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Review Article

Soil salinization under irrigated farming: A threat to sustainable food security and environment in semi-arid tropics

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ABSTRACT: Soil salinization is a major challenge of irrigated agriculture with substantial impact on the sustainability of crop and food security. World-widely, salinization has been a major bottleneck to the expansion and advancement of irrigated farming, resulting in a significant environmental degradation, lower yields and food insecurity. The problem of soil salinity varies across the regions and it has more extensive implications in arid and semi-arid regions where the rate of evaporation is higher than precipitation. To minimize the problem, it is necessary to adopt effective management practices that reduce salinization process in irrigated agriculture. However, the effective management options need a thorough understanding of the problem itself, the way it occurs, and their contributory effects to various aspects of development. This review therefore, presents an ample description on soil salinization as a threat to the sustainability of crop production and food security in the semi-arid tropics. The review focuses on the causes, extent and distribution of salt affected soils under irrigated agriculture, influence of irrigation water on soil salinization, the effects of salinization on plant growth, crop production and soil productivity. Furthermore, the review highlights the impact of salinization on food security and social economic aspects. It also proposes management options that should be adopted to either minimize or remedy soil salinity to the desired level and increase soil quality in semi-arid areas.

Keywords: Environmental degradation, irrigated agriculture, sodicity, salinity.

INTRODUCTION

The increasing demand for food due to increasing global population calls for sustainable food production (Shrestha and Mahat, 2022). It is projected that by the next 30 years, there will be over 9.9 billion people which will increase exploitation of natural resources and food production systems. (United Nation, 2017; United Nation, 2020). Of all food supplying sector, agriculture remains the most important sector that would keep on enhancing food security to feed the increasingly growing population (Smith *et al.,* 2020; United Nation, 2020). Despite its importance, the sector is highly affected by unreliable rainfall and periodic droughts, which necessitates the need for irrigation in order to resilient of agricultural production (MAFSC, 2013). However, irrigated agriculture itself is faced by deterioration of water quality and pollution of water resources from natural and anthropogenic activities. The quality of ground water is generally unacceptable for most uses due to high salinity and fluoride concentration that exceed standards (NBS, 2015). Apart from other usage, the groundwater is used for irrigation of crops such as sugarcane, rice, grapes, vegetables and flowers, but irrigation without proper drainage results in to environmental problems induced-salinization.

Salinization refers to the process of buildup of salt concentration or substantial amount of exchangeable sodium ions in soils above the threshold limit (Whitney *et* *al.,* 2018); and has a direct impact on the agriculture production, environmental health and quality of life (Shadid *et al.,* 2018; Wallender and Kenneth, 2012). A recent FAO estimate indicated that a large portion of global soil resources are affected by salinity (FAO, 2020). The problem is persistently expanding especially in arid and semi-arid regions due to high rate of evaporation and evapotranspiration (Amin *et al.,* 2016; Butcher *et al.,* 2016; Corwin and Scudiero, 2019; Omuto *et al.,* 2020).

Globally, salinization affects 1 billion ha of land with 200 million ha found in Africa (Tully *et al.,* 2015). Based on global estimates, more than 20% of the irrigated areas are affected by a problem of soil salinization due to inappropriate irrigation practices or irrigation with saline water (Qadir *et al.,* 2014, Manasa *et al.,* 2020; Fathizad *et al.,* 2020; Pulido-Bosch *et al.,* 2018; Singh, 2015; Amin *et al.,* 2016; Shadid *et al.,* 2018; Stavi *et al.,* 2021). If left unattended the problem could expand to over 50% of the total global irrigated area by 2050, consequently increasing food insecurity (Butcher *et al.,* 2016). This situation is extensive in areas with arid and semi-arid climates where irrigated farming is a fundamental factor for sustainable agricultural development (Qadir *et al.,* 2015). However, good quality water for irrigation has become a scarce resource and its availability threatening the sustainability of irrigated agriculture especially in arid and semi-arid regions (Mahanavelu *et al.,* 2021).

The shortage of freshwater for irrigation has become chronic problem making natural ground water as an alternative source for irrigating high value cash and food crops in these regions (Chaudhary and Satheeshkumar, 2018). However, soil salinization remains to be a potential challenge to the use of natural ground water for irrigation purposes. In most cases, the source of irrigation water is surface water which, along the pathway can dissolve salts from parent material and transfer them to accumulate in the irrigation schemes. This can take place if the internal drainage is insufficient to drain the salt that are brought in with irrigation water (Connor *et al.,* 2012). In addition to that, most irrigation schemes are found on the foot slopes of the rift valley Escarpment, which are characterized by high temperatures, most often on leeward sides, and hence unreliable or low precipitation.

In Tanzania for example, the case is for most irrigation schemes such as Usangu plain, lake Rukwa valley, Korogwe district in Tanga region and Kilimanjaro region. Other areas are hinterland depressions or valley equally characterized by high temperatures and low precipitations, including the Dodoma, Singida, Tabora and Shinyanga irrigation schemes. These areas are characterized by poor leaching due to high water table just near the soil surface, leading to salt accumulation over the surface. The problem is increased by poor irrigation infrastructure (canals without lining) and old canals without adequate renovation and close supervision (Meliyo *et al.,* 2016). Nearly 90% of irrigation schemes in Tanzania had inadequate infrastructure with poor drainage systems, which contributes to often accumulation of salt in the soil surface as a result of increased soil salinization with the extent depending on the frequency of irrigation and drainage conditions (Kashenge-kilenga *et al.,* 2016).

Increased salinization is a severe problem and foremost limiting factor that affects plant growth and crop production around the globe (Majeed and Muhammad, 2019). Generally, soil salinization affects all aspects of plant growth including germination, vegetative growth, reproductive improvement and crop yields (Machado and Serralheiro, 2017). When the level of salts in soils and irrigation water is too high, water tends to flow in a reverse mechanism from the plant roots back to the soil. This creates an osmotic potential outside the seed, thus impeding the absorption of water. Through this process, the plants become dehydrated due to reduced leaf area and chlorophyll content that affects photosynthesis as a result of limiting plant growth and in extreme cases cause plant death and consequently reduce yield of crops (Rekta, 2024). About 10 – 20% yield losses can be caused by salinity for many crops, which may prevent cropping altogether when severe and lead to desertification (Shahid *et al.,* 2018). Crops vary greatly in their tolerance to salts in the soil solution. How specific plants respond to salts will depend on soil texture and moisture content as well as environmental conditions such as temperature, humidity and wind speed. According to Zamora *et al*. (2022) approximately 25% of yield decrease occurs at 2.7dS/m and 50% occurs at 4.5dS/m for most crops.

Furthermore, apart from affecting plant growth and productivity or yield of irrigated lands, salinization has broad negative influence on the physical and chemical fertility of the soil hence decreasing soil productivity (Farifteh *et al.,* 2006). Alteration of soil physical properties resulting from the swelling and dispersion of the colloidal soil particles caused by the presence of excess sodium. This situation finally results in poor water and air circulation, water-holding capacity, restricted root penetration and seedling development problems (Ganjegunte *et al.,* 2014). The sodicity increases with the bulk density because of the dispersive action of the sodium on soil particles resulting in soil compaction, changing the pore size distribution and decreasing the total volume of soil which seriously affects the development of plants, microflora and fauna and other soil dwelling organisms (Chatterjee *et al.,* 2015; Amin *et al.,* 2016; Zaman *et al.,* 2018). The negative impacts of soil salinization on farmers' fields have been reported, including loss of crop yields, spoiling irrigation water quality and abandonment of arable land in some irrigated areas after becoming unproductive (Kashenge-Kilenga *et al.,* 2016), research results show that if such soils are properly managed, they are highly productive with significant economic potential and can hence be used for crop production (Oadir *et al.,* 2017; Stavi *et al.,* 2021).

The economic potential of salinized soils can only be realized if a detailed understanding of the problem and its occurrence are well identified to allow a proper selection of technologies for their effective management options to deal with this threat for increased crop production and food security under irrigated farming. However, up-to-date information on challenges associated with salinization under irrigated areas is lacking. Thus, knowledge and comprehensive understanding of the current information are the way forward towards the alleviation of this challenge, thereby increasing productivity and food security. This review therefore aims to present a holistic overview of salinization and its relationship with crop production, soil productivity and food security under irrigated agro-ecologies.

Types, causes, and extent of salinization in soils

Salinization of soils and water is caused by primary processes influenced by salty parent materials, mineralogy, groundwater, windblown salt particles, and flood (Omuto *et al.,* 2020; Stavi *et al.,* 2017). This type of salinization is driven by geological processes, specific types of minerals in the rocks, saline groundwater rise and seawater inclusion (Ruto*,* 2018). Secondary salinization results from human induced activities which include irrigation with poor drainage or with salty-rich water, inappropriate fertilizer application, improper waste disposal, misuse of soil amendment, inappropriate soil-water management and land use change (Cuevas *et al.,* 2019). At present, climate change has been perceived as the main driver of salinization, this is evidenced by increasing the frequency of weather events, with unusually low precipitation, high temperatures, high potential evapotranspiration and more recurrent drought which decrease the length of growing seasons due to poor distribution of rainfall patterns in most parts of the world (Kashenge-Kilenga *et al.,* 2016; Corwin, 2020; Malhi *et al.,* 2021).

Salt-affected soils are categorized into three groups which include (i) saline soils which is characterized by high electrical conductivity of paste extract (ECe > 4 dSm^{-1}), where the dominant cations in this soils are Calcium (Ca^{2+}), Magnesium (Mg^{2+}) and or Potassium (K^+) while the dominant anions are Chlorides (Cl^-), Sulphates ($SO_4^{\ 2-}$), Carbonates ($CO_3^{\ 2-}$) and bicarbonates (HCO_3^-) (Wallender and Kenneth, 2012). (ii) Sodic soils with higher exchangeable sodium percentage (ESP > 15%) but low ECe where the dominant cations in sodic soils are mainly sodium (Na^+) and the dominant anions are carbonate (CO_3^-), bicarbonate (HCO_3^{2-}) and/or chloride (Cl^-), and sulphate (SO_4^{2-}). A high concentration of sodium increases soil pH (alkalization) through the presence of HCO_3^- and CO_3^{2-} (Leogrande and Vitti, 2019; Shahid *et al.,* 2018). (iii) Saline-sodic soils are a combination of saline and sodic soils characterized by high electrical conductivity ECe > 4 dSm^{-1} and ESP > 15% (Alcívar *et al.,* 2018; Wallender and Kenneth, 2012). These are considered to be highly degraded in terms of soil physical, chemical, and biological properties and hence least productive (Chaganti *et al.,* 2015). Saline-sodic soils are more challenging in reclamation than saline soils because separate treatments are required for both salinity and sodicity (Alcívar *et al.,* 2018). The dominant cations in this soils are sodium (Na+), calcium (Ca2+), magnesium (Mg2+), and/or potassium (K+), while dominant anions are chloride (Cl-), sulphate (SO42-), bicarbonate (HCO3-) and nitrate (NO3-). Criteria for categorization of salt affected soils into these groups are usually done using sodium adsorption ratio (SAR) and exchangeable Sodium percentage (ESP) (FAO, 2021).

Recently published data by FAO (2021) showed that there will be global distribution of salt-affected land area at topsoil (0-30 cm) and subsoil (30-100 cm) profile of cultivable lands by 2050 if it continues increasing at the present rate (Kumar *et al.,* 2020). However, their distribution is relatively more extensive in the arid and semi-arid lowland and in Rift valley areas, where evaporation rates is higher than precipitation (Aslam and Prathapar, 2009; Farifteh *et al.,* 2006). The global estimate suggests that 412 million hectares are affected by salinity and 618 million hectares have been affected by sodicity (FAO, 2016). Several studies have reported the extent and distribution of salt-affected soils on all the continents in different countries, including Ethiopia (11 million hectares), Kenya (8.2 million hectares), Nigeria (5.6 million hectares), Sudan (4.8 million hectares), Tanzania (3.6 million hectares), Tunisia (1.8 million hectares), and Ghana (0.79 million hectares) (Bellido-Jim’enez *et al.,* 2021; FAO, 2020; Gebremeskel *et al.,* 2018; Berhane and Chala, 2017; FAO, 2003).

Occurrence of salinity and sodicity under irrigated areas

In 2012 irrigated lands worldwide were estimated around 324 million ha (FAO-AQUASTAT, 2016), with 20% or 62 million ha salt affected (Qadir *et al.,* 2014). This occur due to inappropriate use of saline irrigation water, poor drainage conditions and increased groundwater recharge that cause the rise of water table (Rao *et al.,* 2014). When irrigation drainage water percolates to an aquifer or ground water table rises cause salts to accumulate at the soil surface when the depth of water table is <1–1.5m depending on the soil texture. The accumulation of salts at the soil surface is the consequence of the upward flow of water and subsequent transport of salts due to capillary rise driven by the evaporative process. Nonetheless, the common cause of salt accumulation is evapotranspiration (ET) by plants, which results in an increase in salt concentration with depth through the root zone and the accumulation of salts below the root zone (FAO and ITPS, 2015). Salt affected soils often occur on irrigated lands, where annual rainfall is insufficient to meet plants' evaporation needs and salts' leaching (Sileshi and Kibebew, 2016). Normally, recharge rates in irrigation areas is much higher than dryland areas due to leakage from both rainfall and irrigation, this leads to high salinization rates. In areas where water table is within two meters of the soil surface indicate the potential of salts to accumulate at the soil surface. Sometimes, salinization occurs due to inefficient irrigation and drainage systems that cause excess leakage and increase the risk of salinity in irrigation areas (Cuevas *et al.,* 2019). In addition, poor water distribution causes the increase of salts in the areas under-irrigation not only that, but also salinization can occur due to an imbalance between transpiration and water inputs from rainfall and irrigation. The imbalance comes from the combination with soil characteristics that impede leaching and cause soil degradation (Mateo-sagasta *et al.,* 2011). Improper irrigation practices and poor planning of land use resources are major drivers of soil salinization (Singh, 2015; Ritzema, 2016). Furthermore, intense groundwater abstraction for agricultural irrigation has resulted in the depletion and deterioration of aquifer all over the world (Faunt *et al.,* 2016).

Studies, have reported the widespread occurrence of salinity and sodicity in different agro-ecologies of Tanzania but are more upsetting in irrigated areas. For instance, Kashenge-Killenga *et al.* (2016) in their study noted that some irrigation schemes indicated 67% of all 19 selected irrigation schemes had salt problems. Similarly, Omar *et al.* (2022) based on farmers' views indicated that about 25% of the land in the surveyed irrigation schemes was salt-affected. This is in agreement with the study by Meliyo *et al.* (2016) who revealed high values of electrical conductivity (EC) ranging from 14 to 19 dSm^{-1} in various irrigation schemes. Moreover, Shemsanga *et al.* (2017) reported higher values of pH, Na, Cl and EC in Hombolo Dam and Hombolo Irrigation Scheme in central Tanzania. These higher values indicate the presence of salinity and sodicity in irrigation water. On top of that, Mkilima (2023) reported that about 94% of all groundwater samples collected from various boreholes from Dar es salaam Tanzania has EC and SAR higher than the recommended permissible limit of 3 dS/m and 10 for EC and SAR respectively. This shows high salinity levels that indicates unsuitable for irrigation. In the survey conducted by Kashenge-Killenga et al. (2014), farmers at Korogwe district in Tanga region, Tanzania reported the presence of indicators which show the presence of salts in their fields, which include; stunted plants, yellow striped plants on middle to upper leaves as sign of high pH indicating zinc and iron deficiency, Whitish top soils with salty taste, patches of bare land, Growth of '*Kuruwira or Minywanywa'* plants (salty bushes). Moreover, farmers claimed that salty taste sugarcane, blackish soils, dry skin after bathing, using a lot of soap when washing clothe. All these indicating the presence of salty water which enters the soil through irrigation.

Influence of irrigation water quality on soil salinity

The quality of irrigation water plays a vital role in sustaining production and productivity of agricultural land (Prasad *et al.,* 2022). However, irrigation water usually contains some amount of salt which enter in the field by irrigation, this accumulate over the soil surface with time affecting the soil and crop production. A wide range of research works have been documented against influence of irrigation water on salinity and sodicity in soils. The study by Batakanwa *et al.* (2015) claimed that spatial distribution of soil salinity in the soil horizon were found to be high at shallow depths of 0-10 cm and decreasing gradually up to a depth of 40 cm. This trend shows that the irrigation water applied was slightly saline with higher sodium content and the quantity applied was not sufficient to leach the salt below the crop rooting zone. The study also reported the mean soil salinity (94.35 mS/cm) in non-irrigated land and (338.5 – 342. 72 mS/cm) for supplementary irrigations. In addition, on average 57% of the sampling station had magnesium concentration exceeding the recommended threshold (50 mg/l) (Basu *et al.,* 2021). The study also indicated that majority of the boreholes studied exhibited water unsuitable for irrigation particularly for salinity-sensitive plants due to the level of SAR which exceeded the recommended threshold of 10 meq/l (Aravinthasamy *et al.,* 2020). The same study reported that, none of the sampling station had an average electrical conductivity (EC) concentration below the suggested guideline of 3 dS/m for irrigation water signifying elevated salinity levels in the water samples. Therefore, Poor quality irrigation water increase the salinity and sodicity of agricultural soil which in turn affect soil health and crop productivity.

SALINIZATION AS A THREAT TO FOOD SECURITY AND ENVIRONMENT

Effects on plant growth and crop productivity

The harmful effect of soil salinization in plant growth and crop productivity varies based on climatic and soil conditions, light intensity and the ability of plant species to grow and tolerate the environment (Acosta-Motos *et al.,* 2017). Plants are affected by salinity via two mechanisms: osmotic stress and ion toxicity. The first is the short term effect caused by Na^+ and Cl^- absorption, which reduces osmotic potential between root and soil solution and infiltrate water availability. Second excessive Na+, Cl^-, $S04^{2-}$ concentrations cause ion toxicity, which affects nutrients uptake (Abbasi *at al.,* 2016). In saline soils, the water tends to shift from higher salt concentration inside the plant to a lower salt concentration outside the plant making it more difficult for plant to absolve water. This leads into considerable loss of shoot and root biomass of plants (Kalhoro *et al.,* 2016; Omar *et al.,* 2022). Consistent losses of crop yield caused by soil salinization as a result of human induced activities such as irrigation may alter the cropping system and reduces crop production (Haider and Hossain, 2013). The effect of salt stress in various crops such as rice, wheat, maize, tomato, onions, grapes and chilli crops have been discussed in several literatures; (Rekta, 2024; Farooq *et al.,* 2017; Hu *et al.,* 2022; Xu *et al.,* 2018; Balasankar *et al.,* 2017; Kashenge- Killenga *et al.,* 2016; Kashenge-Killenga *et al.,* 2013). Notwithstanding, Crops vary greatly in their tolerance to salts in the soil solution. So understanding how specific plants respond to salts will help to manage and mitigate salinity stress for ensuring food security and sustainable agricultural practices.

Effects on soil resource and its productivity

Soil salinization is a major soil degradation process that threatens ecosystems at a global level. It interferes with natural biological, biochemical, hydrological and erosional earth cycle (Berendse *et al.,* 2015). The adverse impacts of increased (ECe) on soil processes such as respiration, decomposition, nitrification and de-nitrification through the decrease of soil microorganism activity is well known (Singh, 2015). Soil salinity degrades fertile and productive land and reduces vegetation (Thiam *et al.,* 2021). Saline soils enter a negative feedback of organic carbon (OC) loss as decreased fertility and microbial activities leads to the production of less biomass which affects distribution and stability of soil aggregates (Singh, 2015). These changes increase distribution of clay particles and greater wind and water erosion rates that further intensify OC losses. On a global scale, salinization causes loss of arable land of about 2000 ha per day hence contributing to soil losses (Meliyo *et al.,* 2016; Zaman *et al.,* 2018). In the survey conducted by Kashenge-Killenga *et al.* (2016) it is reported that the estimated area loss due to salinization in irrigation schemes ranges from 5 to 25%. Moreover, the elevated concentration of salt in the soils are harmful to the soil ecosystem, which adversely reduces the microbial diversity of soils and thus decreases soil health and productivity (Kumawat *et al.,* 2022).

Impacts on socio-economic aspects

Besides its negative effects on crop and soil productivity, salinization also has negative impacts on social-economic aspects. High salinity level can thus result into loss of emerging resources, goods and services which cause negative impact on environmental health. Consequently, this affects the sociocultural and human health issues that interrupt the economic and general welfare of the people (Brevik *et al.,* 2015). Several studies have reported the estimated costs due to salinity and sodicity in different arid and semi-arid areas of the global (Wichelns and Qadir, 2014). The global estimate of soil salinity induced costs due to crop failure in irrigated areas reaches US $ 27.3 billion based mainly on crop yield losses and due to outmigration of local populations from salt affected regions, with the estimated cost of US $ 441 per ha of land (Wichelns and Quadir, 2014). These costs are expected to be even higher when other cost components are taken into consideration, such as environmental costs associated with salt- affected land and the potential social cost on farm businesses. Although salinization has strong implications on social economic aspects, yet very few studies have conducted on the aspect of its impacts (Shahid *et al.,* 2018). One of the study in India conducted by Chatterjee *et al.* (2020) on the economic effect of salinity at household farm level. The study reported the economic effect of salt-affected area of 56,760 ha of irrigated land and the considerable costs for soil reclamation of that land was equivalent to € 69 million. Similarly, Montanarella. (2007) conducted a study in three European countries (Spain, Hangary and Bulgaria) which estimated annual costs of soil salinization at € 158 – 321 million. Similar finding was reported in India where, the soil salinization induced costs due to crop losses valued at Rs. 230.20 billion which has strong implications on Indian national economy (Mandal *et al.,* 2018). Due to this, farmers' living standard, regular life activities and socio-economic conditions are affected, and are forced to shift their livelihood strategies. Moreover, other social consequences of soil salinization include decline in agricultural harvest, low income, change of livelihood preferences and related limits (Kumar and Sharma, 2020). These can lead to substantial economic losses for farmers and agricultural industries. So, it is effective to develop cost-effective strategies to minimize these losses and support the livelihoods of farmers.

MANAGEMENT OPTIONS OF SALINE AND SODIC SOILS

Management of saline and sodic soils require a profound knowledge of reclamation through various proper soil and water management practices and optimal utilization of natural resources (Daba and Qureshi, 2021). Proper soil management practices and the maintenance of soil quality are central issues to agricultural sustainability. There are a number of salinity management options that can be used to mitigate and control the effects of salinity (Wudu and Mahider, 2020). These are normally developed based on the type of the salt existing, extent of the problem and availability of site-specific amendment materials and climatic conditions of a particular location (Omar *et al.,* 2023). However, most of these options are cost and time consuming. Details of best-bet options for the management of soil salinity and sodicity are discussed below.

Organic amendments

Organic amendments refer to the application of organic materials in the topsoil of saline land to reduce soil evaporation, salt water movement and salt accumulation by regulating the distribution of salt in the rhizosphere (Cuevas *et al.,* 2019). The use of organic materials to saline soils improves porosity, hydraulic conductivity, soil aggregate stability and permeability. Moreover, organic amendments help to improve soil aggregate formation and stability by binding the small particles in saline sodic and sodic soils to form large, water-stable aggregates (Diacono and Montemurro, 2015). Organic materials include compost, crop straw, organic manure, green manure, humic substances, municipal solid waste and biochar. These materials can be used alone or in combination with inorganic materials for the recovery of affected soils (El Hasini *et al.,* 2019; M. Huang *et al.,* 2019; Sheoran *et al.,* 2021).

Application of green manure, compost and municipal solid waste compost on improving physical, biochemical, and microbial properties of salt-affected soils is well acknowledged by several studies. For example; in Ethiopia, Kaledhonkar *et al.* (2019) revealed that, application of Farm Yard Manure (FYM)10 tha-^{1}, Sunhemp and dhaincha as green manuring in Vertisol (Sodic soils) was made a different in reducing soil ESP from 35 to 22.6 in 2017/2018 season. In addition, Khatun *et al.* (2019) reported that in a saline soil (10.6 dS m^{-1}) irrigated with a slightly saline water (4.28 dS m^{-1}), vermi-compost and cow dung as organic amendments were found to improve the soil EC (3.37 dS m^{-1}) and pH, thus increasing maize growth compared to untreated control. Apart from livestock derived organic amendment, this process also can utilize crop residue materials, for example it has been indicated that, application of wheat straw at 0.75 t ha^{-1} contribute an adequate amount of Ca^{2+} and Mg^{2+} cations replacing amount of Na^{2+} cations in the soil solution and thus makes them available for plant uptake (Chagantii *et al.,* 2015). Other studies have reported the combined application of green waste compost, sugarcane compost, and gypsum to reclaim saline soils (Diacono and Montemurro, 2015; El Hasini *et al.,* 2019; Leogrande and Vitti, 2019). Furthermore, organic materials stimulate nitrogen mineralization in salt-affected soils by increasing organic matter solubilization (Wang *et al.,* 2019). In addition, Bio-organic amendments have potential to improve both soil and crop productivity through increased soil organic matter, essential nutrients (especially, N and P) and water availability (Bello and Yusuph, 2021). Bio-organic amendment is a term used to indicate the integrated use of beneficial soil microbes and organic sources of nutrients in the cultivation of crops for an increased yield. Beneficial soil microbes play a significant role in nutrient cycling through mineralization and immobilization and thus, have positive effect on soil nutrient availability, aeration and organic matter (Xu *et al.,* 2015). Many studies have described the potential of soil microbes such as pseudomonas stutzeri and trichoderma harzianum in enhancing glycophytes tolerance to salinity stress (Mbark *et al.,* 2017; Bacilio *et al.,* 2016). For instance, it has been demonstrated that *Trichoderma harzianum* potentially improves the yield of tomato, as well as soil fertility and biodiversity under salinity stress conditions (Wagner *et al.,* 2016). Furthermore, Daliakopoulos *et al.* (2019) indicated that inoculation of *Trichoderma harzianum* reduces Sodium Adsorption Ratio and increases tomato fruit yield and the available soil P levels in a saline soil condition. Currently, the application of biochar as an organic amendment for salt-affected soils has been reported and has involved substantial attention from different scientists (Phuong *et al.,* 2020; Yang *et al.,* 2020; Kul *et al.,* 2021; Bin Yousaf *et al.,* 2022; Singh *et al.,* 2022; Saifullah *et al.,* 2017; Ur-Rahman, 2022), with emphasis on the improvement of the physical, chemical, and biological properties of salt-affected soils. Many studies have reported positive results using biochar as an amendment for saline soils, however, its efficiency is controlled by various factors namely temperature, feedstock, soil salt types, and biotic interactions (Freitas *et al.,* 2020; Huang *et al.,* 2021 2019; Ippolito *et al.,* 2020). In addition, biochar reduces salt injury through the following mechanisms: (1) transient binding of Na+ sodium (Na+) on its exchange sites, which reduces (K+) uptake; 2) rising potassium in soil solution, which maintains the Na+/K+ ionic balance, hence preventing Na+ uptake; and 3) improving water retention that rises soil moisture content causing dilution Na+ effects to reduce the reduces uptake (Yang *et al.,* 2020; Ali *et al.,* 2021; Ketehouli *et al.,* 2019; Mehmood *et al.,* 2020). Notwithstanding, the high cost of production and application rate are among the major constraints of applying biochars for the amelioration of salt-affected soils (Saifullah *et al.,* 2017). Besides with good results reported on the use of organic amendments in the management of salt affected soil in various semi-arid tropics, Meliyo *et al.* (2016) have recommended 3– 8 tons/ha of (FYM) to boost soil organic matter and improve the infiltration rate in Tanzania, thereby accelerating the leaching of soluble salts down the root zone on clay soil. Moreover, the application of FYM at 25 t ha-^{1} improves the infiltration rate and available water capacity of sodic soils (Makoi and Ndakidemi, 2007). However, small-scale farmers find it difficult to access bulk Farm Yard Manure (FYM) for salt-affected soil management unless alternative organic sources are considered (Makoi and Ndakidemi, 2007). The locally available organic amendment materials like rice husk, rice straw, and sawdust incorporated in salt-affected soils 45 days before flashing are effective in improving soil infiltration ECe, and yield comparable to gypsum (Meliyo *et al.,* 2016).

Inorganic amendment

Inorganic amendments involve the chemical materials for application and incorporation in the soil to help in the management and reclamation of salt affected soils for long-term productivity (Stamford *et al.,* 2015). These materials are either mined or synthesized, , for instance, dolomite lime, application of sulfur-containing compounds such as gypsum lime, vermiculite and perlite. Other related chemical amendments include element S, sulfuric acid (H_2SO_4), polysulfide of sulfur and hydrogen sulfite and gypsum-like byproducts–e.g., phosphogypsum (a byproduct of phosphoric acid manufacturing), coalgypsum (a byproduct of coal power plants), and lacto gypsum (a byproduct of lactic acid and lactate manufacturing) (Abdelhamid *et al.,* 2013; Lastiri-Hernández *et al.,* 2019; Wang *et al.,* 2019). Among the widely known inorganic amendments for reclaiming salt-affected soils, gypsum application is the foremost (Qadir *et al.,* 2017). Following the application of amendments, and solubilization of Na+, the soluble salts must be leached by excess irrigation (Paz *et al.,* 2020). The rate of gypsum application depends on the magnitude of sodification, and the prevailing biophysical conditions, of which most important are the prevailing climate, parent material, soil type, quality of irrigation and underground water, and the coming crop variety (Paz *et al.,* 2020). Chemical remediation of saline-sodic soils is similar to that of sodic soils, followed by salinity remediation practices through improving soil drainage, lowering the water-table level, and leaching of salts other than Na+ (North Dakota State University Extension Service, 2014). The role of gypsum application in saline soils is the provision of Ca^{2+} which remove a substantial percentage of exchangeable Na^{+}, and the reaction can be rapidly accomplished using $CaSO_4{\cdot}2H_2O$. Several studies have reported the importance of gypsum and associated S-containing compounds to improve the growth of many crops, including cabbage, barley, maize and tomato grown under salinity stress conditions (Chen *et al.,* 2015; Shalaby, 2018; Riffat and Ahmad, 2020; Silva *et al.,* 2014). $CaSO_4{\cdot}2H_2O$ and polysulfides are among the t effective inorganic amendments in soil reclamation as they improve the soil's physical and chemical characteristics, biomass and crops production (Lastiri-Hernández *et al.,* 2019; Wang *et al.,* 2017; Kim *et al.,* 2016; Alcívar *et al.,* 2018). The application of inorganic materials for the management of saline and sodic soils have been recommended globally. The combination of FYM at the rates of 25 t ha-1 and gypsum 12.5 t ha-1 significantly reduced EC, ESP, and increases infiltration rate compared to the treatment of FYM and gypsum alone in sodic soil (Makoi and Ndakidemi, 2007). Furthermore, the integrated use of gypsum and various organic amendments improved the quality and productivity of saline-sodic soils by changing the soil properties (Alcívar *et al.,* 2018; Bello *et al.,* 2021). Nevertheless, gypsum and water are applied in large quantities for effective reclaiming saline soils (Stamford *et al.,* 2015; McKenna *et al.,* 2019; Bello *et al.,* 2021). The amount of the gypsum required to reclaim a particular saline soil is calculated based on soil gypsum requirement equation developed by Alcívar *et al.* (2018).

Salt flushing and leaching

Apparently, the uppermost salt-affected soil layer is mechanically removed by using heavy tractor-scraper machineries. However, it is expensive, and short-term (Cuevas *et al.,* 2019). At the same time, flushing with sufficient volume of high-quality water is suitable for heavy textured soils with salt crusts, where the flushed salts from the soil surface enter the drainage system and are thus removed from the target land (Shahid *et al.,* 2018). The method is possible only when the salt forms a layer of crust on the soil surface. However, the process is inefficient and can remove very little amount of salt (Abdel-Fattah, 2018; Shankar and Evelin, 2019). Together with salt flushing leaching the salts out of the soil profile through excess irrigation, should be coupled with a drainage system deep enough to prevent capillary rise of the water back into the root zone or soil surface (Cuevas *et al.,* 2019). For example, in west-central Kazakhstan, in furrow irrigation agricultural systems irrigation water is applied beyond the crops' requirements throughout the cropping season, thus, leaching the salts from the rooting zone (Devkota *et al.,* 2015).

Leaching of salts from the root-zone is the effective technique for salt management. This is the process by which salts from the upper layer of soil are forced to move downward much below the root zone. This method requires good quality of water with low electrolyte concentration that percolate through the soil profile to facilitate dissolution of salts and their downward movement to prevent buildup of excess salt in the root zone. Initially, reclamation rate depends on the amount of water traveling through the profile and out of the root zone, volume of soil to be reclaimed, the texture of soil and desired salt level in the rhizosphere (Chagantii *et al.,* 2015). Leaching is preferable when the soil has low moisture content, the ground water table is deep and the water applied has little salt (FAO, 2017). Leaching can be carried out in different ways, such as continuous ponding, intermittent ponding and sprinkling. Continuous ponding is more appropriate for medium textured soil and can achieve leaching in a short duration of time. Intermittent ponding can accomplish the same level of leaching with about one-third less water used in continuous ponding however it may take longer duration of time. It is more suitable for fine textured soils especially in fields with shallow water table or a tile drainage system. In situations where a surface seal develops on soil surface, intermittent ponding can induce formation of cracks to allow water infiltration (Abdel-Fattah, 2018). Sprinkling is an energy and cost-intensive method suitable for fields that are not prepared for ponded leaching. Generally leaching is cost intensive and depend on the availability of water and proper drainage system as well as it reduces the total nitrogen, total organic carbon, microbial activity and the overall soil fertility (Shankar and Evelin, 2019).

Adequate drainage

Drainage is the removal and disposal of water with excess salt either from the ground surface or from the crop root zone (Sharma *et al.,* 2016). The water with excess salt may be caused by rainfall or by using too much poor quality irrigation water but may also have other origins such as canal seepage. In very dry areas, there is often accumulation of salts in the soil. There are two types of drainage namely; surface drainage and sub-surface drainage. Sub-surface drainage refers to the drainage which gathers and evacuates water from the soil's surface (Abduljalee *et al.,* 2023). In sub-surface drainage, ditches are quickly and inexpensively made to channel gravitational water. Ditches require periodic cleaning and maintenance for effective drainage of agricultural wetlands. The installation of sub-surface drainage is recommended for supplementing open drain systems (Asad *et al.,* 2018). Drainage is improved by planting deep-rooted plants under maintained permeability. The canal water should be intercepted or sealed before entering the field to reduce seepage.

Use of salt stress tolerant plants

The choice of high salt stress tolerant crops in saline soil is important. These crops should be tolerant to various levels of salt concentration (Farooq *et al.,* 2017). The use of halophyte species in agriculture facilitates crop adaptation to increased salinization while contributing to the improvement of soil quality and food security (Munns and Gilliham, 2015). The economically important halophytes include sorghum, rye, date palm, grape, guava, mango, olive, oilseed rape, guar, cotton, artichoke, kenaf and mustard (Li *et al.,* 2019). These crops have been identified for their use as vegetables and traditional foods in different parts of the world (Hasanuzzaman *et al.,* 2014; Ventura and Sagi, 2013). Additionally, planting trees is also one of the way to improve the productivity of affected land. Trees are planted to take up part of excess salt to decrease salt discharge into streams and prevent secondary salinization of the surrounding areas (Irakoze *et al.,* 2021; Manuel *et al.,* 2017).

Use of salt tolerant cultivars

These are mainly deep-root crop varieties that extract water from the deep soil in order to reduce the risk of groundwater discharge and the upward migration of salts to the ground surface (Cuevas *et al.,* 2019). The use of salt tolerance cultivars is an efficient way of addressing the challenge of soil salinity to sustain growth under osmotic effects, ion toxicities, and nutrient imbalance conditions (Manuel *et al.,* 2017; Zhang *et al.,* 2019). Among cereal crops, barley (*Hordeum vulgare L.*) is highly tolerant to dry conditions and soil salinity, some relatively new barley cultivars proved to be exceptionally salt tolerant (Shahbaz and Ashraf, 2013). Among vegetable crops, potato (*Solanum tuberosum L*.), carrot (*Daucus carota*), onion (*Allium cepa L*.), lettuce (*Lactuca sativa L.*), and cabbage (*Brassica oleracea L*.) (de Vos *et al.,* 2016). Among forage crops, alfalfa (*Medicago sativa L*.) tolerates soil salinity (Qiu *et al.,* 2023). Kallar grass (*Leptochloa fusca L.*), a fodder crop has been widely used in salt-affected and water-logged lands in Pakistan, and has proved to effectively tolerate saline, sodic, and saline-sodic soils (Nadeem *et al.,* 2017). Also, research efforts have led to the identification of a number of fruit crops for sustainable land use in salt-affected environments (Singh *et al.,* 2018). Moreover, Chiconato *et al.* (2019) reported the performance of two genetically diverse cultivars of sugarcane under different concentrations of salinity (0, 40, 80 and 160 mM Nacl) over a period of 30 days.

AGRONOMIC AND CULTURAL PRACTICES FOR RECLAMATION OF SALT AFFECTED SOILS

Irrigation practices

With reference to the irrigation practices, flood and furrow irrigation is a common cause of water table rising especially in clay and loam soils, where deep drainage is impeded resulting into salt which is present in ground water to ascend to the upper soil layer (Wichelns *et al.,* 2014). Thus, flood and furrow irrigation may be avoided in this case to minimize aquifer recharge with excess salts hence, limiting soil salinization (Cuevas *et al.,* 2019). Similarly, in non-flooding irrigation methods that use routine, frequent high dose irrigation to leach salts from the rhizosphere increase the risk of groundwater salinization (Devkota *et al.,* 2015). This risk is relevant in drylands, where the risk of soil salinization is high even when high-quality water is used for irrigation (Cuevas *et al.,* 2019). On the other hand, water-saving irrigation methods, such as micro irrigation systems, and specifically drip irrigation systems, decrease the risk of groundwater recharge, while effectively leaching salts (Stavi, 2020). Yet, depending on the quality of irrigation-water, as well as associated agronomic practices, soil salinization and sodification can still occur even under drip irrigation systems (Liu *et al.,* 2020; Stavi, 2020). In addition, micro-irrigation has several advantages when the irrigation water is saline, except for low growing crops. Irrigation with micro-sprinklers or sprayers avoids wetting of the leaves with saline water, thus preventing extensive damages to the green tissues of the plant. On the other hand, (Borena and Hassen, 2022) demonstrated that for a given amount of applied water, the wetting pattern around emitters results in a higher leaching fraction and lower salinity levels than in other irrigation systems. Sub-surface drip irrigation has been proposed as additional measure since it reduces evaporation from the soil and permits better moisture distribution compared to conventional drip irrigation (El Mokh *et al.,* 2014). Apart from minimizing salinity hazard to plants, drip irrigation also offers a number of advantages such as improved soil-water regime, partial soil wetting, water savings, weed control and higher yields. Moreover, Amankwaa-yeboah *et al.* (2023) proposes that irrigated agriculture could be sustained by better irrigation practices such as adoption of partial root zone drying methodology, and drip or micro jet irrigation to optimize use of water.

Mulching soil surface

In salt affected soil environment, application of mulches is an alternative coping mechanism for sustainable soil and crop productivity improvement (Joardar and Basu, 2018). Mulches are organic or inorganic materials that may be placed on the soil surface in order to minimize evaporation over the surface. It has been demonstrated that mulching with various materials can decrease soil water evaporation, retains soil moisture, reduces soil compaction, regulates soil temperature, and improves soil quality there by reducing salt buildup in the soils (Deng *et al.,* 2021). The persistence of a residue layer in the surface of the soil notably decreases secondary salinization (Kader *et al.,* 2019). Straw mulching is a promising option to control soil salinity as it decreases soil water evaporation and regulates soil water and salt movement. Zhao *et al.* (2014) found a significant decrease in salt content in the upper 40 cm soil depth when straw mulching was implemented. Straw mulching reduces salt content of the soil surface by vertical distribution which reduces salt damage to the crop. This enhances crop yield consequently reduces the risk of soil salinization and soil erosion (Fraga and Santos, 2018). Furthermore, Buesa *et al.* (2021) suggested that, combining direct drilling and mulching improves rain water infiltration and reduces moisture evaporation from the soil, thus diminishing the accumulation of salt in the upper soil layer during summer and improving leaching during winter. Therefore, mulching is the better field management option for reducing soil erodibility due to salinity and upward movement of salts and evaporation of water from the soil surface (Nzeyimana *et al.,* 2017).

Crop rotation

Crop rotation practice has been reported to effectively halt salinization, where crops with high tolerance to salinity are planted during the dry period, while crops which are susceptible to salt stress are planted during wet season (Cuevas *et al.,* 2019). One option in this context is to include summer active herbaceous crops such as Lucerne (*Medicago sativa L*.) species that fits well in the rotation providing valuable summer fodder, additional transpiration as well as soil fertility management option (Shawkhatuzamman *et al.,* 2023). Alfalfa and river hemp (*Sesbania spp*.) also increase the system’s nutrient availability and ecrease the soil’s salinity and solidity levels (Stavi *et al.,* 2021). Weaver *et al.* (2013) analyzed drainage water quality in the subsoil of sodic and non-sodic vertisol under selected crop rotations including cotton, for instance in continuous cotton (*Gossypium hirsutum L*), Cotton – dolichos (*Lablab purpureus Sweet*), and cotton – Wheat cropping system. Their results indicated that in all cases the salinity of the drainage water was many times higher than that present in the water used for irrigation (Cuevas *et al.,* 2019). Also, Gabriel *et al.* (2014) analyzed the impact of replacing long fallow by barley (*Hordeum vulgare L.*) and vetch (*Vicia villosa Roth*) as cover crops on water, nitrogen and salinity dynamics of a maize cropping system. The results indicated that, replacing fallow cover crops such as barley (*Hordeum vulgare L.*) and vetch (*Vicia villosa Roth*) reduces nitrate leaching and minimizes top layer soil salinity. This usually, lowers irrigation volumes and reduces the risk of deepwater contamination due to nitrate leaching. (Gabriel *et al.,* 2012).

Afforestation and reforestation

Planting tree and shrub species with deep root systems and high water demand proved to be effective in controlling the discharge of underground water. This limits salinization or sodification of the upper soil layers and subsequently restores saline, sodic, and saline-sodic soils (Yildiz *et al.,* 2017). Agroforestry system, a farming where trees and crops are planted together can also be suitable to overcome the upper and most saline or sodic layers. For instance, trees and shrubs are planted in the furrows’ salt-washed micro-habitats, may be suitable for reducing salinization process (Sharma *et al.,* 2014). Alternatively, sub-surface planting, where the trees and shrubs are planted in deep holes or trenches whose depth exceeds the salt-affected surface layer, may be necessary to restore saline or sodic soil layers (Banyal *et al.,* 2017). In west-central Uzbekistan, afforestation of saline croplands with Euphrates poplar (*Populus euphratica Oliv.*) and Siberianelm (*Ulmus pumila L*.) proved to be highly effective in reducing soil salinity, while improving the soil's aggregate stability and organic carbon pools (Hoa *et al.,* 2020). In northern India, mesquite (*Prosopis juliflora (Sw.) DC*.), tamarisk articulate (*Tamarix articulate Vahl*.), and goma arábiga (*Acacia nilotica L*.) were reported to be highly effective in restoring sodic soils. At the same time, forest red gum (*Eucalyptus tereticornism.*), Indian rosewood (*Dalbergia sissoo Roxb*.), arjuna, neem (*Azadirachta indica A.*), and lebbeck (*Albizia lebbeck L*.) among other tree species, were reported to restore sodic croplands, with specific improvement of the physio-chemical, biological, and bio-chemical properties of soil (Singh *et al.,* 2012). In addition to regular afforestation and reforestation practices, agroforestry and silvo-pasture systems are known to restore saline, sodic, and saline-sodic soils, while providing food, feed, and fiber (Dagar, 2014).

CONCLUSION AND THE WAY FORWARD

Irrigated agriculture worldwide has threatened by severe salinization which results into low yields, food and nutritional insecurity as well as environmental degradation. The problem is persistently increasing especially in arid and semi-arid regions. In the look of its severe impact in some parts of the world, an intervention to safeguard food sustainability and environment is critical. Thus, appropriate information is vital to reduce salinization on agricultural land for sustainable crop production. Following up on the reviewed literatures, it has been noted that, various mitigation techniques such as addition of amendments, planting of salt-tolerant crops, appropriate irrigation and drainage management, phytoremediation and bioremediation, have successfully tackled soil salinity and sodicity problems in many parts of the world. However, its effectiveness varies based on the soils physicochemical properties, water availability and the climatic conditions of a particular location. In light of the above conclusion, it is recommended that taking steps towards measurement of soil salinity and mapping of salt-affected areas are essential for effective planning of agricultural activities in salt affected soils and to establish the most appropriate irrigation and soil management practices. Monitoring is also required to follow on-going salinization/desalinization campaign over time and to ensure up-to-date delineation of crop management zones and for regional land manage-ment. Also, alternative approaches such as irrigation management to improve irrigation water efficiencies and to control percolation losses need to be prioritized. Finally, in areas where salinity level is high the use of salt-tolerant crops and halophytes should be encouraged.

CONFLICT OF INTEREST

The authors declared that no competing interest exists.

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REFERENCES

Abbasi, H., Jamil, M., Haq, A., Ali, S., Ahmad, R., Malik, Z., & Parveen, Z. (2016). Salt stress manifestation on plants, mechanism of salt tolerance and potassium role in alleviating it: a review. *Zemdirbyste-Agriculture*, *103*(2), 229-238.

Abdel-Fattah, M. K. (2019). Reclamation of saline-sodic soils for sustainable agriculture in Egypt. *Sustainability of Agricultural Environment in Egypt: Part II: Soil-Water-Plant Nexus*. Pp. 69-92.

Abdelhamid, M. T., Eldardiry, E. & El-Hady, M. A. (2013). Ameliorate salinity effect through sulphur application and its effect on some soil and plant characters under different water quantities. *Journal of Agricultural Science, 4*(1), 39-47.

Abduljalee, Y., Amiri, M., Amen, E. M., Salem, A., Ali, Z. F., Awad, A., Loczy, D., & Ghzal, M. (2024). Enhancing groundwater vulnerability assessment for improved Environmental Management: Addressing a criyicle environmental concern. *Environmental Science and Pollution Research*, *31*, 19185-19205.

Acosta-Motos, J. R., Ortuño, M. F., Bernal-Vicente, A., Diaz-Vivancos, P., Sanchez-Blanco, M. J., & Hernandez, J. A. (2017). Plant responses to salt stress: adaptive mechanisms. *Agronomy*, *7*(1), 18.

Alcívar, M., Zurita-Silva, A., Sandoval, M., Muñoz, C., & Schoebitz, M. (2018). Reclamation of saline–sodic soils with combined amendments: impact on quinoa performance and biological soil quality. *Sustainability*, *10*(9), 3083.

Ali, E. F., Al-Yasi, H. M., Kheir., A. M. S. & Eissa, M. A. (2021). Effect of biochar on CO_2 sequestration and productivity of pear millet plants grown in saline sodic soils. *Journal of Science and plant Nutrition, 21*(2), 897-907.

Amankwaa-Yeboah, P., Yeboah, S., Osei, G., Waaley, L., Kyeremateng, P., Agyeman, K., Akoriko, F. A., Adomako, J., Danquah, E. O. & Ampong, A. N. (2023). Critical attributes and considerations for selecting irrigation systems for wastewater. *Journal of the Ghana Institution of Engineering, 23*(2), 64-75.

Amin, S., Ghadiri, H., Chen, C., & Marschner, P. (2016). Salt-affected soils reclamation carbon dynamics and biochar: A review. *Journal of Soils and Sediments*, 16(3), 939-953.

Aravinthasamy, P., Karunanidhi, D., Subramani, T., Srinivasamoorthy, K., & Anand, B. (2020). Geochemical evaluation of fluoride contamination in groundwater from Shanmuganadhi River basin, South India: implication on human health. *Environmental Geochemistry and Health*, *42*, 1937-1963.

Asad, S. Q., Tesfaye, E., & Melese, M. (2018). Prospects of alternative copping systems for salt-affected soils in Ethiopia. *Journal of Soil Science and Environmental Management,* 9(7), 98-107.

Aslam, M. R., & Prathapar, S. A. (2009). Strategies to mitigate secondary salinization in the Indus Basin of Pakistan: A selective review. International Water Management Institute. Colombo, Sri Lanka. *Research Report*, 97.

Bacilio, M., Moreno, M., & Bashan, Y. (2016). Mitigation of negative effects of progressive soil salinity gradients by application of humic acids and inoculation with *Pseudomonas stutzeri* in a salt-tolerant and a salt-susceptible pepper. *Applied Soil Ecology*, *107*, 394-404.

Balasankar, D., Praneetha. S., Arumugam, T., Jeyakumar, P., Manivannan, N., & Arulmozhiselvan, K. (2017). Genotypic Response of Chilli (*Capsicum annuum* L.) on Germination and Seedling Characters to Different Salinity Levels. *International Journal of Current Microbiology Applied Sciences*, *6*(4), 2197-2205.

Banyal, R., Rajkumar, M., Kumar, M., Yadav, R. K., & Dagar, J. C. (2017). Agroforestry for Rehabilitation and Sustenance of Saline Ecologies. *Agroforestry Anecdotal to Modern Science*, *3*(16), 413-454.

Basu, S., Clark, R. E., Bera, S., Casteel, C. L., & Crowder, D. W. (2021). Responses of pea plants to multiple antagonists are mediated by order of attack and phytohormone crosstalk. *Journal of Molecular Ecology,* 30, 4939-4948.

Batakanwa, F. J., Mahoo, H. F., & Kahimba, F. C. (2015). Influence of irrigation water quality on soil salinization in semi-arid areas: A case study of Makutupora, Dodoma-Tanzania. *International Journal of Scientific and Engineering Research, 6*(9), 2229-5518.

Bellido-Jim´enez, J. A., Est´evez, J., & Garc´ia-Mar´in, A. P. (2021). New machine learning approaches to improve reference evapotranspiration estimates using intra-daily temperature based variables in semi-arid region of Spain. *Agricultural Water Management*, *245*, 106-558.

Bello, A. H., Suleiman, K., Alayafi, S. G. A. L., Solaimani, K. & Abo-Elyousr, A. M. (2021). Mittigating Soil Salinity Stress with Gypsum and Bio-organic amendments: A review. *Agronomy Journal*, *11*(9), 1735.

Bello, S. K., & Yusuf, A. A. (2021). Phosphorus influences the performance of mycorrhiza and organic manure in maize production. *Journal of Plant Nutrition*, *44*(5), 679-691.

Berendse, F., van Ruijven, J., Jongejans, E., & Keesstra, S. (2015). Loss of plant species diversity reduces soil erosion resistance. *Ecosystems*, *18*, 881-888.

Berhane, G. G., & Chala, A. Q. (2017). Plant physiological stimulation by seeds salt priming in maize (*Zea mays*): Prospect for salt tolerance. *African Journal of Biotechnology, 16*(5), 209-223.

Bin Yousaf, M. T., Nawaz, M. F., Yasin, G., Cheng, H., Ahmed, I., Gul, S., Rizwan, M., Rehim, A., Xuebin, Q., & Ur Rahman, S. (2022). Determining the appropriate level of farmyard manure biochar application in saline soils for three selected farm tree species. *Plos One*, *17*(4), e0265005.

Borena, F. R., & Hassen, J. M. (2022). Impacts of Soil Salinity on Irrigation Potential: The Case of Middle Awash. Ethiopian Review. *Open access Library Journal,* 9(4), e8123.

Brevik, E. C., & Burgess, L. C. (2015). *Soil: Influence on human health: Encyclopedia of environmental management.* Jorgensen, S. V. (ed.). CRC Press. Pp. 1-13.

Buesa, I., Miras-Ávalos, J. M., De Paz, J. M., Visconti, F., Sanz, F., Yeves, A., Guerra, D., & Intrigliolo, D. S. (2021). Soil management in semi-arid vineyards: Combined effects of organic mulching and no-tillage under different water regimes. *European Journal of Agronomy, 123*, 126-198.

Butcher, K., Wick, A. F., Dessutter, T., Chatterjee, A., & Harmon, J. (2016). Soil salinity: A threat to global food security. *Agronomy Journal, 108*(6), 2189-2200.

Chagantii, V., Crohn, D., & Simunek, J. (2015). Leaching and reclamation of a biochar and compost amended saline-sodic soil with moderate SAR reclaimed water. *Agricultural Water Management, 158*(1), 255-265.

Chatterjee, A., Geaumont, B., DeSutter, T., Hopkins, D. G., & Rakkar, M. (2015). Rapid shifts in soil organic carbon mineralization within sodic landscapes. *Arid Land Resource Management Journal*, *29*, 255-263.

Chatterjee, S., Chakraborty, R., & Banerje, H. (2020). Economic impact assessment of conservation agriculture on small and marginal farm households in eastern, India. *Journal of Agricultural and Applied Economic Research, 33*, 127-138.

Chaudhary, V., & Satheeshkumar, S. (2018). Assessment of groundwater quality for drinking and irrigation purposes in arid areas of Rajasthan, India. *Journal of Applied Water Science,* 8, Article number 218.

Chen, J., Wang, W. H., Wu, F. H., He, E. M., Liu, X., Shangguan, Z. P., & Zheng, H. L. (2015). Hydrogen sulfide enhances salt tolerance through nitric oxide-mediated maintenance of ion homeostasis in barley seedling roots. *Journal of Sciences,* 5, Article number 12516.

Chiconato, D. A., Sausa-Junior, G. S., Mathias de Santo, M. D., & Munns, R. (2019). Adaptation of sugarcane plants to saline soils. *Environmental and Experimental Botany, 162*, 201-211.

Connor, J. D., Schewabe, K., King, D., & Knapp, K. (2012). Irrigated agriculture and climate change: The influence of water supply variability and salinity on adaptation. *Ecological Economics journal, 77*(1), 147-157.

Corwin, D. L. (2020). Climate change impacts on soil salinity in agricultural areas. *European Journal of soil science, 72*(2), 842-862.

Corwin, D. L., & Scudiero, E. (2019). *Review of soil salinity assessment for agriculture across multiple scale using proximal and/or remote sensors* (1st Edition). USDA-ARS/UNL. p. 2148. Retrieved from https://digitalcommons.unl.edu/usdaarsfacpub/2148.

Cuevas, J., Daliakopoulos, I. N., Fernando, M., Hueso, J. J., & Tsanis, I. K. (2019). A Review of Soil Improving Cropping Systems for Soil Salinization. *Agronomy Journal, 9*(6), 295.

Daba, A. W. & Qureshi, A. S. (2021). Review on of soil salinity and sodicity challenges to crop production in the low land irrigated areas of Ethiopia and its management strategies. *Journal of Land Use Optimization*, *10*(12), 1377.

Dagar, J. C. (2013). Greening salty and waterlogged lands through agroforestry systems for livelihood security and better environment. In *Agroforestry systems in India: livelihood* *security & ecosystem services* (pp. 273-332). New Delhi: Springer India.

Daliakopoulos, I. N., Apostolakis, A., Wagner, K., Deligianni, A., Koutskoudis, D., Stamatakis, A., Tsanis, I. K. (2016). Effectiveness of *Trichoderma harzianum* in soil and yield conservation of tomato crops under saline irrigation. *Catena, 175*, 144-153.

De Vos, A., Bruning, B., Van Straten, G., Oosterbaan, R., Rozema, J., & Van Bodegom, P. (2016). *Crop salt tolerance under controlled field conditions in the Netherlands, based on trials conducted*. Salt Farms Texel. p. 39.

Deng, Y. P., Sun, C. T., Sun, Y. S., Zhang, J. P., Mi, Z. R., Mao, W. B., & Sun, Y. X. (2021). Water and Salt Distribution and Evaporation Characteristics of Coastal Saline Soils under Straw Mulching Conditions. *China Rural Water Hydropower*, *202*, 128-133.

Devkota, M., Martius, C., Gupta, R. K., Devkota, K. P., McDonald, A. J., & Lamers, J. P. A. (2015). Managing soil salinity with permanent bed planting in irrigated production systems in Central Asia. *Agricultural Ecosystem Environment, 202*, 90-97.

Diacono, M., & Montemurro, F. (2015). Effectiveness of organic wastes as fertilizers and amendments in salt-affected soils. *Journal of Agriculture*, *5*(2), 221-230.

El Hasini, S., Iben Halima, O., El Azzouzi, M., Douaik, A., Azim, K. & Zouahri, A. (2019). Organic and inorganic remediation of soils affected by salinity in the Sebkha of Sed El Mesjoune Marrakesh (Morocco). *Soil and Tillage Research*, *193*, 153-160.

El Mokh, F., Nagaz, K., Masmoudi, M., & Mechlia, N. B. (2014). Effects of surface and subsurface drip irrigation regimes with saline water on yield and water use efficiency of potato in arid conditions of Tunisia. *Journal of Agriculture and Environment for International Development*, *108*(2), 227-246.

FAO & ITPS (2015). Status of the World's soil resources (SWSR) – Main report. Food and Agriculture Organization of the United Nations. Rome, Italy.

FAO (2003). The state of food insecurity in the world, Monitoring progress towards the World food summit and Millennium Goals. Food and agriculture Organizations of the United Nations. Rome, Italy.

FAO (2016). The state of food and agriculture. Food and Agriculture Organization of the United Nations report. Rome.

FAO (2020). Mapping of salt-affected soils: Technical Manual. Food and Agricultural Organization. Rome, Italy.

FAO (2021). The state of food security and nutrition in the world. Transforming food systems for food security, improved nutrition and affordable healthy diets for all. Rome Food and Agriculture Organization of the United Nations. Retrieved from https://doi.org/10.4060/cb4474en.

FAO-AQUASTAT (2016). Country profile – United Republic of Tanzania Food and Agriculture Organization of the United Nations. Rome, Italy.

Farifteh, J., Farshad, A., & George, R. J. (2006). Assessing salt affected soils using remote sensing solute modelling and geophysics. *Journal of Geoderma*, *130*(3), 191-206.

Farooq, M., Gogoi, N., Hussain, M., Barthakur, S., Paul, S., Bharadwai, N., Migdadi, H. M., Alghamdi, S. S., & Siddique, K. H. M. (2017). Plant Physiology and Biochemistry Effects, tolerance mechanisms and management of salt stress in grain legumes. *Plant Physiology and Biochemistry*, *118*, 199-217.

Fathizad, H., Hakimzadch, M., Sodaiezadeh, H., Kerry, R. & Taghizadeh, R. (2020). Investigation of the spatial and temporal variation of soil salinity using random forests in the central desert of Iran. *Journal of Geoderma, 10*(16), 144-233.

Faunt, C. C, Sneed, M., Traum, J. & Brandt, J. T. (2016). Water availability and land subsidence in the Central Valley, California, USA. *Hydrogeology Journal*, *24*(3), 675-684.

Food and Agriculture Organization of the United Nations (2017) Report of the 25th session of the committee on agriculture, Rome, 21–30 Sept 2016. http://www.fao.org/3/a-mr949e.pdf.

Fraga, H., & Santos, J. A. (2018). Vineyard mulching as a climate change adaptation measure: Future simulations for Alentejo. *Portugal Agricultural System, 164*, 107-115.

Freitas, A. M., Nair, V. D., & Harris, W. G. (2020). Biochar as influenced by feedstock variability: Implications and opportunities for phosphorus management. *Frontiers in Sustainable Food systems*, 4, 1-11.

Gabriel, J. L., Almendros, P., Fernandez, C. H., & Quemada, M. (2012). The role of cover crops in irrigated systems: Soil salinity and Salt leaching. *Agriculture Ecosystems and Environment, 158*, 200-207.

Gabriel, J. L., Vanclooster, M. & Quemada, M. (2014). Integrating water, nitrogen, and salinity in sustainable irrigated systems: cover crops versus fallow irrigation. *Journal of Irrigation Drainage Engeneers, 140*, 14002.

Ganjegunte, G. K., Sheng, Z. & Clark, J. A. (2014). Soil salinity and sodicity appraisal by electromagnetic induction in soils irrigated to grow cotton, *Land Degradation Development*, *25*, 228-235.

Gebremeskel, T. G., Kioe, M., Meresa, E., Gebremedhin, T., & Girmay, A. (2018). Salinization pattern and its spatial distribution in the irrigated agriculture of Northern Ethiopia: An integrated approach of quantitative and spatial analysis. *Agricultural Water Management, 206,* 147-157.

Haider, M. Z., & Hossain, M. Z. (2013). Impact of salinity on livelihood strategies of farmers. *Journal of Soil Science and Plant Nutrition*, *13*(2), 417-431.

Hasanuzzaman, M., Bhuyan, M., Mahmud, J. A., Nahar, K., Mohsin, S. M., Parvin, K. & Fujita, M. (2018). Interaction of sulfur with phyto-hormones and signaling molecules in conferring abiotic stress tolerance to plants. *Plant Signal Behavior*, *3*(1), 477-905.

Hoa, D. I., Eike, L. I., & Cory, W. (2020). Decision analysis of agroforestry options reveals adoption risks for resources-poor farmers. *Agronomy for Sustainable Development*, *40*(3), 1-12.

Hu, D., Li, R., & Dong, S. (2022). Maize (Zea mays L.) responses to salt stress in terms of root anatomy, respiration and ant oxidative enzyme activity. *Journal of Plant Biology, 22*, Article number 602.

Huang, H., Reddy, N. G., Huang, X., Chen, P., Wang, P., Zhang, Y., & Garg, A. (2019). Effects of pyrolysis temperature, feedstock type and compaction of water retention of biochar amended soil. *Scientific Reports*, *11*(1), 1-19.

Ippolito, J. A., Cui, L., Kammann, C., Wrage-Mönnig, N., Estavillo, J. M., Fuertes-Mendizabal, T., Cayuela, M. L., Sigua, G., Novak, J., Spokas, K. & Borchard, N. (2020). Feedstock choice, pyrolysis temperature and type influence biochar characteristics. *comprehensive Meta-Data Analysis, 2*(4), 421-438.

Irakoze, W., Prodjinoto, H., Nijimbere, S., Bizimana, J. B., Birigimana, J., Rufyikiri, G., & Lutts, S. (2021). $NaCl^-$ and Na_2So_4 induced salinity differentially affect clay soil chemical properties and yield components of two Rice varieties. *Agronomy Journal, 11*(3), 1-15.

Joardar, J. C. & Basu, B. (2018). Mulching as a management tool for reducing salt stress in Bangladesh. *Journal of Soil Science*, *40*(2), 15-25.

Kader, M. A., Singha, A., Begum, M. A., Jewel, A., Khan, F. H., & Khan, N. I. (2019). Mulching as water-saving technique in dry land agriculture. *Bulletin of the National Research Centre, 43*, 1-6.

Kaledhonkar, M. J., Meena, B., & Sharma, P. C. (2019). Reclamation and nutrient management for salt affected soils. *Indian Journal of fertilizers*, *15*, 566-575.

Kalhoro, N. A., Rajpar, I., Kalhoro, S. A., Ali, A., Raza, S., Ahmed, M., Kalhoro, F. A., Ramzan, M., & Wahid, F. (2016). Effect of Salts Stress on the Growth and Yield of Wheat (*Triticum aestivum* L.). *American Journal of Plant Sciences, 7*, 2257-2271.

Kashenge-Killenga, S., Meliyo, J., Urassa, G. & Kongo, V. (2016). Extent of salt-affected soils and their effects in irrigated and lowland rain-fed rice growing areas of southern Tanzania: In Climate Change and multi-dimensional Sustainability in Agriculture. *Climate Change and Sustainability in Agriculture,* Pp. 97-126.

Kashenge-Killenga, S., Tngoona, P. & Derera, J. (2013). Morphological and physiological responses of Tanzania rice genotype under saline conditions and evaluation of traits associated with stress tolerance. *International Society for Development and sustainability*, *2*(2), 1457-1475.

Kashenge-Killenga, S., Tngoona, P., Derera, J. & Kanyeka, Z. (2014). Farmers' perception of salt-affected soils and rice varieties preferences in the Northern -eastern Tanzania and their implications in breeding. *International Journal of Development and Sustainability, 33*(66), 2168-8662.

Ketehouli, T., Carther, K. F. I., Noman, M., Wang, F. W., Li, X. W., & Li, H. Y. (2019). Adaptation of plants to salt stress: characterization of Na+ and K+ transporters and role of CBL gene family in regulating salt stress response. *Journal of Agronomy, 9*(11), 687.

Khatun, M., Shuvo, M. A. R., Salam, M. T. B., & Rahman, S. H. (2019). Effect of organic amendments on soil salinity and the growth of maize (Zea mays L.). *Plant Science Today*, *6*(2), 106-111.

Kim, H. S., Kim, K. R., Lee, S. H., Kunhikrishnan, A., Kim, W. I., & Kim, K. H. (2016). Effect of gypsum on exchangeable sodium percentage and electrical conductivity in the Daeho reclaimed tidal land soil in Korea. *Journal of Soils Sediments*, *18*, 336-341.

Kul, R., Arjumend, T., Ekinci, M., Yildirim, E., Turan, M. & Argin, S. (2021). Biochar as an Organic soil conditioner for mitigating salinity stress in tomato. *Soil Science and plant nutrition Journal, 67*(6), 693-706.

Kumar, P., & Sharma, P. K. (2020). Soil Salinity and food security in India. *Frontiers in Sustainable Food Systems, 4*, 533-781.

Kumar, S., Raju, R., Sheoran, P., Sharma, R., Yadav, R. K., Singh, R. K. Sharma, P. C. & Chahal, V. P. (2020). Techno-economic evaluation of recharge structure as localized drainage option for sustainable crop production in sodic agro-ecosystems. *Indian Journal of Agricultural Sciences*, *90*, 212-219.

Kumawat, K. C., Nagpal, S. & Sharma, P. (2022). Potential of plant growth-promoting rhizobacteria-plant interactions in mitigating salt stress for sustainable agriculture: A review. *Pedosphere. 33*(2), 223-245.

Lastiri-Hernández, M. A., Alvarez-Bernal, D., Bermúdez-Torres, K., Cárdenas, G. C., & Ceja-Torres, L. F. (2019). Phytodesalination of a moderately saline soil combined with two inorganic amendments. *Journal of Bragantia*, *78*, 579-586.

Leogrande, R., & Vtti, C. (2019). Use of organic amendment to reclaim saline and sodic soils: *Arid Land Research and Management*, *33*(1), 1-21.

Li, B., Wang, J., Yao, L., Meng, Y., Ma, X., Si, E., Ren, P., Yang, K., Shang, X. & Wang, H. (). Halogeton Glomeratus is a promising candidate for the phytoremediation of heavy metals-contaminated saline soils. Journal of Plant Sciences, *442*(1), 323-331.

Liu, H., Li, M., Zheng, X., Wang, Y., & Anwar, S. (2020). Surface salinization of soil under mulched drip irrigation. *Water*, *12*(11), 3031.

Machado, R. M. A., & Serralheiro, R. P. (2017). Soil salinity: effect on vegetable crop growth. Management practices to prevent and mitigate soil salinization. *Horticulturae*, *3*(2), 30.

MAFSC (2013). National Agriculture policy, Ministry of Agriculture Food security and cooperatives, United Republic of Tanzania.

Mahanavelu, A., Naganna, S. R., & Al-Ansari, N. (2021). Irrigation induced salinity and sodicity hazards on soil and Ground water: An Overview of its causes, Impacts and mitigation strategies. *Journal of Agriculture,* 11(10), 193.

Majeed, A., & Muhammad, Z. (2019). *A major agricultural problem – Causes, Impact on crop productivity and managemnet strategies. Journal of Plant Abiotic Stress Tolerance, 97*, 83-99.

Makoi, J. H., & Ndakidemi, P. A. (2007). Reclamation of sodic soils in northern Tanzania, using locally available organic and inorganic resources. *African Journal of Biotechnology*, *6*(16), 1926-1931.

Malhi, G. S., Kaur, M., & Kaushik, P. (2021). Impact of climate change on agriculture and its mitigation strategies: A review. *Sustainability*, *13*(3), 1318.

Manasa, P., Maitra, S. & Barman, S. (2020). Yield Attributes, yield, competitive ability and economics of summer maize-legume intercropping system. *International journal of Agriculture Environment and Biotechnology*, 13(1), 23-26.

Mandal, S., Raju, R., Kumar, A., Kumar, P. & Sharma, P. C. (2018). Current status of research, technology response and policy needs of salt affected soils in India – A Review. *Journal of Indian Society of Coastal Agricultural Research*, 36(2), 40-53.

Manuel, R., Machado, A., & Serralheiro, R. P. (2017). Soil Salinity: Effect on growth and management practices to prevent and mitigate soil salinization. *Journal of Horticulture*, 3(2), 1-13.

Mateo-sagasta, J., & Burke, J. (2011). Agriculture and water quality interactions. A Global overview. *Solaw Background Thematic report*. Pp. 46.

Mbark, S., Cerda, A., Brestic, M., Mahendra, R., Abdelly, C. & Pascual, J. A. (2017). Vineyard compost supplemented with Trichoderma Harzianum T78 improve saline soil quality. *Journal of Land Degradation Development*, *28*, 1028-1037.

McKenna, B. A., Kopittke, P. M., Macfarlane, D. C., Dalzell, S. A., & Menzies, N. W. (2019). Changes in soil chemistry after the application of gypsum and sulfur and irrigation with coal seam water. *Journal of Geoderma*, *337*, 782-791.

Mehmood, S., Ahmed, W., Ikram, M., Imtiaz, M., Mahmood, S., Tu, S. & Chen, D. (2020). Chitosan modified biochar increases soybean (Glycine max 1.) resistance to salt-stress by augmenting root morphology, antioxidant defense mechanisms and the expression of stress-responsive genes. *Journal of Plant, 9*(9), 1-25.

Meliyo, J. L., Kashenge-Kilenga, S., Victor, K. M., Mfupe, B., Hiza, S., & Kihupi, A. L., Boman, B. J., Dick, W. (2016). Evaluation of salt affected soils for rice (*Oryza sativa*) production in Ndungu irrigation scheme Same district, Tanzania. *Sustainable Agricultural Research*, *6*(1), 24-38.

Mkilima, T. (2023). Groundwater salinity and irrigation suitability in low-lying coastal areas. A case of Dar es Salaam, Tanzania. *Watershed Ecology and the Environment*, *5*(8), 173-185.

Montanarella, L. (2007). Trend in land degradation in Europe: In climate and land degradation. Pp. 83-104.

Munns, R., & Gilliham, M. (2015). Salinity tolerance of crops – What is the cost? Tansley insight. *The New Phytologist, 208*(1), 668-673.

Nadeem, M. Y., Khan, I., Umar, W., Safeer, M., Chattha, M. U., & Saif, M. (2017). Kallar grass (*Laptochloa fusca*) "The salt grass" an important fodder crop to ameliorate salt-affected soils in Pakistan. *Technology Times Journal, 8*, 10-16.

NBS (2015). Environment Statistics 2014 – Tanzania Mainland. National Bureau of Statistics. Statistics for development.

NDSU (2014). Saline and sodic soils. North Dakota State University Extension Service. Research Extension Centre. *Saline and Sodic Soils Bulletin* No. 02.

Nzeyimana, I., Hartemink, A. E., Ritsema, C., Stroosnijder, L., Lwanga, E. H., & Geissen, V. (2017). Mulching as a strategy to improve soil properties and reduce soil erodibility in coffee farming systems of Rwanda. *Catena*, *149*, 43-51.

Omar, M. M., Shitind, J. M., Massawe, B. H. J., Fue, K. G., Meliyo, J. L., & Pedersen, O. (2023). Salt affected soils in Tanzanian agricultural lands: Type of soils and extent of the problem. *Environmental Resource Management, 9*(1), 2765-8511.

Omar, M. M., Shitindi, J. M., Massawe, B. H. J., Fue, K. G., Meliyo, J. L., & Pedersen, O. (2022). Exploring farmers' perception, knowledge and management techniques of salt affected soils to enhance rice production on small land holdings in Tanzania. *Cogent Food and Agriculture*, *8*(1), 214-470.

Omuto, C., Vargas, R., ElMobarak, A., Mohamed, N., Viatkin, K., & Yigini, Y. (2020). Mapping of salt-affected soils: Technical manual, FAO. *Rome Italy*, p. 151.

Paz, A., Hristov, B., Amezketa, E., Falsone, G., Zambujo, J., Canfora, L., Mastrorilli, M., Goncalves, M., Prins, P., & Ramos, T. (2020). Prevention, mitigation and adaptation strategies for soil salinization at farm level. Brussel: EIP-AGRI Focus Group soil salinization. https://www.researchgate.net/publication/342985779

Phuong, N. T. K., Khoi, C. M., Ritz, K., Linh, T. B., Minh, D. T. T., & Toyota, K. (2020). Influence of rice husks biochar and compost amendments on salt contents and hydraulic properties of soil and rice yield in salt-affected fields. *Agronomy Journal*, 10(8), 1-23.

Prasad, K., Devkota, M., Rezaei, M. & Oosterbaan, R. (2022). Agricultura production in salt-affected soils of irrigated dry lands. *Agricultural systems journal,* 198(1), 1-16.

Pulido-Bosch, A., Rigol-Sanchez, J. P., Vallejos, A., Andreu, J. M., Ceron, J. C., Molina-Sanchez, L., & Sola, F. (2018). Impacts of agricultural irrigation on groundwater salinity. *Environmental Earth Sciences*, 77, 1-14.

Qadir, G., Ahmad, K., Qureshi, M., Saqib, A., Zaka, M., Sarfraz, M., Warraich, I., & Ullah, S. (2017). Integrated use of inorganic and organic amendment for reclamation of salt affected soils. *International Journal of Biosciences*, 11(2), 1-10.

Qadir, M., Mateo-Sagaster, J., Jimenez, B., Siemens, J. & Hanjra, M. A. (2015). Environmental risks and cost-effective Risk Management of Wastewater in economic assets in an urbanising world. Pp. 55-72.

Qadir, M., Quillérou, E., Nangia, V., Murtaza, G., Singh, M., Thomas, R. J., Drechsel, P. & Noble, A. D. (2014). Economics of salt-induced land degradation and restoration. *Hal Open Science, 1*(1), 1-27.

Qiu, Y., Wang, Y., Fan, Y., Hao, X., Li, S. & Kang, S. (2023). Root, Yield and Quality of Alfalfa affected by soil salinity in North West China. *Journal of Agriculture*, 13(4), 750.

Rao, N. D., Riahi, K., & Grubler, A. (2014). Climate impacts of poverty eradication. *National Climate Change*, *4*, 749-751.

Rekta, K. (2024). Impact of salinity stress on Agricultural crops: Responses and Challenges. *Journal of Fundamentals of soil science, 81*(2), 19-32.

Riffat, A., & Ahmad, M. S. A. (2020). Alleviation of adverse effects of salt stress on growth of maize (*Zea mays L.*) by sulfur supplementation. Pakistan Journal of Botany, *52*, 763-773.

Ritzema, H. P. (2016). Drain for grain: Managing salinity in irrigated lands. *Agricultural water management, 176*, 18-28.

Ruto, W. S. (2018). Land use-land-cover changes in Saiwa Swamp watershed in Western Kenya. *International Journal of Research in Environmental Science*, *4*(4), 1-7.

Saifullah, D. S., Naeem, A., Rengel, Z., & Naidu, R. (2017). Biochar application for the remediation of salt-affected soils: Challenges and opportunities. *The Science of the Total Environment*, *625*(1), 320-335.

Shahbaz, M., & Ashraf, M. (2013). Improving salinity tolerance in cereals. *Critical Reviews in Plant Sciences*, *32*(4), 237-249.

Shahid, S. A., Zaman, M. & Heng, L. (2018). *Soil salinity: Historical perspective and a world overview of the problem: Guideline for salinity assessment, mitigation and adaptation using nuclear and related techniques*. Springer, New York, USA. Pp. 43-53.

Shahid, S. A., Zaman, M., & Heng L. (2018b). Salinity and sodicity adaptation and mitigation options. In: Guideline for salinity assessment, mitigation and adaptation using nuclear and related techniques. *International Atomic Energy Agency*, *3*, 55-89.

Shalaby, O. A. E. S. (2018). Alleviation of salinity stress in red cabbage plants by urea and sulfur applications. *Journal of Plant Nutrition*, *41*(12), 1597-1603.

Shankar, V., & Evelin, H. (2019). Strategies for reclamation of saline soils. In: *Microorganisms in saline environments: Strategies and functions*, Springer, Cham. Pp. 439-449.

Sharma, A., Rana, C., Singh, S., & Katoch, V. (2016). *Soil salinity causes, effects and management in cucurbits: Handbook of cucurbits "growth, cultural practices and physiology*. Taylor and Francis, CRC Press. Pp. 419-434.

Sharma, D. K., Chaudhari, S. K., & Singh, A. (2014). Agroforestry is a promising option. *Journal Indian Farming*, *63*, 19-22.

Shawkhatuzamman, M., Sumona, R. R., Alam, Z., Majumder, P. N., Anka, N. & Jahan, A. K. H. (2023). Soil fertility management practices in coastal areas of Bangladesh. *Research in Agriculture Livestock and fisheries*, 10(1), 1-7.

Shemsanga, C., Nzibavuga, A., Muzuka, N., Martz, L., Komakech, H. C., Elisante, E., Kisaka, M., & Ntuza, C. (2017).

Origin and mechanisms of high salinity in Hombolo Dam and groundwater in Dodoma municipality Tanzania. *Journal of Applied Water Sciences,* 7, 2883-2905.
Sheoran, P., Kumar, A., Singh, A., Parjapat, K., Sharma, R., & Yadav, R. K. (2021). Pressmund Alleviates soil sodicity stress in a rice – Wheat rotation: Effects on soil properties, physiological adaptation and yield-related traits. *Land Degradation and Development*, *1*(1), 1-14.
Shrestha, S., & Mahat, J. (2022). Sustainable food security: how to feed an increasing population? A review. *INWASCON Technology Magazine*, *4*, 15-18.
Sileshi, A. A., & Kibebew, K. (2016). Status of salt affected soils, irrigation water quality and land suitability of dubti/tendaho area, North Eastern Ethiopia (Doctoral dissertation, Haramaya University).
Silva, M. L. D. S., Trevizam, A. R., Piccolo, M. C., & Furlan, G. (2014). Tomato production in function of sulfur does application. Rev. Bras. Technology. *Applied Sciences Agrarias*, *7*, 47-54.
Singh, A. (2015). Soil salinization and waterlogging: A threat to environment and agricultural sustainability. *Journal of Ecology, 57*, 128-130.
Singh, A., Sharma, D. K., Kumar, R., Kumar, A., Yadav, R. K., & Gupta, S. K. (2018). *Soil salinity management in fruit crops: A review of options and challenges: Handbook of engineering practices for management of soil salinity*. Apple Academic Press, p. 48.
Singh, K., Pandey, V. C., Singh, B., & Singh, R. R. (2012). Ecological restoration of degraded sodic lands through afforestation and cropping. *Journal of Ecology and Engineers,* 43, 70-80.
Singh, M., Kukar, M. S., Irmak, S., & Jhala, A. J. (2022). Water use characteristics of weeds: Best practices and future directions. *Frontiers in Plant Sciences, 12*(79), 3389-4090.
Stamford, N. P., Figueiredo, M. V. B., Junior, S. S., Freitas, A. D. S., & Santos, C. R. S. (2015). Effect of gypsum and sulfur with *Acidithiobacillus* on soil salinity alleviation and on cowpea biomass and nutrient status as affected by PK rock bio fertilizer. *Journal of Science and Horticulture, 192*, 287-292.
Stavi, I. (2020). On-site use of plant litter and yard waste as mulch in gardening and landscaping systems. *Journal of Sustainability*, *12*(18), 7521.
Stavi, I., Shem-Tov, R. G., & Lekach, J. (2017). Ancient to recent-past runoff harvesting agriculture in recharge play as of the hyper-arid Southern Israel. *Water*, *33*(9), 912-991.
Stavi, I., Thevs, N., & Priori, S. (2021). Soil salinity and sodicity in drylands: A review of causes, effects, monitoring, and restoration measures. *Frontiers in Environmental Science*, *10*, 3389-7128.
Thiam, S., Villamor, G. B., Faye, L. C. J., Bienvenue sehe, J. H., Diwediga, B., & Kyei-baffour, N. (2021). Monitoring land use and soil salinity changes in coastal landscapes. A case study from Senegal. *Environmental Monitoring and Assessment Journal, 193*, Article number 259.
Tully, K., Sullivan, C., Weil, R., & Sanchez, P. (2015). The state of soil degradation in Sab-Saharan Africa: Baselines, trajectories and solutions. *Journal of Sustainability, 7*(6), 6523-6552.
United Nation (2017.) The sustainable development goals report. Pp. 1-52. Retrieved from http://unstats.un.org/sdgs/report/2017.
United Nation (2020). The sustainable development goals report. Pp. 24. Retrieved from https//Unstats.un.org/sdgs/report/2020.
Ur-Rahman, S. (2022). Effect of organic amendments in soil on physiological and biochemical attributes of *Vachellia nilotica* and *Dalbergia sissoo* under saline stress. *Journal of Plant Biology*, 11(2), 228.
Ventura, Y., & Sagi, M. (2013). Halophyte crop cultivation: The case for Salicornia and sarcocornia. *Journal Environmental and Experimental Botany*, *92*, 144-152.
Wagner, K., Apostolakis, A., Daliakopoulos, I. N., & Tsanis, I. (2016). Can tomato inoculation with Trichoderma compensate yield and soil health deficiency due to soil salinity. *EGU General Assembly Conference,* p. 18.
Wallender, W. W., & Kenneth, T. K. (2012). Agricultural salinity assessment and management. In: *American Society of Civil Engineers*, p. 905.
Wang, S. J., Chen, Q., Li, Y., Zhuo, Y. Q., & Xu, L. Z. (2017). Research on saline-alkali soil amelioration with FGD gypsum. *Journal of Resource Conservation Recycling*, *121*, 82-92.
Wang, W., Xu, Y., Chen, T., Xing, L., Xu, K., Xu, Y., Ji, D., Chen, C., & Xie, C. (2019). Regulatory mechanisms underlying the maintenance of homeostasis in *Pyropia haitanensis* under hypersaline stress conditions. *Journal of Science and Total Environment*, 662, 168-179.
Weaver, T. B., Hulugalle, N. R., Ghadiri, H., & Harden, S. (2013). Quality of drainage water under irrigated cotton in vertisols of the lower Namoi Valley, New South Wales, Australia. *Irrigation and Drainage Journal*, *62*, 107-114.
Whitney, C. W., Lanzanova, D., Muchiri, C., Shepherd, K. D., Rosenstock, T. S., Krawinkel, M., Tabuti, J. R. S., & Luendeling, E. (2018). Probabilistic decision tools for determining impacts of agricultural development policy on household nutrition. *Earth's Future*, *6*, 359-372.
Wichelns, D., & Qadir, M. (2014). Achieving sustainable irrigation requires effective management of salts, soil salinity, and shallow groundwater. *Journal of Agriculture and Water Management*, *157*, 31-38.
Wudu, A., & Mahider, W. (2020). Soil salinity and its management options in Ethiopia. *Journal of Environmental and Earth science*, *3*(2), 1042.
Xu, J., Tang, X., Shao, H., & Wang, H. (2015). The foliar spray of *Rhodo-pseudomonas palustris* grown under Stevia residue extract promotes plant growth via changing soil microbial community. *Journal of Soils and Sediments*, *16*, 916-923.
Xu, N., Chu, Y., Chen, H., Li, X., Wu, Q., Jin, L., Wang, G., & Huang, J. (2018). Rice transcription factor OsMADS25 modulates root growth and confers salinity tolerance via the ABA–mediated regulatory pathway and ROS scavenging. *PLoS genetics*, *14*(10), e1007662.
Yang, A., Akhtar, S. S., Li, L., Fu, Q., Li, Q., Naeem, M. A., He, X., Zhang, Z., & Jacobsen, S. E. (2020). Biochar mitigates combined effects of drought and salinity stress in Quinoa. *Agronomy Journal*, *10*(6), 912.
Yildiz, O., Altundağ, E., Çetīn, B., Güner, Ş. T., Sarginci, M. & Toprak B. (2017). Afforestation restoration of saline-sodic soil in the Central Anatolian Region of Turkey using gypsum and sulfur. *Silva Fennica, 51* (1), Article number 1579.
Zaman, M., Shahid, S. A., & Heng, L. (2018). Guideline for salinity assessment, mitigation and adaptation using nuclear and related techniques. *In soil water management and crop* (p. 164). Springer Nature.
Zamora, S., Ferratges, F. A., García-Penas, A., & Aurell, M. (2022). Field guidebook: In 8th Symposium on Fossil Decapod Crustaceans. p. 165.

Zhang, W. W., Wang, C., Xue, R., & Wang, L. (2019). Effects of salinity on the soil microbial community and soil fertility. *Journal of Integrated Agriculture*, *18*, 1360-136.
Zhao, Y., Pang, H., Wang, J., & Huo, L. (2014). Effects of straw Mulch and buried Straw on soil moisture and salinity in relation to sunflower growth and yield. *Field Crops Research*, *161*, 16-25.