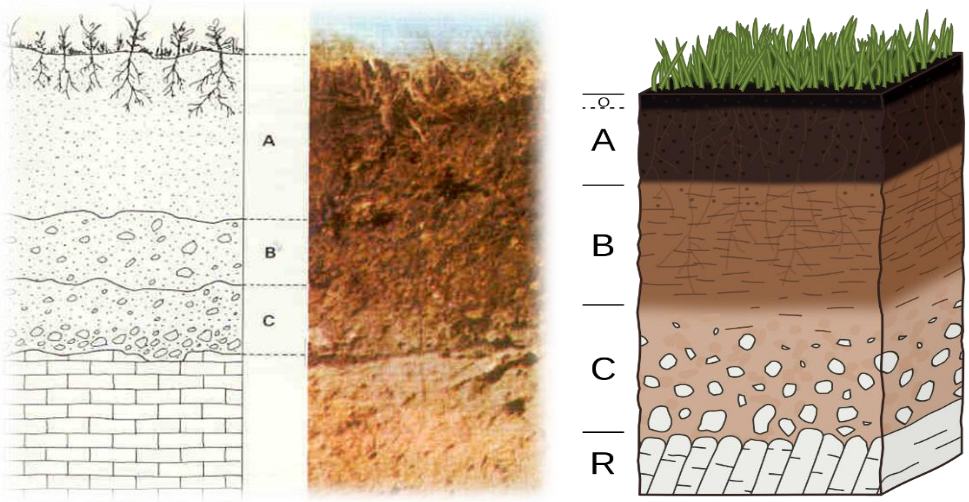

Fig. 2. Horizons differentiate the pedogenesis that results in soils from geologic weathering (Simson, 1959).

Source: By Carlosblh, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=563611
By Tomáš Kebert, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=101870773

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.

Fig. 5. Some common uses of soil include as a foundation for bridge building, a pump station for agricultural drainage (the upper photos), channel or drainage ditch (the middle photos), for building construction, or as a public garden (lower photos). Photos by El-Ramady.

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.

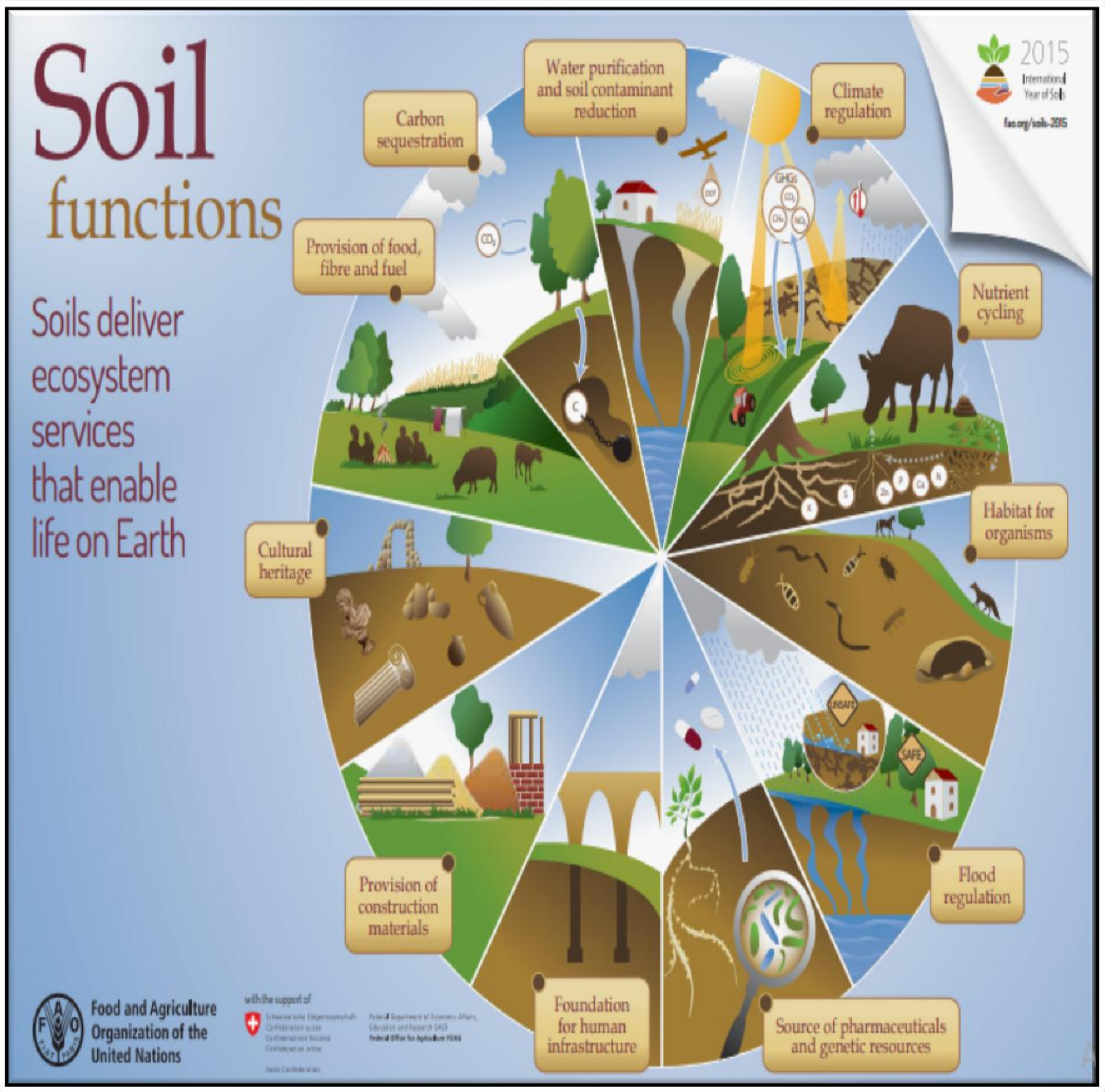

Fig. 8. The main soil functions as presented by FAO (2015). Soils deliver ecosystem services that enable life on Earth (source https://www.fao.org/3/ax374e/ax374e.pdf).

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.

Fig 10: Greenhouses, such as these along the southern coast of Spain, are often used in arid environments to provide controlled conditions for plant production in what would otherwise be an inhospitable environment for most crop production. Photo by Brevik.

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).

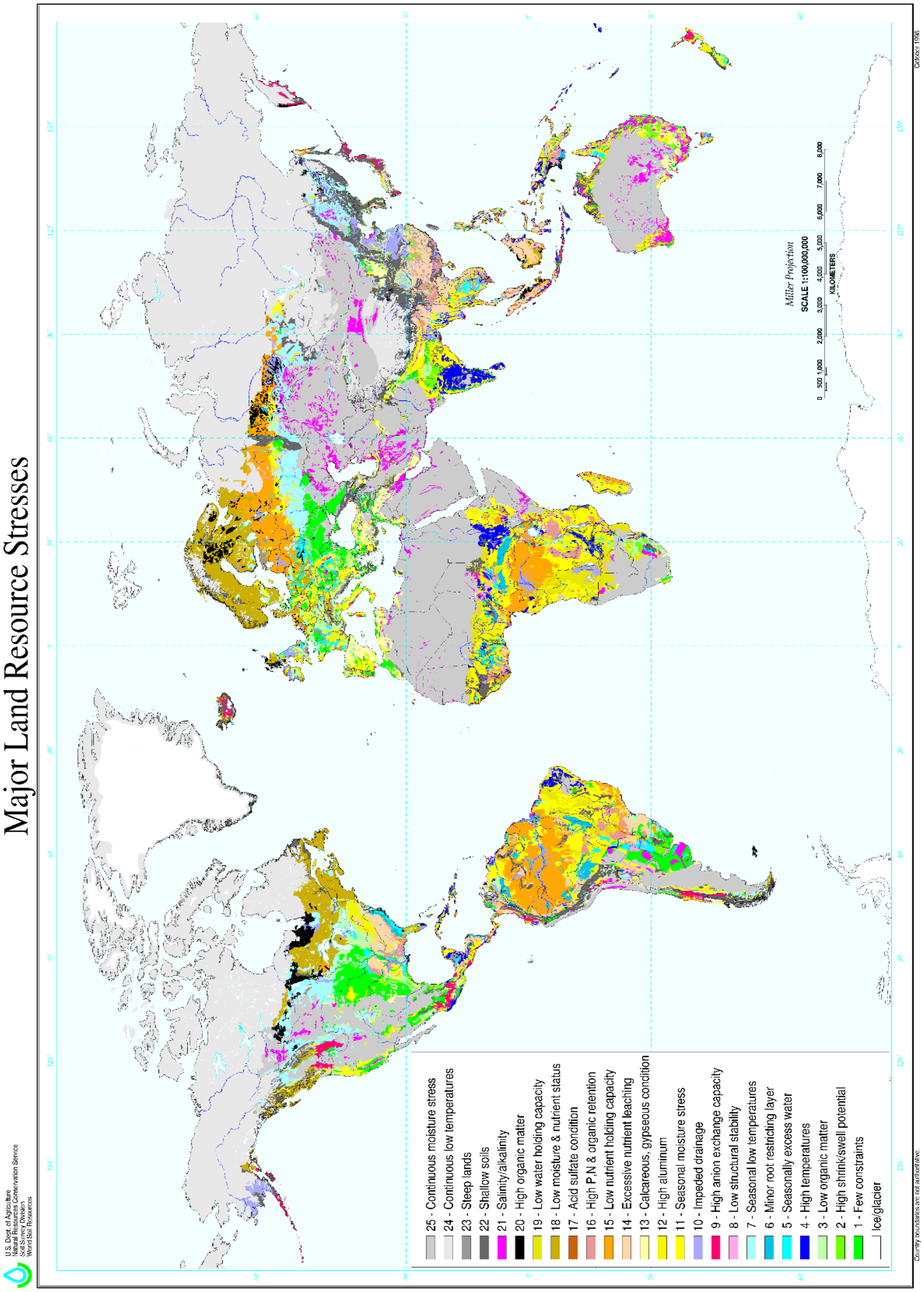

Fig. 12. A global map of soil stressors. Areas in pink are affected by salinity or alkalinity. Map courtesy of USDA-NRCS.

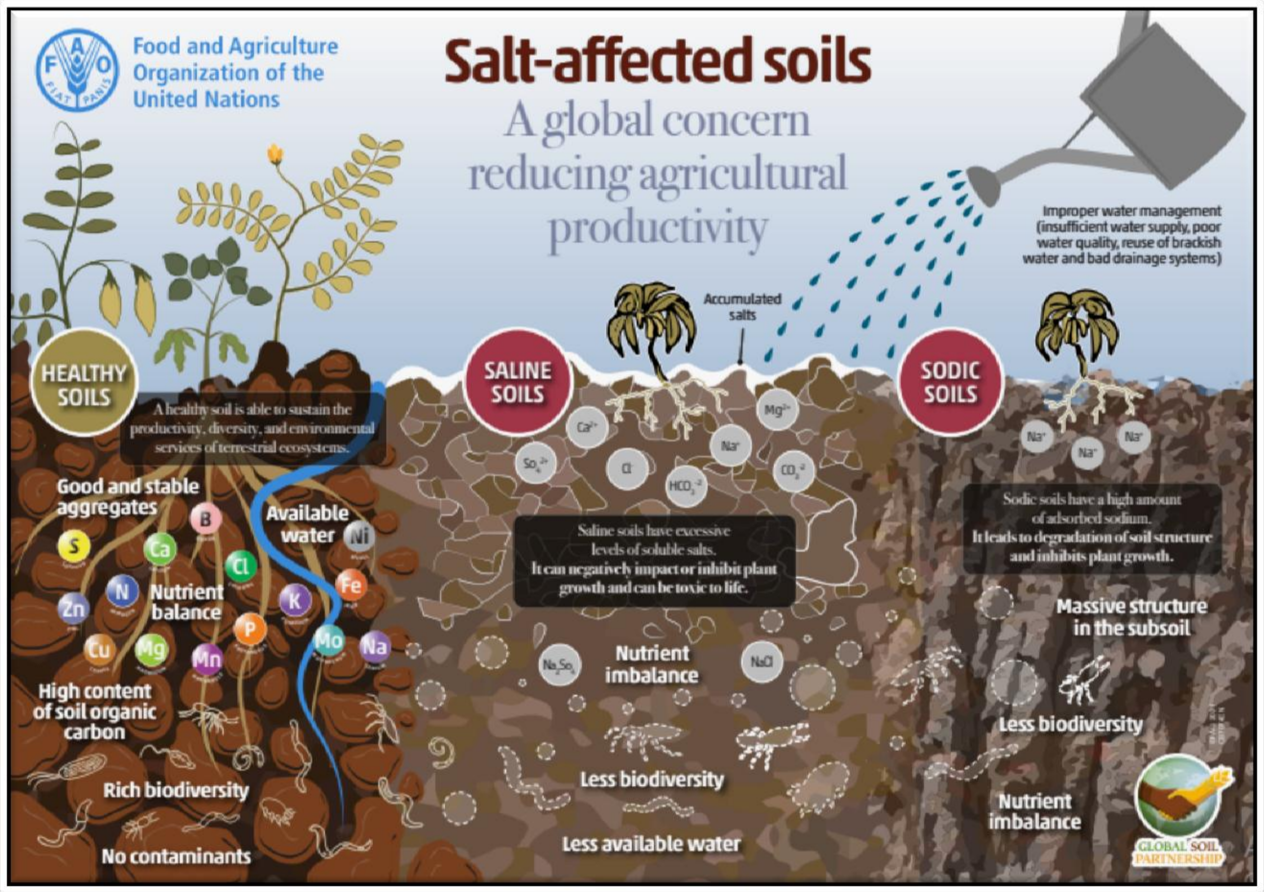

Fig. 13. Differences between healthy, saline, and sodic soils. The healthy soils have good and stable aggregates, high organic-C and nutrients contents and available water capacity, are rich in biodiversity, and have no pollution. The saline soil has nutrient imbalances, less biodiversity, and lower available water compared to healthy soil. The sodic soils have a massive structure in the subsoil, nutrient imbalances, and less biodiversity compared to healthy soils. Source: https://www.fao.org/3/cb7074en/cb7074en.pdf; accessed 20 March 2022.

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 bio-ameliorators 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.

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).

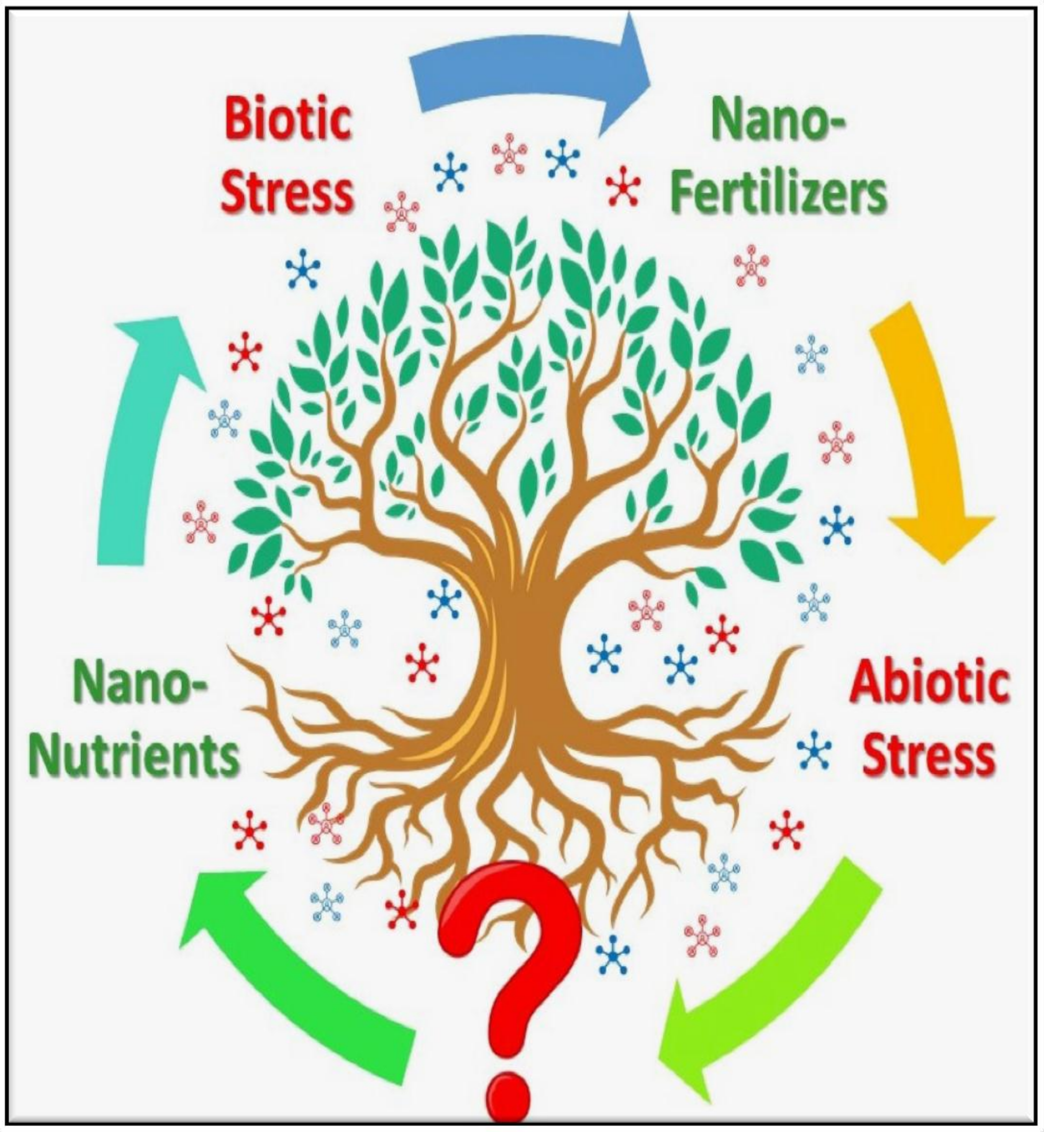

Fig. 15. The role of nano-nutrients or nanofertilizers in supporting the growth of cultivated plants under abiotic and/or biotic stresses is important and needs more research. Studies that investigate the interplay between stressed plants and nano-nutrients is critical for human health. Red color in 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

Table 1. Impact of nanomaterials or nanofertilizers in promoting crop production under salt-affected soils.

Cultivated crop	Used nanomaterials	Soil characteristics	Response of crop	Ref.
Rice (*Oryza sativa*, L.), var. Giza 178	Nano -Zn, nano-Si (30, 25 nm and 50, 2.5 mg L^{-1}, resp.)	Clayey, EC 7.6 dS m^{-1}, SAR (14), ESP (22.5)	Integrated management using both nano-Zn, and nano-Si in addition to using straw–filled ditches	[1]
Faba bean (*Vicia faba* L.), var. Sakha 1	Nano-ZnO at levels of 1, and 2 $g·L^{-1}$ (40–50 nm)	pH (8.43), EC (7.48 dS m^{-1}), SAR, ESP (16.23, 18.6) clayey	Integrated application of nano-ZnO compost and S to reclaim saline-sodic soils	[2]
Banana (*Musa* spp.)	Green nano-silica (150 and 300 mg L^{-1})	Sandy irrigated with groundwater (EC = 4.12 dS m−1)	Green nano-silica improved the productivity and quality under sandy soil and saline irrigation	[3]

List of refs. [1] Kheir et al. (2019), [2] El-Sharkawy et al. (2021), [3] Ding et al. (2022)

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), $ZnSO_4$, gypsum, lime, Si-enriched materials, phytohormones, nanomaterials like nanofertilizers and nano-based growth promotors, 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-effected 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.

Consent for publication: All authors declare their consent for publication.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

Contribution of Authors: All authors shared in writing, editing and revising the MS and agree to its publication.

References

Abou-Baker NHA, El-Dardiry EA (2015). Integrated Management of Salt Affected Soils in Agriculture: Incorporation of Soil Salinity Control Methods. Academic Press, Cambridge, MA.

Amundson R, Berhe AA, Hopmans JW, Olson C, Sztein AE, Sparks DL (2015). Soil and human security in the 21st century. Science, 348. https://doi.org/10.1126/science.1261071

Arora S (2021). Microbial Approaches for Bio-Amelioration and Management of Salt Affected Soils. In: A. Rakshit et al. (eds.), Soil Science: Fundamentals to Recent Advances, https://doi.org/10.1007/978-981-16-0917-6_22, pp: 433 – 447. Springer Nature Singapore Pte Ltd.

Barman A, Sheoran P, Yadav RK, Abhishek R, Sharma R, Prajapat K, Singh RK, Kumar S (2021). Soil spatial variability characterization: Delineating index-based management zones in salt-affected agroecosystem of India.

Journal of Environmental Management, 296, 113243. doi:10.1016/j.jenvman.2021.113243

Bockheim JG, Gennadiyev AN, Hartemink AE, Brevik EC (2014). Soil-forming factors and Soil Taxonomy. Geoderma 226, 231-237. https://doi.org/10.1016/j.geoderma.2014.02.016

Brevik EC (2012). Soils and climate change: gas fluxes and soil processes. Soil Horizons 53(4), 12-23. https://doi.org/10.2136/sh12-04-0012

Brevik EC, Arnold RW (2015). Is the traditional pedologic definition of soil meaningful in the modern context? Soil Horizons 56(3), https://doi.org/10.2136/sh15-01-0002.

Brevik EC, Pereg L, Pereira P, Steffan JJ, Burgess LC, Gedeon CI. 2019. Shelter, clothing, and fuel: often overlooked links between soils, ecosystem services, and human health. Science of the Total Environment 651, 134-142. https://doi.org/10.1016/j.scitotenv.2018.09.158

Chhabra R (2021). Salt-affected Soils and Marginal Waters Global Perspectives and Sustainable Management. Springer Nature Switzerland AG, https://doi.org/10.1007/978-3-030-78435-5

Dagar JC, Yadav RK, Singh A, Singh NT (2019). Historical Perspectives and Dynamics of Nature, Extent, Classification and Management of Salt-affected Soils and Waters. In: J. C. Dagar et al. (eds.), Research Developments in Saline Agriculture, https://doi.org/10.1007/978-981-13-5832-6_1, pp: 3 – 52. Springer Nature Singapore Pte Ltd.

Dazzi, C, Lo Papa G (2022). A new definition of soil to promote soil awareness, sustainability, security and governance. International Soil and Water Conservation Research 10, 99-108. https://doi.org/10.1016/j.iswcr.2021.07.001 2095

Devkota KP, Devkota M, Rezaei M, Oosterbaan R (2022). Managing salinity for sustainable agricultural production in salt-affected soils of irrigated drylands. Agricultural Systems 198, 103390. https://doi.org/10.1016/j.agsy.2022.103390

Ding Z, Zhao F, Zhu Z, Ali EF, Shaheen SM, Rinklebe J, Eissa MA (2022). Green nanosilica enhanced the salt-tolerance defenses and yield of Williams banana: A field trial for using saline water in low fertile arid soil. Environmental and Experimental Botany 197, 104843. https://doi.org/10.1016/j.envexpbot.2022.104843

El-Sharkawy M, Abd EL-Aziz M, Khalifa T (2021). Effect of nano-zinc application combined with sulfur and compost on saline-sodic soil characteristics and faba bean productivity. Arabian Journal of Geosciences 14, 1178. https://doi.org/10.1007/s12517-021-07564-8

Emran M, Doni S, Macci C, Masciandaro G, Rashad M, Gispert M (2020). Susceptible soil organic matter, SOM, fractions to agricultural management practices in salt-affected soils. Geoderma, 366, 114257. doi:10.1016/j.geoderma.2020.11425

Fiedler DJ, Clay DE, Joshi DR, Engel A, Marzano SY, Jakubowski D, Bhattarai D, Reese CL, Bruggeman SA, Clay SA (2021). CO_2 and N_2O emissions and microbial community structure from fields that include salt-affected soils. Journal of Environmental Quality 50, 567-579.

Gangwar RK, Makádi M, Demeter I, Táncsics A, Cserháti M, Várbíró G, Singh J, Csorba A, Fuchs M, Michéli E, Szegi T (2021). Comparing Soil Chemical and Biological Properties of Salt Affected Soils under Different Land Use Practices in Hungary and India. Eurasian Soil Science, 54, (7), 1007–1018. DOI: 10.1134/S1064229321070048

Gao YH, Lu XH, Guo RJ, Hao JJ, Miao ZQ, Yang L, Li SD (2021). Responses of Soil Abiotic Properties and Microbial Community Structure to 25-Year Cucumber Monoculture in Commercial Greenhouses. Agriculture, 11, 341. https://doi.org/10.3390/agriculture11040341

García-Sánchez F, Simón-Grao S, Martínez-Nicolás JJ, Alfosea-Simón M, Liu C, Chatzissavvidis C, Pérez-Pérez JG, Cámara-Zapata JM (2020). Multiple stresses occurring with boron toxicity and deficiency in plants. J. Hazard. Mater., 397, 122713.

Hafez EM, Osman HS, El-Razek UAA, Elbagory M, Omara AE-D, Eid MA, Gowayed SM (2021). Foliar-Applied Potassium Silicate Coupled with Plant Growth-Promoting Rhizobacteria Improves Growth, Physiology, Nutrient Uptake and Productivity of Faba Bean (*Vicia faba* L.) Irrigated with Saline Water in Salt-Affected Soil. Plants, 10, 894. https://doi.org/10.3390/plants10050894

Hasan, F ul, Fatima B, Heaney-Mustafa S (2021). A critique of successful elements of existing on-farm irrigation water management initiatives in Pakistan. Agricultural Water Management, 244, 106598. doi:10.1016/j.agwat.2020.106598

Hossain MS (2019). Present Scenario of Global Salt Affected Soils, its Management and Importance of Salinity Research. Int. Res. J. Biol. Sci., 1 (1), 1-3.

Imbellone PA, Taboada MA, Damiano F, Lavado RS (2021). Genesis, Properties and Management of Salt-Affected Soils in the Flooding Pampas, Argentina. E. Taleisnik and R. S. Lavado (eds.), Saline and Alkaline Soils in Latin America, https://doi.org/10.1007/978-3-030-52592-7_10, pp: 191 – 208. Springer Nature Switzerland AG

Imran M, Ashraf M, Awan AR (2021). Growth, yield and arsenic accumulation by wheat grown in a pressmud amended salt-affected soil irrigated with arsenic contaminated water. Ecotoxicology and Environmental Safety 224, 112692. https://doi.org/10.1016/j.ecoenv.2021.112692

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 Bangladesh. Journal of Environmental Management 288, 112413. https://doi.org/10.1016/j.jenvman.2021.112413

Kheir AMS, Abouelsoud HM, Hafez EM, Ali OAM (2019). Integrated effect of nano-Zn, nano-Si, and drainage using crop straw–filled ditches on saline sodic soil properties and rice productivity. Arabian Journal of Geosciences 12, 471. https://doi.org/10.1007/s12517-019-4653-0

Koriem MA, Gaheen SA, El-Ramady H, Prokisch J, Brevik EC (2022). Global Soil Science Education to Address the Soil – Water – Climate Change Nexus. Env. Biodiv. Soil Security, 6, 2022, 000-00**.** DOI: 10.21608/jenvbs.2022.117119.1160

Lei XQ (2022). Two-dimensional finite element modeling of seepage-erosion coupled process within unsaturated soil slopes. Journal of Mountain Science 19(2). https://doi.org/10.1007/s11629-021-6776-5

Liu X, Li Y, Ren X, Chen B, Zhang Y, Shen C, Wang F, Wu D (2020). Long-Term Greenhouse Cucumber Production Alters Soil Bacterial Community Structure. Journal of Soil Science and Plant Nutrition 20, 306–321. https://doi.org/10.1007/s42729-019-00109-9

Mahajan G, Das B, Morajkar S, Desai A, Murgaokar D, Kulkarni R, Sale R, Patel K (2020). Soil quality assessment of coastal salt-affected acid soils of India. Environmental Science and Pollution Research 27, 26221–26238. https://doi.org/10.1007/s11356-020-09010-w

Mahmood F, Al-Ansari TA (2021). Design and thermodynamic analysis of a solar powered greenhouse for arid climates. Desalinization 497, 114769. https://doi.org/10.1016/j.desal.2020.114769

Mall AK, Misra V, Santeshwari, Pathak AD, Srivastava S (2021). Sugar Beet Cultivation in India: Prospects for Bio-Ethanol Production and Value-Added Co-Products. Sugar Tech 23(6), 1218–1234. https://doi.org/10.1007/s12355-021-01007-0

Mohamed NN (2017). Management of Salt-Affected Soils in the Nile Delta. In: A.M. Negm (ed.), The Nile Delta, Hdb Env Chem, Springer International Publishing AG, DOI 10.1007/698_2016_102

Munir N, Hanif M, Dias DA, Abideen Z (2021). The role of halophytic nanoparticles towards the remediation of degraded and saline agricultural lands. Environmental Science and Pollution Research 28, 60383–60405. https://doi.org/10.1007/s11356-021-16139-9

Ondrasek G, Rathod S, Manohara KK, Gireesh C, Anantha MS, Sakhare AS, Parmar B, Yadav BK, Bandumula N, Raihan F, et al. (2022). Salt Stress in Plants and Mitigation Approaches. Plants, 11, 717. https://doi.org/10.3390/plants11060717

Ouda SAH, Zohry AE, Morsy M (2018). Cropping Pattern Modification to Overcome Abiotic Stresses: Water, Salinity and Climate. Springer, Cham.

Pandey CS, Singh RP, Pandey AK (2021). Reclamation of Salt Affected Soil Through Fruit Tree Plantation: An Eco-Friendly and Sustainable Approach. LAP LAMBERT Academic Publishing, Saarbrücken.

Raab G (2019). The Tor Exhumation Approach – A New Technique to Derive Continuous *In-Situ* Soil Erosion and Surface Denudation Models. D. Sc. Thesis, Zürich Uni., DOI: 10.13140/RG.2.2.29904.87043

Rani A, Kumar N, Sinha NK, Kumar J (2022). Identification of salt-affected soils using remote sensing data through random forest technique: a case study from India. Arabian Journal of Geosciences 15, 381. https://doi.org/10.1007/s12517-022-09682-3

Riveros G, Urrutia H, Araya J, Zagal E, Schoebitz M (2022). Microplastic pollution on the soil and its consequences on the nitrogen cycle: a review. Environmental Science and Pollution Research 29, 7997–8011. https://doi.org/10.1007/s11356-021-17681-2

Shaddad SM, Buttafuoco G, Elrys A, Castrignanò A. (2019). Site-specific management of salt affected soils: A case study from Egypt. Science of The Total Environment, 688, 153–161. doi:10.1016/j.scitotenv.2019.06.2

Shalaby TA, Bayoumi Y, Eid Y, Elbasiouny H, Elbehiry F, Prokisch J, El-Ramady H, Ling W (2022). Can Nanofertilizers Mitigate Multiple Environmental Stresses for Higher Crop Productivity? Sustainability, 14, 3480. https://doi.org/10.3390/su14063480

Sharma DK, Singh A (2017). Current Trends and Emerging Challenges in Sustainable Management of Salt-Affected Soils: A Critical Appraisal. In: S. Arora et al. (eds.), Bioremediation of Salt Affected Soils: An Indian Perspective, DOI 10.1007/978-3-319-48257-6_1, pp: 1 – 40. Springer International Publishing AG

Sheikh AT, Mugera A, Pandit R, Burton M, Davies S (2022). What determines the time to gypsum adoption to remediate irrigated salt-affected agricultural lands? Evidence from Punjab, Pakistan. Soil and Tillage Research 217, 105266. https://doi.org/10.1016/j.still.2021.105266

Simonson RW (1959). Outline of a generalized theory of soil genesis. Soil Science Society of America Proceedings 23, 152-156.

Stockman U, Minasny B, McBratney AB (2014). How fast does soil grow? Geoderma, 216, 48-61. https://doi.org/10.1016/j.geoderma.2013.10.007

Taboada MA, Damiano F, Cisneros JM, Lavado RS (2021). Origin, Management and Reclamation Technologies of Salt-Affected and Flooded Soils in the Inland Pampas of Argentina. E. Taleisnik and R. S. Lavado (eds.), Saline and Alkaline Soils in Latin America, https://doi.org/10.1007/978-3-030-52592-7_11, pp: 209 – 228. Springer Nature Switzerland AG

Taleisnik E, Raúl S. Lavado RS (2021). Saline and Alkaline Soils in Latin America Natural Resources, Management and Productive Alternatives. Springer Nature Switzerland AG, https://doi.org/10.1007/978-3-030-52592-7

Thimmappa K, Raju R, Tripathi RS, Dagar JC, Yadav RK (2019). Management of Salt-affected Soils in India: Gender and Socioeconomic Dimensions for Sustainable Livelihoods. In: J. C. Dagar et al. (eds.), Research Developments in Saline Agriculture, https://doi.org/10.1007/978-981-13-5832-6_29, pp: 835 – 851. Springer Nature Singapore Pte Ltd.

Wang J, Lin C, Han Z, Fu C, Huang D, Cheng H (2022). Dissolved nitrogen in salt-affected soils reclaimed by planting rice: How is it influenced by soil physicochemical properties? Science of The Total Environment, 824, 153863. https://doi.org/10.1016/j.scitotenv.2022.153863

Weil RR, Brady NC (2017). The soils around us. In: The nature and properties of soils. The 15th Ed.; chapter, one. Publisher, Pearson Education, Inc, 13, 978-0133254488.

Yadav AN (2021). Soil Microbiomes for Sustainable Agriculture: Functional Annotation. Sustainable Development and Biodiversity Book Series, Volume 27. Springer Nature Switzerland AG, https://doi.org/10.1007/978-3-030-73507-4

Yang S, Zhao W, Liu Y, Cherubini F, Fu B, Pereira P (2021). Prioritizing sustainable development goals and linking them to ecosystem services, A global expert's knowledge evaluation. Geography and Sustainability, 1, 321e330. https://doi.org/10.1016/j.geosus.2020.09.004

Yang Y, Shi Y, Sun W, Chang J, Zhu J, Chen L, Wang X, Guo Y, Zhang H, Yu L, et al. (2022). Terrestrial carbon sinks in China and around the world and their contribution to carbon neutrality. Sci China Life Sci 65, https://doi.org/10.1007/s11427-021-2045-5

Yao R, Li H, Zhu W, Yang J, Wang X, Yin C, Jing Y, Chen Q, Xie W (2022). Biochar and potassium humate shift the migration, transformation and redistribution of urea-N in salt-affected soil under drip fertigation: soil column and incubation experiments. Irrigation Science 40, 267–282. https://doi.org/10.1007/s00271-021-00763-x.