Soil and Irrigation Water Salinity in Ethiopia

Subjects: Soil Science

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The salt problem in Ethiopia has been further exacerbated by a number of factors, including poor water quality, ineffective on-farm water management techniques, and a lack of appropriate and technically sound drainage infrastructure at irrigation sites. Soil and irrigation water salinity have a substantial link with crops and agricultural communities in Ethiopia. Salinity has a significant impact on soil and water fertility, resulting in poorer agricultural production, food insecurity, and poverty. Salinity has a significant impact on crops in the country, from the germination stages to the harvesting stages during the growing season. If the current state of soil and water management continues, the severity of both soil and irrigation water salinity will reach an irreversible level that significantly impedes the country's agricultural production capacity. As a result, cultured irrigation water treatment, crop selection based on salinity and sodicity levels, irrigation water quality, leaching, and fertilizer use in combination with organic manures are scientifically proven actions to address the salinity problem.

soil salinity | irrigation water salinity | agriculture | Ethiopia

1. Introduction

According to current studies, more than half of the world's agricultural fields will be salt-affected by 2050 [1][2]. Soil salinization affects 19 million hectares of land in Sub-Saharan Africa [3]. Ethiopia is first in Africa in terms of the size of saline-affected soils caused by both human activity and natural sources, and seventh in the globe in terms of the proportion of total land area impacted by salinity [4].

There are over 12 million hectares of arable land in Ethiopia [5]. Even if the potential and actual irrigated area are not well understood [6][7], estimates of Ethiopia's irrigable land range from 5.3 to 7.5 million hectares [8], with an average of 6.4 million ha. Around 11,000 acres of Ethiopia's total land area are thought to be affected by salinity and sodicity. According to predictions, this will make up 13% of the nation's irrigated land and 9% of the nation's total landmass [9].

Every year, salinity and sodicity render a sizable portion of Ethiopia's lowlands unusable. According to [10], salinity and alkalinity issues are more prevalent in Ethiopia's 75 million hectares (66 percent of the country's total area) of arid and semiarid dryland zones. Contrarily, the majority of the country's export crops, including cotton, sugarcane, citrus fruits, bananas, and vegetables, are grown in the dryland regions.

Poor-quality water, combined with extensive coverage of soils for irrigated agriculture, insufficient on-farm water management techniques, and a lack of effective drainage systems, are all contributing to Ethiopia's soil salinity problems [11]. According to [12], as large-scale irrigation projects have grown, soil salinity issues have become more severe and have spread quickly, causing crops to completely fail due to a lack of adequate drainage systems for salt control. Salinity issues have long been recognized, and they are becoming more and more severe at worrisome rates [13].

Bioremediation approaches, such as cultivating halophytic forages in high saline areas where traditional field crop development is hampered, may be used to reclaim these soils. Despite these facts, the country is unable to not only reclaim the damaged soil but also cultivate the previously productive land due to economic difficulties. As a result, studies into arid regions and soils affected by salinity are crucial for modern agricultural management, especially in developing countries such as Ethiopia, where agriculture is the primary source of food and income [6].

In Ethiopia, the regions between Ziway and Shala, the Abaya and Chamo lakes, the southern Rift Valley, and the basins of the Awash and Omo Rivers have the most salinity-affected soils. The majority of Ethiopia's salinity-affected soils are found in the lowlands of Afar, Somalia, and parts of Oromia, Amhara, Tigray, and the southern regional states [13].

2. Severity of Soil Salinity in Agriculturally Potential Areas of Ethiopia

The scholars [14] investigated the status of soil salinity in the country's northeastern region (coded as sites one, two, and three). They discovered that electrical conductivity (EC) ranged from non-saline to moderately saline (0.831 to 7.52 dS/m) in the upper soil depth (0 to 50) and (0.482 and 5.08 dS/m) on the subsequent subsurface layer (50 to 200 cm soil depth) at site one, and non-sites.

The pH of the surface soil ranged from 8.01 to 8.47 in research conducted in the northern portion of the country by [15], with pH values of soil profiles moderately increasing with increasing depth. As a result, the soil in the area was alkaline, posing a threat to nutrient availability. The relative quantity of alkaline-producing cations is the principal driver of this soil characteristic.

In Ethiopia's northwestern region, [16] evaluated the salinity and sodicity dangers of soil and irrigation water. According to United Soil Salinity Laboratory Staff (USSLS) [17], the soils irrigated by the Shewa Robit River met the requirements for being classed as saline soils because the EC was greater than 4 dS/m and the exchangeable sodium percentage (ESP) was less than 15%. Nonetheless, soils watered by a mixture of Shewa Robit River and groundwater sources were classified as saline–sodic soils using the same criterion because the EC was greater than 4 dS/m and the ESP was greater than 15%.

According to [18], the PH of the soil increased as it progressed down the soil profile. As a result, the soil PH in the Ziway region was somewhat alkaline at the surface (7.90) and gradually went down the profile to alkaline, reaching 9.57 in the subsurface layers. According to [19], the surface and sub-surface soils in the Meki Ogolcha area of central Ethiopia, which were irrigated using Lake Ziway and groundwater, were determined to be saline–sodic and sodic soils. Similarly, the ESP of the soil profile opened increased from 9.03 at the surface of 0–28 cm to 19.56 at a depth of 166–200 cm at the Ehio-Flora farm at Meki Ziway [20].

Salinity-affected soils dominate around 80% of the Dubti/Tendaho state farm, according to another source [4], which constitutes 27.14 percent saline, 29.22 percent saline–sodic, and 23.36 percent sodic soils. Salinity-affected soils comprise roughly 82 percent of the Dubti/Tendaho state farm, as predicted by Kriging (29.0 percent saline, 30.63 percent saline–sodic, and 22.54 percent sodic soils). Finally, shallow (less than 2 m) groundwater with poor water quality due to high salt occupied more than half of the Dubti/Tendaho state farm. He said, in general, that the rate of expansion of salinity-affected soils had accelerated through time and space. In general, the findings revealed that the salinity of the soils in the area is unavoidably saline, ranging from mild to severe. When these salty soils are correlated with agricultural productivity in the same region, it is easy to see how salinity is decreasing agricultural productivity by diminishing soil and water fertility.

3. Severity of Irrigation Water Salinity in Ethiopia

All irrigation waters include varying degrees of dissolved salts and other components. When dissolved elements are present in small to moderate concentrations, they can help crops thrive, but when they are present in excessive quantities, they can degrade soils and impede plant growth [14]. Many researchers have looked into how irrigation water quality affects soil quality over time [21]. Water quality difficulties in irrigated agriculture include salinity, sodicity, specific ion toxicity, decreased infiltration rate, and hydraulic conductivity [22]. According to physical observations and publicly available information, soluble salts have accumulated in the soils of recently created small-scale irrigation systems and groundwater sources in Tigray [23].

According to [15], Mg^{2+} was the most prevalent cation at the Tumuga site, followed by Ca^{2+}, Na^{+}, and K^{+}. Ca^{2+} was the most abundant cation in the Gerjale site, followed by Mg^{2+}, Na^{+}, and K^{+}. HCO_3^{-} was the most prevalent anion at both sites, followed by Cl^{-}, CO_3^{-2}, and SO_4^{-2}. However, according to USSLS, the boron concentration was below the standard set for the toxicity level of sensitive crops at both sites (1954). SAR ranged from 0.19 to 4.95 at Tumuga and 0.25 to 3.28 at Gerjale in the same study by [15] with Ca^{+2} and Mg^{+2} concentrations greater than Na+ concentrations at both sites. Furthermore, at Tumuga, total dissolved salt (TDS) levels in irrigation water range from 674.17 to 1215.41 mg L^{-1}, whereas at Gerjale, TDS levels range from 408.21 to 1204.87 mg L^{-1}. The concentrations of TDS were classed as mild to moderate in their potential concern based on the degree of restriction placed by [24] on the use of water for irrigation. As a result, if correct management is not implemented, irrigation water will pose a significant salinity problem in the area. Similar to these findings [25] classified the area's irrigation water quality as mild to moderate with a significant potential irrigation concern.

Farmers in the Bora district use groundwater for irrigation, according to [26], and the water had a pH > 8.5, EC 4 dS/m, and ESP > 31. As a result, according to the FAO's definition of salinity, irrigation water is classified as sodic. Bora district

In general, Ethiopia is among the low-income countries in which the economy is extremely vulnerable. Irrigation development is capital investment intensive. Therefore, unless this observed ongoing salinity problem is tackled on time and appropriate irrigation practices are adopted, the country could face irreparable economic failure. Not only an economic failure but also environmental degradation causing severe food insecurity around arid and semi-arid dryland areas of the country.

4. Salinity Effects on Crops at Different Growth Stages

Even though most crop plants are prone to salinity generated by high salinity concentrations in the soil, salinity is one of the most severe ecological variables limiting agricultural performance [27]. It has a significant impact on crop quality and yield. These saline effects on many crops are cumulative consequences posed at several growth phases. Crops in Ethiopia's semi-arid and arid lowlands and valleys are being harmed by salinity and alkalinity [28]. According to [29], the most tolerant crops can withstand a salinity concentration of saturation extract up to 10 gL^{-1}, the fairly tolerant crops up to 5 gL^{-1}, and the responsive crops up to 2.5 gL^{-1}. Despite this, most crops are unable to thrive beyond these limits. Enhancing salinity tolerance in cultivated plant species is an important strategy to take advantage of the large area of saline soils and saline water sources.

4.1. Effects of Salinity on Vigor, and Relative Water Content of Selected Crops

The most useful measures for assessing crop plants' salt tolerance are germination and seedling growth indices [30]. Salinity, on the other hand, has an impact on early survival, seedling emergence, and seed germination [31]. Salinity affects physiological growth and has acoustic effects on crops due to osmotic embarrassment and ionic toxicity [32].

Furthermore, in [33], two haricot bean cultivars (Lehade and Chercher) were examined at five different salinity levels (0, 2, 4, 8, and 16 mM). It was found that the seedling and root vigor indices, shoot phytotoxicity, and relative water content of the shoot and root varied significantly between cultivars under the various salinity pressures.

The Lehade cultivar has greater seedling, shoot, and root vigor indices than the Chercher cultivar. In comparison to the Chercher cultivar, the Lehade cultivar exhibits higher seedling, shoot, and root vigor indices. This was due to the fact that Chercher recorded 91.5 percent germination while Lehade claimed 100% germination.

Lehade showed a similar germination % to controls in all circumstances, although having shorter root and shoot lengths [33]. A crop variety may sprout well under salinity stress. Salinity, on the other hand, may stifle the growth of its seedlings [34]. Similarly, numerous cultivars showed the highest initial germination % even at high salinity (16 dS/m), but their vigor declined as seedling growth parameters advanced [35][36].

4.2. Phytotoxicity of Salinity on Shoot, Root, and Seedling Relative Water Content

The phytotoxicity of the shoot and root increased as the salt concentration rose [33]. The study discovered the highest levels of phytotoxicity in the shoot (57.04%) and root (58.74%) at 16 mM doses. The work [37] asserts that wheat's root and shoot phytotoxicity increased at greater concentrations and decreased at lower quantities. Increasing the amount of NaCl has a salinity inhibitory or toxic effect, which is typically noticed as soon as the radicle starts to elongate [38].

4.3. Effects of Salinity on Seed Germination and Early Growth Stages

Significant reductions in germination percentage, rate, root and shoot length, and fresh root and shoot weights were seen with increased salinity [39]. It is rational to expect that enhancing crop salt tolerance will be a significant component of plant breeding in the future if global food production is to be sustained [40] given the projected growth in global food production over the next few decades. Germination and seedling traits are the most practical factors for choosing salinity-tolerant crops [41].

Salinity tolerance at the two early growth stages and the levels of salinity tolerance varied greatly among genotypes, according to research on the effects of salinity on seed germination and early vegetative growth of nine barley genotypes (five landraces and four breeding lines) at four salinity concentrations (0, 100, 150, and 200 mM) and four seawater concentrations (0, 20, 30, and 40%) [42]. The percentages of reduction for all variables in all genotypes rise with rising saline concentrations.

Despite the fact that reduction percentages differ from genotype to genotype, an experiment in seawater (saline water) demonstrates that all of the variables under consideration, such as the reduction percentage of germination, emergence, radicle length, and dry weight of roots and shoots, decline with increasing salinity concentrations [42]. The germination stage is the developmental stage that is most impacted by salt stress, according to [31][43].

Salinity slows or prevents the mobilization of reserve nutrients, suspends cell division, and enlarges and injures hypocotyls, all of which hinder bean seedling growth [44]. The work [45] likely found that when salinity levels rose, shoot length decreased. The work [35] examined the impact of salinity on 20 Sorghum (*Sorghum biolor* L. Moench) accessions' seedling biomass production and relative water content at salinity values of 2, 4, 8, and 16 dS/m. Seedling shoot fresh weight, seedling shoot dry weight, seedling root fresh weight, and seedling root dry weight were the variables that were measured. According to [46], seedling root fresh weight decreased at salinity levels of 4 and 8 dS/m in all accessions, but the effect was more pronounced at 8 dS/m, and 6 accessions were the most salinity affected. Seedling shoot fresh weight of 8 sorghum accessions was more salinity affected at these salinity concentrations. At 8 dS/m, the seedling shoot's dry weight was significantly influenced. The accessions most impacted by salinity were eight (8). All accessions saw a decrease in seedling root dry weight between 4 and 8 dS/m, however, this reduction was more pronounced at the later salinity concentration, and six accessions were more salinity-affected. As the saline level rose, the relative water content of seedling roots and shoots decreased.

5. Management of Soil Salinity and Its Impacts on Agricultural Production

Saline–sodic soil typically does not exhibit severe sodicity indications. However, when sodicity and salinity coexist in the same soil, management of both conditions becomes more challenging. Consequently, complex issues may not necessarily require an easy fix [47]. Two main strategies are frequently used to maintain production in a saline–sodic environment: (1) adapting the environment to the plant; and (2) adapting the plant to the environment. Both strategies can be used separately or together. For better plant response, the first strategy has been used more frequently [37].

Drainage, leaching, chemical additives, and the plant's bio-remediation suit alter the saline–sodic environment. While the drainage and leaching methods are challenging and costly. Additionally, unless it is not practical, leaching without subsurface drainage is only suitable in locations with low soil moisture content and deep groundwater tables [38][39][48]. An additional method to address saline–sodic issues beneath shallow water table locations is the application of chemicals followed by bio-remediation [39].

Many studies have been conducted in Ethiopia's Amibara, Melka Sedi, and Melka Werner dryland irrigation areas to determine how to recover saline–sodic soil utilizing either gypsum with leaching or just halophytic species [49][50][51]. In recent decades, halophytic species have been used in combination with chemical techniques to successfully reclaim saline–sodic soil in numerous countries, including Egypt and Pakistan, but not in Ethiopia. Gypsum and halophytic species are used together, which not only improves the efficacy of salinity and sodicity reclamation but also shortens the period of reclamation compared to single-used amendments [52].

Additionally, ripping is a technique that can be utilized to help with salt leaching and, ultimately, reclamation if soil compaction is a problem, which is typically a concern in sodic soils [44][53]. Shaygan et al. [45] revealed that saline–sodic land reclamation can be accomplished successfully through soil ripping up to a depth of 15 cm. However, ripping should be supplemented with chemical ameliorates (i.e., Ca^{2+} supplements), particularly for sodic soils [54], to solidify the newly generated pore structure in order to produce long-term improvement in soil physical conditions, particularly in macro porosity. Additionally, the soil needs to be guarded against re-compaction during irrigation [54].

6. Producers' Perception and Consequences of Salinity to Rural Socio-Economic Conditions

Salinity is a major challenge to rural livelihoods because it has devastating effects on agricultural productivity. As a result, understanding farmers' views on salinity and adaptive mechanisms to deal with salinity problems is a good starting point for recommending interventions that can help solve the problem [54]. The salinity problem initially impacts soil fertility, resulting in lower agricultural production, food insecurity, and poverty. Although irrigation has become increasingly important in Ethiopia in responding to the stresses of food security, employment, rural revolution, and poverty reduction, and has emerged as a cure for dependable agricultural development, and, thus, for the country's inclusive economic development, the salinity problem is reversing the importance of damage [55].

Lee and Senadhira 1998 [55] investigated the effects of salinity on producer livelihoods and socio-economic conditions in the Afar Region of Northeastern Ethiopia, finding that 91.18% of respondents believe salinity is increasing, while 5.88% and 2.94% believe salinity is decreasing in their respective localities. As the scholars concluded, the rising trend in salinity indicates that farmers are not attempting to manage salinity to the best of their ability in a variety of ways. They also concluded that the problem could be due to a lack of practical knowledge and technical solutions in the areas, leaving producers with little choice but to live with the salinity problem.

7. Conclusions

The salinity problem in Ethiopia, both in soil and irrigation water, and its impact on agricultural production is worsening. It can be argued that soil salinity and irrigation water salinity have a substantial relationship. As a result, salt in irrigation water sources results in saline soil, and vice versa. This is a strong indication that irrigation and soil management in the country are not properly managed. It is also discovered that cash crops of export quality and used as a source of foreign currency are grown in salinity-affected areas of the country, implying that salinity is one of the numerous factors contributing to the country's foreign currency shortfall. It may also be concluded that if the current irrigation system is maintained, it is likely that the majority of currently farmed lands will become unproductive, necessitating systematic farm area management to protect informed knowledge of their level and improve management operations.

One of the simplest methods for recovering and controlling salinity-affected soil is biological, particularly for Ethiopian smallholder farmers who lack the resources necessary to carry out expensive corrective treatments. Smallholder farmers should be educated about biosaline remediation techniques and halophytes plants, especially woody species, to achieve this. Compost application is also one of the more easily accessible salinity restorative techniques that smallholder farmers can use. It is important to carefully assess the capacity of numerous multifunctional tree species to reduce salinity in arid areas, including salinity bush (*Atriplex* spp.).

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