Chapter 13
Status, Drivers, and Suggested Management Scenarios of Salt-Affected Soils in Africa

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Abstract Africa with its massive land area covering 3 billion ha and 65% of the uncultivated arable land is a strategic continent that will determine the future of food systems in the world. Therefore, Africa must prepare itself to rapidly modernize its agriculture for unlocking its full potential while maintaining properly the vast expanses, which are currently in use by millions of smallholder farmers. This chapter discusses soil salinity and sodicity, which are types of soil degradation, and widely prevalent in semi-arid and arid regions of Africa. Presumably, salt-affected soils in Africa occupy about 80,000,000 ha of which 69 million ha are found in the Sub-Saharan Africa (SSA). In SSA an estimated 180 million people are affected while the economic loss due to land degradation is estimated at $68 billion per year. The predominant mechanisms triggering the accumulation of soluble salt in the agricultural soils of Africa are seawater intrusion, rising ground waters in low-lying topography from saline aquifers, and irrigation waters. As the soil dries, salts become concentrated in the soil solution, increasing salt stress. Soils, especially in hot and dry areas, are often naturally salty, but inefficient irrigation and poor drainage lead to waterlogging, which raises the water table, bringing salts in the subsoil nearer the surface. When the water evaporates, salt is left around the roots of plants, preventing them from absorbing water and stunting growth. The more that irrigation is used to boost food production, the more soils turn out to be saline. The accumulation of salts in the root zone can have a variety of agricultural impacts. Vitally, salt not only degrades soils and crop productivity but also increases poverty and social instability. Reversing of soil salinity or sodicity is possible although it takes time and is expensive, as well. Solutions include diversifying the land use types, improving the efficiency of irrigation methods with efficient drainage systems, in-situ moisture conservation using mulches to keep the soils cool and moist, and the use of multipurpose salt tolerant crops with a rotation plan.

Keywords Africa · Causes · Impact · Management · Reclamation · Salt-affected soils

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1 Introduction

The increasing global demand for food and agricultural raw materials makes future studies to optimize the utilization of soil resources very important and urgent. In many arid and semi-arid regions, good soils are scarce with their overall productivity declining because of soil degradation and lack of proper soil and water management practices. Salt-affected soils which are widespread in arid, semi-arid, and coastal regions of sub-humid areas have low productivity. Food production in many parts of the world is severely affected by high salt content soils (IPBES 2018).

Africa is the second-largest continent with about 30 billion ha including adjacent islands, it covers 6% of Earth's total surface area and 20% of its land area of which two-thirds are covered with soils (Sayer et al. 1992). The continent measures about 8,000 km from north, *Ras ben Saka* in Tunisia (37°21′ N) to south, *Cape Agulhas* in South Africa (34°51′15″ S); and about 7,400 km from east, *Ras Hafun*, (51°27′52″ E), which is the most easterly projection that neighbours Cape Guardafui, the tip of the Horn of Africa in Somalia to west, Cape Verde, (17°33′22″ W). Moreover, the coastline in Africa is 26,000 km long (Lewin 1924). Besides, the continent is divided in half almost equally by the Equator. The seas that bound the continent are the Mediterranean Sea, the Red Sea, the Indian Ocean, and the Atlantic Ocean (Fig. 1). Moreover, Africa is the second most populous continent on Earth after Asia with a human population of over 1.2 billion. Relative to the rest of the world, Africa has an abundance of the major natural resources necessary for crop and livestock production. Of the world's land area suitable for sustainable production expansion, Africa has the largest share by far, accounting for about 45% of the total (Deininger et al. 2011). Despite this abundance of natural resources, deforestation, desertification, land degradation, water shortage and contamination, threat to biodiversity, and climate change are the major environmental problems that Africa experiences today. Furthermore, sustaining a reasonably high economic growth rate to match the human population growth rate coupled with ensuring the environmental and natural resources integrity is one of the key challenges (UNEP 2008). The combined effects of these multiple crises have serious consequences on its economic development and social welfare (NEPAD 2013).

Agriculture forms a significant portion of the economies of all African countries, as a sector it can, therefore, contribute towards major continental priorities, such as eradicating poverty and hunger, boosting intra-Africa trade and investments, rapid industrialization and economic diversification, sustainable resource and environmental management, and creating jobs, human security, and shared prosperity. Small farms that are dependent on family labour, with very little machinery and several activities, reflect the dominant type of agriculture in Africa. Subsistence farming remains important. To date, Africa has 33 million family farms of less than 2 ha, accounting for 80% of farms. Africa will have a population of two billion people by 2050, the majority of women and youth. This projection alone underscores the scale of agricultural challenges in Africa particularly in connection to feed Africans,

Fig. 1 Map of Africa showing the surrounding oceans and seas (https://images.app.goo.gl/9NSiY1LP5MnzKrZX8)

to create wealth for them, and to conserve resources for future generations (NEPAD 2013).

Africa, in particular, is vulnerable to land degradation and desertification; and is severely affected. Desertification affects around 45% of Africa's land area, with 55% of this area at high or very high risk of further degradation. It is often considered that land degradation in Africa has been vastly detrimental to agricultural ecosystems and crop production and, thus, an impediment to achieving food security and improving livelihoods (UNEP 2015). The annual cost of desertification is estimated at US$ 9.3 billion. Furthermore, water scarcity will affect over 1.8 billion people by 2025 (AWDR 2006). Within the next 15 to 20 years, the areas considered to have relative water security in Africa will fall from nearly 53 to 35%, affecting some 600 million people. According to some estimates, by 2025, up to 16% of Africa's population (i.e., ~230 million people) will be living in countries facing water scarcity, and 32% (i.e., ~460 million people) in water-stressed countries (IAASTD 2009).

Soil salinization and alkalinization are major threats to the soil resource in Africa and are among the most common land degradation processes. Salt is the savour of foods but the blight of agriculture; in excess, salt kills growing plants. Salt-affected soils pose lower agricultural productivity, instable ecology, economic crisis, eventually social unrest, and downfall of human civilization. According to ADR (2012) reports 4–12% of Africa's GDP is also lost due to environmental degradation. Salt-affected soils in Africa are estimated to cover 80,000,000 ha of which the 68.8 million ha are found in the Sub-Saharan Africa (SSA). In SSA an estimated 180 million people are affected (Mirzabaev et al. 2014) while the economic loss due to land degradation is estimated at $68 billion per year (Nkonya et al. 2016).

2 An Overview of the Africa's Physical Geography

2.1 Topography

The African continent can be described as a huge crystalline mass surrounded by a sedimentary fringe (D'Hoore 1964). To the north, these sediments are folded, forming the Atlas chains, the altitude of which is between 1,500 and 3,600 m. The region of the High Plains, which separates the two principal chains is studded with numerous salt lakes, and varies in altitude from 900 to 1200 m. In the extreme south, the Cape system, equally folded but older, has a relief which is lower and more rounded. Elsewhere (i.e., West Africa, North-West Africa, and the Sahara) the sedimentary fringe has not been folded and the relief is less deformed. The continental plateau of Africa is slightly sloping from S.E. to N.W.: in the S.E. its altitude is of the order of 1500 m, whereas in the N.W. it is of the order of 300 m. The highest summits of the continent, covered by perpetual snow, are found there (Kilimanjaro 6010 m, Kenya 5600 m, Ruwenzori 5500 m) (D'Hoore 1964). Vast plains and plateaus are characteristic of Africa's geography. Second only to Asia in size, Africa is structured around three stable zones of ancient mountain formations called "cratons"—the North-West African craton located in the western Sahara desert, the Congo craton roughly corresponding to the Congo Basin, and the Kalahari (Kgalagadi) craton in southern Africa (Summerfield 1996). Rift Valleys starts in Syria, forms the Jordan Valley, the Dead Sea, the Gulf of Akaba, the Red Sea, and penetrate into the African continent by way of the Awash Valley. On leaving the Abyssinian cleft it divides into two principal branches which pass around Lake Victoria: the easterly one, with Lake Rudolf and a string of lakes, the other one to the west, with the Lakes Albert, Edward, Kivu, Tanganyika, and Rukwa. The crystalline plateau is also marked by big tectonic basins which are very extensive, but slightly lower than the sills and domes which separate them. To the north can be distinguished the basins of the low Sahara, Taoudeni, Murzuk, and the Libyan desert; to the south of the Sahara, the Niger, Chad, Bahr-el-Chazal, White Nile and Congo basins, Lakes Victoria and Kyoga, and the two Kalahari basins (D'Hoore 1964).

2.2 Geology

The African continent has remarkable geologic and tectonic features that make the continent not only full of resources but also susceptible to annual hazards. These features include the oldest cratons, plate subdivision below the Eurasian plate at the North, East African Rift System in the East, the African super swell is a region including the Southern and Eastern African plateaus and the South-eastern Atlantic basin where exceptional tectonic uplift has occurred, resulting in terrain much higher than its surroundings) in the Southern and the divergence with the American plates in the West. Parent material is one of the pedogenetic factors that affect soil properties (Burke 2002; Koojiman et al. 2005; Rodrigo-Comino et al. 2018). The greater part of the African continent can be considered as a Precambrian crystalline massif, bounded to the north by the Atlas chain and to the south by the Cape system. This formation crops out over about a third of the surface of the continent. Rocks of Precambrian age underlie large parts of northern and western Ethiopia and smaller areas in the south and east of the country. The lower beds consist mainly of granite, gneiss, and schists. They are covered by more characteristically sedimentary formations (i.e., quartzites, limestones, dolomites, and phyllites). The Upper Precambrian is made up mainly of sandstone but also contains some schistose formations, limestones, and dolomites, the other two-thirds of the crystalline base are covered by various sediments which, except for primary sediments, are of continental origin (D'Hoore 1964; Thomas 2006). Primary sediments are mostly located in North Africa and the Sahara but the extension of their various formations towards the south is patchy. The Cambrian, which followed a glacial period, is indicated by the presence of tillites, and consists of conglomerates, limestones, schists, sandstones, and volcanic veins. These are also found in Mauritania and Mali. The Devonian, containing schists, limestones, and sandstones, goes down as far as the Ghanaian coast (D'Hoore 1964; Thomas 2006). The Carboniferous is limited to North Africa. These outcrops of primary sediments, of which sandstones and schists are dominant, are relatively important in West Africa. In Africa south of the equator and to the west of longitude 30°E extend the Kalahari deposits, consisting of polymorphous sandstones, sands of fluviatile and aeolian origin, and in places, calcareous lenses of lacustrine origin (D'Hoore 1964; Thomas 2006). The Quaternary formation is characterized by important volcanic eruptions, some of which are active, by lacustrine, fluvial, and fluviomarine sediments, and by coverings of colluvial origin. The Volcanic formation covers huge areas on the continental border which include Ethiopia, Kenya, Rwanda, the Cameroons, Central Nigeria, and Uganda whereas the Aeolian sand deposits form the ergs of the Sahara and the South West African deserts, which cover the greater part of the Kalahari and extend towards the north to just beyond the equator, i.e., the east of Angola, the west of the Zimbabwe, the southern half of the Congo basin (D'Hoore 1964; Thomas 2006).

2.3 Climate

Climate is one of the factors governing the distribution of soils in Africa. Rainfall and temperature regimes are the two most important environmental factors that affect both soil characteristics and soil use. The continent of Africa is characterized by several climatic regimes and ecological zones. All parts of the continent, except the Republic of South Africa, Lesotho, and the Mediterranean countries north of the Sahara, have tropical climates. These tropical climates may be divided into three distinct climatic zones: wet tropical climates, dry tropical climates, and alternating wet and dry climates (Huq et al. 1996). Africa is the world's hottest continent; the average annual temperature exceeds 10 °C. The hottest part receives the most solar radiation and lies between the two tropics as a result of the seasonal displacement of the thermal equator or intertropical convergence zone (ITCZ). At a specific time during the season, the air within this region becomes highly heated and rises to condense at high altitudes over the zone of maximum rainfall (Newell et al. 1972; Nicholson 1994). Overland, the ITCZ tends to follow the seasonal march of the sun and oscillates between the fringes of the Sahara in boreal summer and the northern Kalahari Desert in the austral summer. Rainfall over Africa exhibits high spatial and temporal variability. Mean annual rainfall ranges from as low as 10 mm in the innermost core of the Sahara to more than 2,000 mm in parts of the equatorial region and other parts of West Africa. The rainfall gradient is largest along the southern margins of the Sahara—the region known as the Sahel—where mean annual rainfall varies by more than 1,000 mm over about 750 km. The latitude zones of these arid and semi-arid deserts demarcate the tropics from the subtropics. Surface air temperatures over most of Africa display a high degree of thermal uniformity, spatially and seasonally (Riehl 1979). Most of the continent having mean temperatures above 21 °C for nine months of the year (Goudie 1996). The mean temperature in the hottest and coldest months of the year varies little for most of equatorial Africa. For instance, the mean temperature during the summer and winter months at Barumbu, Democratic Republic of the Congo, varies by only 1.4 °C (Griffiths 2005). However, away from the equator and the coast, seasonal variation can be dramatic. In the heart of the Sahara Desert there can be up to a 24 °C difference between the mean temperatures of the coldest and hottest months (Griffiths 2005). Daily temperature variability is primarily influenced by proximity to a coast; generally, the further inland, the more extreme the variation (Griffiths 2005). Rainwater leaches soils and heat triggers chemical processes, hastening the decomposition of minerals.

2.4 Vegetation

Africa's pattern of vegetation zones largely mimics its climate zones (Fig. 2). Areas with the greatest rainfall have the greatest volume of biomass or primary productivity. Accordingly, Africa's equatorial climate zone is its most species-rich area (Meadows 1996). Rainforests in Africa represent slightly less than one-fifth of the total remaining rainforest in the world; Asia and Latin America contain the rest (Sayer et al. 1992). Only about a third of Africa's historical forest extent remains, with West Africa's forests being lost faster than those of any other region. Savannahs with few trees and dry deciduous forests in Africa occur where there are long dry seasons, while dense rain forests occur where rainfall is consistent year-round. Plants characteristic of the Mediterranean region of Africa is drought-tolerant, or xerophytic and able to survive occasional freezing winter temperatures in elevated and inland areas (Stock 2004). The Cape Province of South Africa is famous for its tremendous biodiversity (MacDonald 2003). This region, known as the Fynbos, is considered a distinct floral kingdom and has the highest rate of generic endemism in the world (Allen 1996). The Kalahari and the Karoo in southern Africa and the Sahel in northern Africa fall into the category of semi-desert where short grasses and scattered spiny plants predominate. The halophytes are fairly scattered in the arid and semi-arid regions of Africa. Halophytes occupy salt flats ("sebkhas") bordering the desert, the largest of which are the Qattarah depression in Egypt and the Oum el-Drouss depression in Mauritania. The parts of these depressions which are not too saline and remain sufficiently humid sustain Atriplex and Salsolaceae vegetation (*Salsola foetida*, *S. sieberi*), and *Zygophyllum album.* A large area of this vegetation type occurs in the Danakil depression in Ethiopia and near Lake Al el Bad. In addition, extensive mangrove forests are found on loamy saline soils exposed directly to the tides in the coastal area from the Senegal river on the Mauritania–Senegal border to the Longa river in Angola, and especially in the Niger delta and the islands of the Gulf of Guinea. The stands have *Rhizophora racemosa*, *R. harrisonii,* and *R. mangle* dominants. The mangroves of Madagascar and the east coast of Africa have a strong Asian affinity and comprise *Rhizophora mucronata* (mangrove with prop roots), *Bruguiera gymnorhyza* (semi-circular roots), *Avicennia officinalis* (long narrow pneumatophores), and *Sonneratia alba* (shorter and thicker pneumatophores).

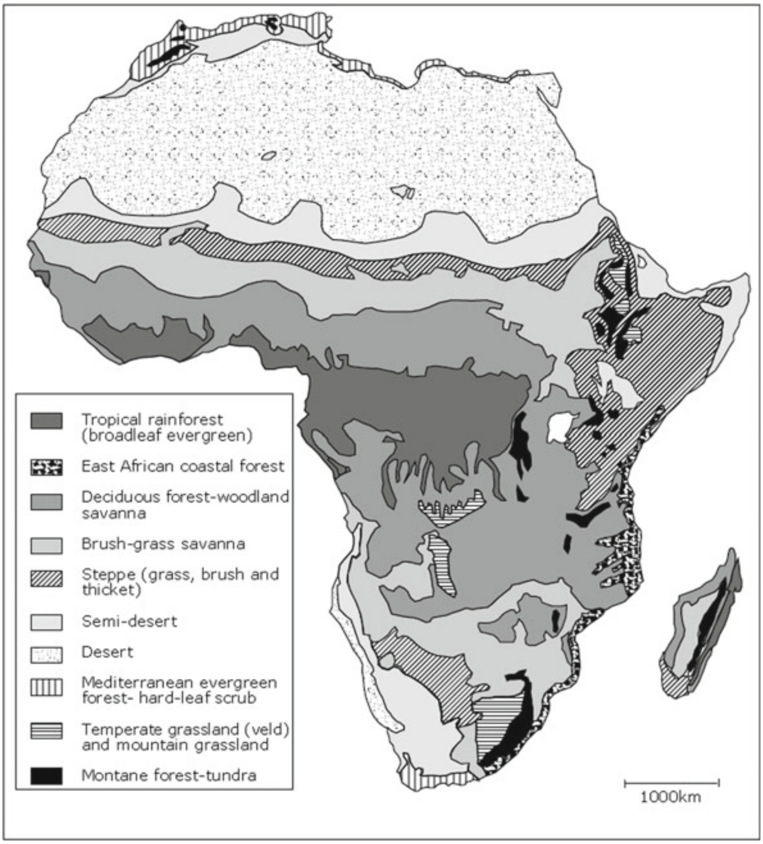

Fig. 2 Principal vegetation zones of Africa (*Source* http://library.berkeley.edu/EART/maps/africa-veg.gif)

2.5 *Soils of Africa*

Soil is the foundation of many of the Sustainable Development Goals. In addition to providing the medium for food, fodder, and fuel wood production (around 98% of the calories consumed in Africa are derived from the soil), soil controls the recycling of nitrogen, phosphorus, carbon, and other nutrients. Soil reduces the risk of floods and protects underground water supplies. Soil organic matter can store more than ten times its weight of water while the soils of Africa store about 200 Gt of organic carbon—about 2.5 times the amount contained in plants. Aridity and desertification affect around half the continent while more than half of the remaining land is characterized by old, highly weathered, acidic soils with high levels of iron and aluminium oxides (hence the characteristics of colour of many tropical soils) that require careful management if used for agriculture. African soils can be characterized in terms of their relations with water (FAO/UNESCO 1977). Over 60% of the soil types of Africa represent hot, arid, or immature soil assemblages, namely, Arenosols (22%), Leptosols (17%), Cambisols (11%), Calcisols (6%), Regosols (2%), and Solonchaks/Solonetz (2%). A further 20% or so are soils of a tropical or subtropical character, which consists of the Ferralsols (10%), Plinthosols (5%), Lixisols (4%), and Nitisols (2%). The behaviour of these soils is impacted by wide-ranging soil forming processes such as volcanic activity, accumulations of gypsum or silica, waterlogging, soluble salts, etc. (Dewitte et al. 2013).

3 Extent and Distribution of Salt-Affected Soils in Africa

As shown in Table 1 and Fig. 3, salinity and sodicity are the most widespread soil degradation processes on Earth. In Africa salt-affected soils are estimated to cover about 209.6 million hectares of which 122.9 million ha are saline soils and 86.7 million ha are sodic soils (Glenn 2009). However, as irrigated agriculture expands, more salinity problems will develop because there are millions of hectares of potentially irrigable land that could become saline. Seemingly, 200 million ha of land is expected to be potentially salt affected in Africa if the soils of semi-arid regions such as Calcisols (161 million ha), Gypsisols (37.5 million ha), Chernozems (1,039,300 ha), Kastanozems (2,672,400 ha) (Dewitte et al. 2013) are brought under irrigation. Salt-affected soils are prevalent largely in the countries of Eastern Africa, along the coast of Western Africa, the countries of the Lake Chad Basin, and in pockets of Southern Africa. Countries where salt-affected soils are currently widespread are Algeria, Angola, Botswana, Burundi, Cameron, Chad, Congo, Egypt, Ethiopia, Kenya, Libya, Madagascar, Malawi, Mali, Mauritania, Morocco, Mozambique, Niger, Nigeria, Rwanda, Uganda, Senegal, Somalia, Sudan, Swaziland, Tunisia, Zambia, and Zimbabwe.

Table 1 Worldwide extent of salt-affected soils

Continent	Saline, Mha	Sodic, Mha	Total, Mha
Africa	122.9	86.7	209.6
South Asia	82.2	1.8	84.0
North and Central Asia	91.4	120.1	211.4
Southern Asia	20.0	–	20.0
South America	69.4	59.8	129.2
North America	6.2	9.6	15.8
Mexico and Central America	2.0	–	2.0
Australia	17.6	340.0	357.6
Global total	411.7	617.9	1029.5

Source Glenn (2009)

Fig. 3 Global distribution of the salt-affected soils 1987 (*Source* Szabolcs)

4 Types and Drivers of Salt-Affected Soils in Africa

Soil salinization, a major soil degradation process, occurs when salts accumulate in the soil to a level where impacts include reductions in crop yields, forest loss, nutrient release from the soil, which can lead to algal blooms and fish mortality, marsh migration inland, expansion of salt tolerant species, loss of critical tidal marsh habitat, soil health issues, change of local climatic conditions, and degraded groundwater (Nachshon 2018; Shrivastava and Kumar 2014). Salinization of soil results from a combination of evaporation, salt precipitation and dissolution, salt transport, and ion exchange (Shimojima et al. 1996). Soil salinity refers to the total salt concentration in the soil solution (i.e., aqueous liquid phase of the soil and its solutes) consisting of soluble and readily dissolvable salts including charged species, e.g., sodium (Na^+), potassium (K^+), magnesium (Mg^{2+}), calcium (Ca^{2+}), chloride (Cl^-), sulphate ($SO_4{}^{2-}$), carbonate ($CO_3{}^{2-}$), bicarbonate ($HCO_3{}^-$), and borates ($B(OH)_4{}^-$) (Corwin 2003). Hypersaline waters may contain trace concentrations of the elements B, Se, Sr, Li, SiO, Rb, F, Mo, Mn, Ba, and Al, some of which may be toxic to plants and animals (Tanji 1990).

When the water evaporates, the salts are left behind. The origin of salts in soil can be natural or anthropogenic, where the former refers to primary salinization and the latter secondary salinization. The primary source of salts in soil and water is the geochemical weathering of rocks from the Earth's upper strata, with atmospheric deposition, seawater intrusion, rising ground waters in low-lying topography from saline aquifers serving as other natural sources, and anthropogenic activities serving as secondary sources. Anthropogenic sources include salts present in irrigation waters, residual salts from amendments added to soil and water, animal wastes, chemical fertilizers, and applied sewage sludge and effluents (Tanji 2002). The predominant mechanism causing the accumulation of salt in the root zone of agricultural soils is loss of water through evapotranspiration (i.e., combined processes of evaporation from the soil surface and plant transpiration), which selectively removes water, leaving salts behind. Salinization commonly occurs on arid and semi-arid zone soils where irrigation and/or rainfall are insufficient to leach salts, where poor drainage and/or shallow water tables exist, where there is an upslope recharge and downslope discharge, and where saline sub-soils formed naturally from marine deposits.

In the African continent as with the rest of the world, the main causes which lead to the development of salt-affected soils are inundation with sea water; mineral/rock weathering; mineral/rock weathering groundwater associated salinity, irrigation-induced salinity and climate change triggered salinity. The brief account of each cause is highlighted below.

4.1 Coastal Salinity

Coastal saltwater inundation is the movement of saline water over terrestrial soils due to rising sea levels. The possible ways sea water can reach the land are flooding during high tide, ingress through rivers and estuaries, groundwater inflows, and salt-laden aerosols. Dry and wet aerosol fallout contributes up to 100 kg/y-ha to 200 kg/y-ha along seacoasts and from about 10 kg/y-ha to 20 kg/y-ha in the interior (Suarez and Jurinak 2012). Rainfall could be another minor source of salinity in agricultural lands. Early showers after a long dry season can add a few kilograms of salts per hectare per annum. Salts influence the chemistry of the soil in which it infiltrates. Once salt-bearing water pushes inland, it may become associated with the soil grains by adsorption or ion exchange, or it may remain in solution. Seawater contains 35 g salt/litre and is typically dominated by chloride and sodium salts with 85% of the salinity derived from these ions (NOAA 2021). Sulfate and magnesium salts account for approximately 10% of the remaining salt content of seawater (NOAA 2021). When water containing salts percolate through soil, positively charged ions (sodium, calcium, magnesium) are attracted and bond with the inherently negatively charged clay mineral surfaces. The extent of bonding depends on the cation exchange capacity and the number of negatively charged sites in the soil.

The coastal zone could be divided therefore into the West and Central African coastal zone, the East African coastal zone, and the Mediterranean coastal zone. The West and Central African coastal zone stretches from Mauritania to Namibia and constitutes 29.5% of the whole area of the African continent. The Eastern African coastal zone can be delimited by latitudes 18°N to 27°S and include coastal areas of the island states Madagascar, Mauritius, Reunion, and Seychelles. A large part of the East African coastal plain which is low-lying is very variable in width. On the other side, the African coastal zone, most of which is very low-lying, consists of the West, Central, East, and Mediterranean coastal zones. Generally, thirty-nine African countries, including the island nations, border an ocean. The continent's coastline is a mix of diverse ecosystems, including estuaries, deltas, barrier islands, lagoons, wetlands, mangroves, and coral reefs (Watson et al. 1997). The depth to water table in the coastal zone is often very shallow and is subject to saline seawater contamination and pollution (Ibe and Awosika 1991).

Over a large area, seawater is in contact more or less directly with the groundwater of the littoral zone. In many arid and semi-arid coastal regions, and sometimes in humid areas, the process of evaporation brings saline groundwater to the surface by capillary movement from shallow water tables, leading to strong soil salinization in countries such as Algeria, Morocco, Senegal, Sierra Leone, Togo, Ghana, and southern Madagascar.

In humid tropical regions, the coastal saline soils of estuaries and deltas, which are rich in organic matter acquire special characteristics where the mangroves (Fig. 4) are associated with Avicennia or Rhizophora vegetation where such soils are drained, they become extremely acidic. They are classified as Thionic Fluvisols and are observed in Sierra Leone, southern Senegal, the Gambia, Guinea Bissan, Guinea, Liberia, Nigeria, Cameron, Gabon, Kenya, Tanzania, Mozambique, and in western Madagascar. Their area is estimated at approximately 3,350,000 ha (CEC 1992). When soluble salts are present, as often in tidal marshes and recently reclaimed sulfidic soils, their osmotic effects can inhibit the uptake of water and nutrients. The toxicity of Na^+ and Cl^{-1} is also common. Within Senegal, the Gambia, and Guinea Bissau, with a pronounced dry season and a decrease of the annual rainfall over the last 20 years, salinity levels with ECe values of 80 dS m^{-1} are not uncommon in the topsoil (Sylla 1994).

4.2 Weathering of Minerals or Rocks

Weathering of rocks containing sodium minerals (feldspars, amphiboles, etc.) produces soluble sodium salts, principally carbonates and bicarbonates, often sulfates, sometimes silicates, and rarely chlorides. Through time, saline seas have inundated large areas of present-day continents. These submerged areas have subsequently been uplifted. The resulting geologic formations provide parent material for soils as well as outcrops and underlying saline strata to soils or other formations, all of which are important zones of contact for salt loading of surface and groundwater. The secondary deposits (i.e., sedimentary rocks) formed from inland seas and weathering of continental rock during inundation are the major sources of salinity and sodicity (Suarez and Jurinak 2012).

In sub-humid regions and in certain semi-arid regions where excess water accumulates, the situation is different. Here, the dissolved sodium accumulates as exchangeable sodium in the B horizon, due to vertical or horizontal leaching. The soils which result are sodic soils. These soils are found in Ghana, Togo, Nigeria, Cameroon, Chad, Malawi, Botswana, Zimbabwe, Swaziland, Lesotho, and other tropical countries. Sodic are very susceptible to water erosion. Numerous Vertisols have a B horizon with a very high exchangeable sodium percentage and possess the physical properties of sodic soils. They occur in Tunisia, Kenya, Tanzania, Uganda, Zambia, Lesotho, Swaziland, and South Africa and have been classified as sodic soils.

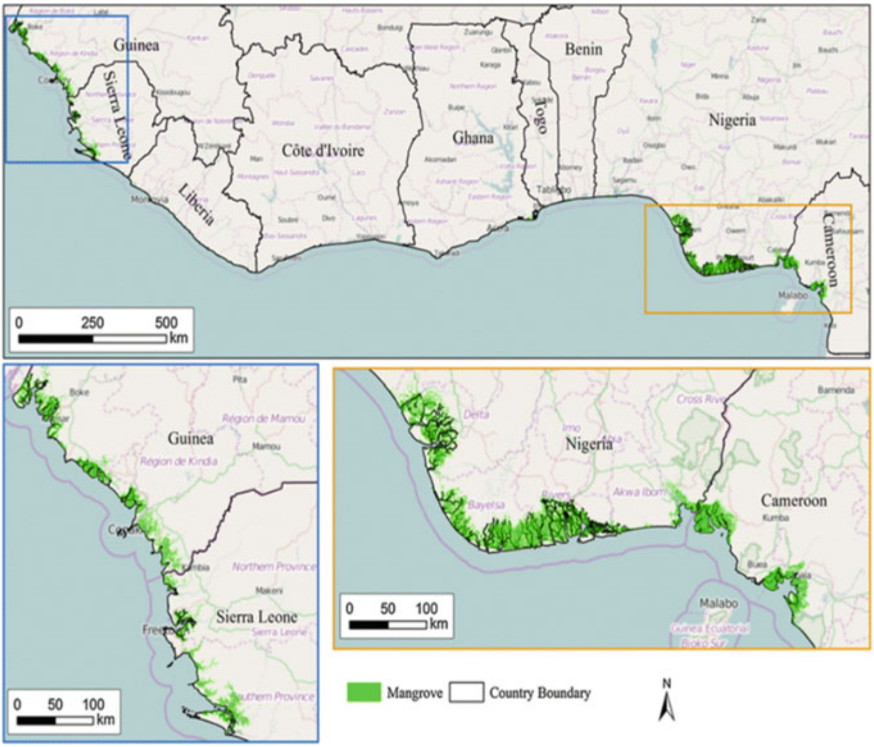

Fig. 4 Map of mangrove coverage in West Africa (*Data Source* USGS; base map: OpenStreetMap)

4.3 Groundwater-Associated Salinity

The water table refers to a saturated zone in the soil (USDA NRCS 2021). The depth of the water table below the surface, together with hydraulic properties of the soil and potential evaporation, control the amount of evaporation at the evaporation front, as they affect capillary water flow from the water table upward (Nachshon 2018). Usually for groundwater levels deeper than 2–3 m, depending on soil properties, evaporation, and resulted salt accumulation will be minor as capillary rise to the evaporation front is negligible (Rengasamy 2006; Salama et al. 1999). In the early stages of saltwater inundation, high freshwater tables in soils tend to attenuate the impact of salts by reducing the movement of saltwater inland (Hussein and Rabenhorst 2001). This eventually leads to lesser impacts from saltwater on soils by lower rates of marsh lateral migration and deforestation (Hussein 2009). When saltwater eventually inundates an upland soil, the amount of soluble salts retained is determined by water table fluctuations (Hussein and Rabenhorst 2001). Utilization of saline groundwater from the saline geologic materials for irrigation is another source of salt-affected soils when drainage is poor, and the climate is arid. Even when the rainfall is as much as 1,000 mm, low-lying impermeable soils may be saline if annual evaporation is high, as it commonly is in tropical Africa. Transported marine salts are often the source of soil salts in Morocco, Algeria, Tunisia, northern Nigeria, Swaziland, Botswana, and South Africa.

Increased groundwater salinity also related to high concentrations of some of the elements like sodium, sulphate, boron, fluoride, selenium, arsenic, and high radioactivity (IAEA 2004). The sedimentary basin with the highest frequency of saline groundwater (EC > 2 dS/cm) is encountered in the North Western Saharan Aquifer underlying Tunisia, Algeria, and Libya and in the North Kalahari Sedimentary basin aquifer in Southern Africa.

4.4 Irrigation-Induced Salinity

Irrigation has contributed significantly to the growth in agricultural production in many countries. However, irrigation-induced salinity is an increasing problem in several of these countries, threatening the productivity of agricultural lands. FAO (1990) reports that about 20–30 million hectares are severely affected by salinity and an additional 60–80 million hectares are affected to some extent. Irrigation-induced salinity can arise as a result of the use of any irrigation water, irrigation of saline soils, and rising levels of saline ground water. When surface or groundwater containing mineral salts is used for irrigating crops, salts are carried into the root zone. The amount taken up by plants and removed at harvest is quite negligible. The more arid the region, the larger the quantity of irrigation water and, water applied in excess of plant evapotranspiration to leach the salt away (Young and Homer 1986). A problem closely related to the problem of irrigation-induced salinity is that of alkalinity or sodicity; its impact is manifested by the degradation of the soil structure. The application of irrigation water to areas with abundant salts (common in arid and semi-arid areas) and more than 15% exchangeable sodium leads to the formation of “alkaline” or “sodic” soils, through the process of alkaline hydrolysis. If the soil has a low chloride and calcium content and if the soil and/or irrigation water applied have abundant exchangeable sodium bicarbonate and/or sodium carbonate (over 15% exchangeable sodium), the clay particles in the soil adsorb the sodium and magnesium salts and swell. The soil loses its permeability (ability to conduct air and water) and filth (friability of the seedbed). Alkalinity may also induce calcium deficiency and various other micro-nutrient deficiencies because of the associated high pH and bicarbonate levels repress their solubilities and concentrations (Kijne and Vander Velde 1992).

According to FAO (2001), the average rate of irrigation development for the Sub-Saharan Africa region (40 countries) over the past 12 years is 43,600 ha/year—an average of 1150 ha/year for each country. Some countries have average rates of development of over 2000 ha/year (e.g., Tanzania, Nigeria, Niger, Zimbabwe, and South Africa). It is well documented that irrigated land leads to increased agricultural productivity, irrigated areas are 2.5 times more productive compared to rain-fed agricultural areas (Stockle 2001). However, the development of an irrigation system can also lead to the build-up of soil salinity when the land is irrigated with poor water quality and water is applied without proper drainage, the evaporation in arid climates can quickly lead to high levels of salt in the soil, reducing the yield potential of the land. Another type of problem that can occur on irrigated lands is known as "waterlogging". This can happen if there is a layer of rock that forms a barrier, through which the water cannot escape. Over time, the water can accumulate and reach the root zone of the plants, making agricultural production impossible.

4.5 Climate Change Triggered Salinity in Africa

Sea level rise associated with climate change includes an increase in coastal erosion and saltwater intrusion. The trend is a result of the coastal degradation and erosion in West Africa. About 56% of the coastlines in Benin, Côte d'Ivoire, Senegal, and Togo are eroding, and this is expected to worsen in the future (Mafaranga 2020). Two of the most salient facts about climate change and Africa are that the continent contributes an insignificant amount to global greenhouse gas emissions (less than 1%), and that it is likely to be the area most affected by climate change. Soil salinization plays a role in global biogeochemical cycles, but its significance is still not as well understood, particularly in regard to different potential management opportunities (e.g., small vs large holder farms). Soil salinization is a key regulator of plant/soil nitrogen pools and, by altering soil electric conductivity and affecting the functioning of soil microorganisms, it impacts nutrient cycling and global fluxes. Moreover, soil salinity may increase N_2O emissions, but the underlying regulatory mechanisms are complex. Soil salinity generally reduces plant productivity in croplands and, consequently, soil carbon storage. Furthermore, the decomposition of soil organic carbon is limited because salinity reduces soil microbial function. Climate change-induced sea surface rise will lead to saltwater intrusion in coastal areas. Moreover, when groundwater is overused, inland aquifers can also be affected, increasing risks of soil salinity. Under climate change scenarios, salinity in drylands can increase due to higher rates of evapotranspiration of shallow groundwater.

5 Impact of Salt-Affected Soils in Africa

5.1 Impact on Soil

A problem closely related to the problem of irrigation-induced salinity is that of alkalinity or sodicity; its impact is manifested by the degradation of the soil structure. The application of irrigation water to areas with abundant salts (common in arid and semi-arid areas) and more than 15% exchangeable sodium leads to the formation of "alkaline" or "sodic" soils, through the process of alkaline hydrolysis. If the soil has a low chloride and calcium content and if the soil and/or irrigation water applied have abundant exchangeable sodium bicarbonate and/or sodium carbonate (over 15% exchangeable sodium), the clay particles in the soil adsorb the sodium and magnesium salts and swell. The soil loses its permeability (ability to conduct air and water) and filth (friability of the seedbed). When this occurs, water infiltration is hindered, and plant roots/soil organism may be starved of oxygen (Rhoades 1990). Alkalinity may also induce calcium deficiency and various other micro-nutrient deficiencies because of the associated high pH and bicarbonate levels repress their solubilities and concentrations (Kijne and Vander Velde 1992).

5.2 Impact on Plants

Excessive soluble salt concentrations or salinity affects plant growth and production primarily by increasing the osmotic potential of the soil solution (Bernstein 1961). Under some conditions, (Bernstein 1974; Bernstein et al. 1956), specific ion toxicities can also be important for some crops, particularly for woody species. The physiological effects of excess salinity are many, but visual symptoms generally do not become evident until salinity conditions are extreme. Plants affected by excessive soluble salt concentrations usually appear normal, but there is a general stunting of growth, foliage may be darker green than for normal plants, and sometimes leaves are thicker and more succulent. Woody species often exhibit leaf burn, necrosis, and defoliation resulting from toxic accumulations of Cl or Na. Chlorophyll formation is inhibited in citrus by specific ion toxicities (Carter and Myers 1963). Occasionally, nutritional imbalances caused by salinity produce specific nutrient-deficiency symptoms (Lunin and Gallatin 1965; Ravikovitch and Porath 1967). The osmotic effect of salinity is to increase the osmotic potential of the soil solution, thereby making soil water less available for plant uptake. Therefore, salt-affected crops often appear the same as crops suffering from drought. As the salt concentration in the soil solution increases, both the growth rate and ultimate size of most plant species progressively decrease. Salinity effects are frequently not recognized, even though yield reduction may be 20–30% because of the general decrease in growth rate and plant size. Not all plant parts are affected the same way, and any relationship between growth response and soil salinity must take this into account (Bernstein and Pearson 1954; Meiri and Poljakoff-Mayber 1970). The leaf-to-stem ratio of alfalfa is affected, influencing forage quality (Hoffman et al. 1975). Vegetative production is decreased more than seed or fibre production for crops such as barley, wheat, cotton, and some grasses (Ayers et al. 1952). Root yields of root crops are generally decreased much more than top yields (Pearson 1959; Hoffman, and Rawlins 1971). The impact of reduced plant production caused by salinity depends upon the purpose for which the plants are grown.

5.3 *Impact on the Socio-Economy*

Soil salinity is one of the biggest threats to our global agricultural soils, the world's largest industry, and the wider food system. In 2018, the Intergovernmental Science Policy Platform of Biodiversity and Ecosystem Sciences (IPBES) completed a global assessment of land degradation. The report revealed that soil salinization was one of the main factors reducing plant growth and agricultural productivity worldwide. The annual global economic cost of lost crop production is US $27.3 billion. Land affected by high levels of salinity totals 1 billion hectares. That farmland generates 40% of the planet's food. The UN university states that since the 1990s, 2500 ha have been lost, daily. We must urgently find cost-effective solutions for salinization to ensure we have enough to eat, to protect our environment, and ensure our very existence on earth. In Sub-Saharan Africa (SSA) an estimated 180 million people are affected, (Mirzabaev et al. 2014) while the economic loss due to land degradation is estimated at $68 billion per year (Nkonya et al. 2016). The socioeconomic impacts of land degradation vary with the geographical, political, and economic context.

6 Suggested Management Scenarios

Every year new salinity problem areas develop and are identified. Salinity is the most important problem facing irrigated agriculture; and solving salinity problems is one of the greatest challenges to agricultural scientists. Use and reclamation of salt-affected soil for agricultural purposes requires a combination of approaches and technologies and the consideration of socioeconomic aspects under local conditions. Agricultural production in salt-affected soils is largely dependent on water availability, climatic conditions, crop, and the availability of resources. In this section, relevant options for reclamation and management of salt-affected soils in the African context are identified and presented below.

6.1 *Use of Salt Tolerant Crops*

Although several reclamation and management practices can reduce salt levels in the soil, there are some situations where it is either impossible or too costly to attain desirably low soil salinity levels. In some cases, the only viable management option is to plant salt-tolerant crops. Actual yield reductions will vary depending on the crop variety and the climatic conditions during the growing season. Moreover, plants are usually most sensitive to salt during the emergence and early seedling stages. Tolerance usually increases as the crop develops. Most of the major cereal crops exhibit high tolerance to soil salinity, which are grown in Africa are sorghum, wheat, triticale, rye, oats, barley, maize, and rice (Maas 1990). Virtually, Africa is the centre of origin and also a major producer of several cereals like sorghum, pearl millet, finger millet, teff, and African rice where these cereals are grown over an area of 98.6 m ha. Breeding of indigenous cultivars to develop salt tolerant varieties that suit the wide-ranging agroecology of Africa will be the most cost-effective technology for managing of salt-affected soils. Besides, because of their fibrous roots, grasses alone or in combination with forage legumes are frequently used in the reclamation of saline and sodic soils to restore good soil structure (Bernstein 1958). Under non-irrigated conditions, grasses that accumulate significantly high concentrations of Na^+ and Cl^- in the shoots may be used to restore soil structure and also to remove these ions from the soil profile (Sandhu and Malik 1975). Furthermore, in typical aridic or semi-aridic environment where salinity is prevalent a wide-ranging salt tolerant perennial plants can be grown. For example, date palm is most frequently cultivated by improving through breeding in Egypt, Sudan, and the other countries of North Africa. The fig and olive are also successful trees, which are grown in the saline environment of North Africa, with about two-thirds of the olive production being processed into olive oil. And orange, which is tolerant to a chloride ion, can be grown in the regions of the southern coast of South Africa and the Mediterranean coast of North Africa, as well as Ghana, Swaziland, Zimbabwe, the Democratic Republic of the Congo, and Madagascar. Sugarcane is also frequently grown perennial grass on saline estates in South Africa, Egypt, Mauritius, and Sudan with a possibility of improved productivity with a reasonable reclamation to lower down the alkaline soil pH through the application of either mined gypsum or phosphogypsum.

6.2 The Irrigation Method

The irrigation method and volume of water applied have a pronounced influence on salt accumulation and distribution. Flood irrigation and an appropriate leaching fraction generally move salts below the root zone. With furrow and pressurized irrigation, soluble salts in the soil move with the wetting front, concentrating at its termination or at its convergence with another wetting front. In drip-irrigated plots, water moves away from the emitter and salts concentrate where the water evaporates. In furrow-irrigated plots, water movement is from the furrow into the bed via capillary flow. When adjacent furrows are irrigated, salts concentrate in the centre of the intervening bed. Manipulating bed shape and planting arrangement are strategies often used to avoid salt damage in furrow-irrigated row crops. Moreover, canal water is of excellent quality, and has, obviously, tremendous value for farmers who are dealing with salinity and/or sodicity. When dealing with genetic salinity, they use canal water for reclamation purposes, while they mitigate the effect of poor-quality tube well water by applying it in conjunction with canal water. The importance of canal water for farmers was substantiated in a survey conducted by Kielen (1996), where farmers singled out canal water as the most important factor for salinity management. In a modelling exercise, the importance of canal water was further confirmed in ensuring a long-term salinity equilibrium at reasonable levels (Smets et al. 1997). Making more canal water available to farmers would, therefore, help them in their salinity management.

6.3 Salt Leaching and Drainage

Salinity problems can be either potential or actual. Both types of problems can be solved by drainage, but they differ with regard to the purpose and requirements of the drainage. Therefore, it is useful to distinguish between two types of salinity drainage: "salinity prevention" and "salinity reclamation" (Van Beers 1966). *"Salinity prevention" drainage* is designed to prevent salinization after the establishment of irrigation facilities in a non-saline area. Therefore, the amount of salt supplied by irrigation water and by capillary rise from the groundwater must be in equilibrium with the amount of salt leaving the root zone by drainage. Salinity prevention drainage generally requires low rate of discharge (about 1–2 mm per day) and deep drains. The depth of the drains is determined mainly by the permissible depth of the groundwater in relation to salinization dangers, the so-called "critical depth", which depends on the type of soil, groundwater salinity, and evaporation. This depth is generally greater than that required for crop-drainage under humid conditions. Because the drainage rate is much smaller, the spaces between drains needed for this type of drainage are much larger. Whereas "*salinity reclamation" drainage* is used to reclaim saline soils by leaching and drainage using large quantities of water. After reclamation, re-salinization has to be prevented by means of a salinity prevention drainage system. Efficient salt leaching by shallow drainage is the most effective way to decrease salinity levels to acceptable limits. Leaching can also increase the pH, lower the specific conductance and the concentration of Al and other salts as well as the partial pressure of CO_2 (Pounamperuma 1972). In Senegal, Béye (1973) observed the beneficial effect of shallow drainage in acid sulfate soils. Sylla and Touré (1988) showed that ridging by plowing as done in the Diola zone is efficient to control salinity as well as iron toxicity. Detrimental acidity and salinity can be overcome by daily leaching with brackish to freshwater tide in Sierra Leone (Sylla et al. 1993).

6.4 Use of Organic Matter

To improve sodic soils, heavy dressings of organic matter have sometimes been applied. It is stated that a heavy dressing of organic matter results in the formation of a more stable structure. The second effect is that, with the decay of the organic matter, CO_2 is produced, as a consequence of which the solubility of $CaCO_3$ is increased. When gas exchange processes in the soil are impeded, the CO_2 concentration may rise considerably and an increased solubility of $CaCO_3$ can be expected. Besides, some green manures, in particular, *Sesbania aculeata* and *Argemone mexicana*, are found to be highly effective in the improvement of sodic soils (Uppal 1966). Both green manures upon decay produce a large amount of organic acids which depress the pH of the soil. Moreover, heavy dressings of molasses, containing large quantities of organic acids, have been reported to be very effective in reducing the alkalinity of the soil (Prettenhoffer 1964).

6.5 Use of Chemical Ameliorant

Phosphogypsum is an almost unused by-product of phosphate fertilizer production, which includes several valuable components—calcium sulphates and rare-earth elements. Phosphogypsum (PG) was found to be better at reclaiming materials than mined gypsum. Application of PG results in a greater decrease in surface soil pH and ESP, resulting in a greater yield of rice and wheat over the equivalent dose of mined gypsum. The contents of soluble P, calcium P, and Fe–P were greater in PG-treated soil than the initial soil and mined gypsum–amended soil. Beretka (1990) reports positive results with the application of 3–5 t/ha of phosphogypsum every 3–5 years. After such applications of phosphogypsum the improvement of soil structure at surface layer and better water infiltration were recorded in unstable structure soils and soil management was easier and faster. Nayak et al. (2011) conducted a research in India on agricultural soil without vegetation, with the addition of 5–20% phosphogypsum and they found that with the increasing amounts of phosphogypsum applied, pH was reduced from 7.9 in control to 5.1 in treatment with 20% phosphogypsum. According to Vyshpolsky et al. (2010) by using phosphogypsum in irrigated areas, the effects of excess Mg^{2+} in soil, which are negative regarding soil structure and ultimately plant growth and yield, are mitigated. Dimitrijević et al. (2010) conducted an experiment with different varieties of wheat on solonetz, with the application of phosphogypsum as a reclamation agent in the amount of 25 t/ha and 50 t/ha, and they found an average yield of 5.17 t/ha (25 t/ha PG) and 3.81 t/ha (50 t/ha PG). According to the aforementioned studies, positive effects of phosphogypsum on soil, water, and plants are prevailing. However, for the sustainable use of phosphogypsum in the reclamation of salt-affected soils, agroecology-based research is imperative.

6.6 Fertilizers

Fertilizers like ammonium sulphate, superphosphate, and calcium nitrate have a favourable effect on sodic soils. In addition to providing an increased fertility, ammonium sulphate tends to lower the pH of the soil. Studies on soil salinity–fertility relationships indicate a positive effect of fertility on crop salinity tolerance. Among the most striking data are those published by Ravikovitch and Yoles (1971). The yields of clover (*Trifolium alexandrinum*) and millet (*Setaria italica*) growing in pots in a greenhouse experiment were greatly increased by the addition of N and particularly P to saline soil. Lüken (1962) reported that positive effects of N and P application on the yield of wheat (*Triticum aestivum* L.) growing on saline soils under dryland conditions were detected. The addition of P improved the yield from tomato (*Lycopersicon esculentum* L.) growing under saline conditions (Cerda and Bingham 1978). Kafkafi (1984) concluded that the use of saline water for irrigation should be combined with a continuous supply of nutrients in the proper concentration. The yield of beans (*Phaseolus vulgaris* L.) was increased by P fertilization for the salinity range studied by Lunin and Gallatin (1965). The addition of P fertilizer (15 and 40 mg P l^{-1}) to pepper plants (*Capsicum annum* L.) during the first 55 days of growth increased the per cent germination of seeds obtained from these plants in the presence of 0.5% NaCl solution, in comparison with untreated plant.

6.7 Reclamation Using Rice Cultivation

Rice cultivation is very effective for improving sodic soils, particularly for leaching soluble salts. On sodic soils with extremely high pH values the growth of rice is stunted. Green manuring with *Sesbania* or an application of a small dressing of sulphur or gypsum promotes the growth of rice on these soils (Uppal 1966). Moreover, rice straw mulching experiments in Senegal proved to be an efficient practice to avoid salinity build-up during the dry season (Béye 1974). Thus, the most important rice-producing countries such as Egypt, Guinea, Senegal, Mali, Sierra Leone, Liberia, Cote d'Ivoire, Nigeria, Tanzania, and Madagascar can tackle soil salinity build-up via rice straw mulching.

6.8 Use of Crop Rotations in the Reclamation

Crop rotation is an agricultural practice, which implicates the cultivation of different crops on the same field. Selection of suitable crop rotation at farmer field is very intricate decision. When the good quality of water supplies is limited a suitable crop rotation is the only means for managing salt-affected soils and maintaining crop yields (Kaur et al. 2007). Crop rotation resulted in several improvements, in soil physical and chemical properties and is also suggested for salt-affected soil, especially when crops with varying degrees of salinity tolerance are used (Lacerda et al. 2011). For suitable crop rotation in salt-affected soils, selected crop should be either salt tolerant or tolerant cultivars must be selected from sensitive or medium tolerant crops with high economic value (Ouda et al. 2016). Abro and Mahar (2007) reported that in rice–wheat cropping system, salinity indicators like soil ECe, pH, and SAR were significantly lowered after the rice harvest, however, a minor increase in ECe and pH were recorded whereas, the SAR levels dwindled further after wheat harvest. Similarly, in a study Liu et al. (2013) reported that the rice-barley crop rotation lowered soil ECe after a reclamation time of more than 10 years. The paddy soil management for 50 years favoured the enhancement of soil organic carbon and decreased the concentrations of Ca, Mg, and Na (Chen et al. 2011). Fu et al. (2014) found that rice-barley crop rotation had more ameliorative effect on soil properties and significantly decreased the pH value than cotton-barley crop rotation system in the same year.

7 Conclusion

While soil salinization may occur naturally, it has been highly exacerbated by a combined anthropogenic and climate change activities in Africa. Land degradation and soil fertility decline in Africa are deeply complex. Now it is clear that salinization and alkalinization of agricultural soils become a threat to the African continent as it visibly impacts food production, the livelihood of millions of smaller holder farmers, and social stability. Sustained and profitable land use systems on salt-affected soils are possible if appropriate decisions on soils, climatic, and landscape characteristics in view of the current and future use of the land are considered intrinsically. Besides, "prevention is better than cure", so does the same concept apply to solving the worldwide problem of soil degradation through salinization. The costs of preventing salinization are incredibly cheaper than the reclamation projects in salinized areas. Thus, it is high time now for the African countries that are threatened by the gravity of salinity and sodicity problems to prepare their respective national plans of actions for managing and versatile use of salt-affected soils both at large and small-scale farming taking into account cost-effectiveness and sustainability.

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