Chapter 5
Prospects of Alternative Agricultural Systems to Improve the Productivity of Marginal Lands in Ethiopia

Asad Sarwar Qureshi, Tesfaye Ertebo Mohammad, and Melese Minaleshoa

Abstract Agriculture is an essential sector in Ethiopia, like in many other sub-Saharan African countries. The agriculture sector in Ethiopia supports 80% of the workforce, whereas 85% of the total population is directly or indirectly attached to agricultural activities to earn their living. Ethiopia's 7 million smallholder farmers are responsible for producing more than 95% of the total agricultural outputs, including food crops, cereals, oilseeds, and pulses. Cotton and sugarcane are mainly grown in state-owned large-scale enterprises. Ethiopia also has significant livestock capital, i.e., cattle, sheep, goats, and camels. Despite this high biodiversity and distinctive ecosystems, food shortages are widespread, and there have been recurrent droughts and subsequent food crises since the 1970s. Today, Ethiopia stands first in Africa in the magnitude of salt-affected soils due to human-induced and natural causes. Current estimates imply that 11 million ha are exposed to salinity and sodicity. Therefore, restoration and rehabilitation of these soils are of critical importance to ensure food security. The restoration of salt-affected soils through engineering techniques such as installing drainage systems is costly and time-consuming. Therefore, the 'biosaline approach' could be an effective and economical approach to tackle this problem. The Biosaline approach is based on adaptable technology packages composed of salt-tolerant fodders and halophytes integrated with livestock and appropriate management systems (on-farm irrigation, soil fertility, etc.). These integrated crop and forage-livestock feeding systems have the capacity to increase the resilience of small-scale crop-livestock farms. This chapter discusses the causes and extent of salinity development and its socio-economic impacts on the livelihood of people in Ethiopia. Furthermore, this chapter recommends a wide variety of salt-tolerant crops that can be used to improve the agricultural productivity of salt-affected lands. The adoption of these feed and fodder species can be a game-changer for improving the livelihood of smallholder farmers living in the marginal lands of Ethiopia.

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R. Choukr-Allah and R. Ragab (eds.), *Biosaline Agriculture as a Climate Change Adaptation for Food Security*, https://doi.org/10.1007/978-3-031-24279-3_5

Keywords Salt-affected lands · Biosaline approach · Salt-tolerant species · Environment · Smallholder farmers

1 Introduction

Irrigated agriculture is challenged by increasing soil salinity problems (Ventura and Sagi 2013; Hasanuzzaman et al. 2014). According to recent estimates, about one billion ha (Bha) land is salinized, which is about 7% of the earth's land surface (Table 1). Currently, about 33% of the irrigated area (76 Mha) is affected by soil salinization, and more than 50% of the farms around the world are expected to be salinized by 2050 (Jamil et al. 2011; Kumar and Shrivastava 2015). Salt-affected soils are increasing at the rate of 1.0–2.0 Mha per year (Omuto et al. 2020). The lack of good-quality irrigation water exacerbates soil degradation in many arid regions (Hopmans et al. 2021).

The soil salinity problems in semi-arid and arid regions are caused by low rainfall and lack of irrigation water, which restricts the leaching of salts. Salt-affected soils are more widespread in northern Africa, South Africa, Botswana, and tropical Africa (Senegal, Mauritania, Upper Volta, Chad, north of Cameron, Swaziland, Malawi, Kenya, Zambia, southern Angola, and southern Mozambique) (Tully et al. 2015) (Table 2). Some countries such as Zaire, Congo, Gabon, Ivory Coast, and Liberia are virtually free of saline soils.

An estimated 11 million hectares in Ethiopia are salinized (Kidane et al. 2006; Gedion 2009; Frew 2012; Ashenafi and Bedadi 2016) (Table 2). This relates to 9% of the total land area and 13% of the irrigated area of Ethiopia (Birhane 2017). Most of these salt-affected soils are in the Rift Valley, Wabi Shebelle River Basin, the Denakil Plains, and other lowlands and valleys, which are home to 9% of the total population (Sileshi 2016).

The primary sources of salts in the rift valley are the gradual rise of the groundwater table caused by the development of large irrigation schemes in the Awash Valley

Table 1 Distribution of salt-affected soils in different regions of the world

Continent/region	Area (Mha)		
	Saline	Sodic/Alkali	Total
North America	6.2	9.6	15.82
Mexico and Central America	2.0	–	2.0
South America	69.5	59.8	129.2
Africa	122.9	86.7	209.6
South Asia	83.3	1.8	85.1
North and Central Asia	91.6	120.0	211.6
Southeast Asia	20.0	–	20.0
Australia	17.6	340	357.6
Total	413.1	617.9	1,031

Table 2 Salt-affected soils in the top 10 African countries (1,000 ha)

Countries	Saline	Sodic	Total
Algeria	3,201	129	3,150
Botswana	5,009	670	5,679
Chad	2,417	5,850	8,267
Egypt	7,360	–	7,360
Ethiopia	10,608	425	11,033
Kenya	4,410	448	4,858
Libya	2,457	–	2,457
Mali	2,770	–	2,770
Nigeria	665	5,837	6,502
Somalia	1,569	4,033	5,602

without appropriate drainage systems. The high evapotranspiration rates are another reason for salinity development in these areas (Frew 2012). The increasing salinity problems in Ethiopia are causing substantial crop losses and the abandonment of farmlands in many regions (Gebremeskel et al. 2018).

The increasing demand for food in Ethiopia is pressing to take contingent measures to rehabilitate and manage saline soils. In Ethiopia, minimal data and information are available on salt-affected soils' causes, extent, and spatial distribution. This chapter presents the available information on salt-affected soils, which can help develop workable strategies for rehabilitating and managing saline soils in Ethiopia.

2 Sources, Causes, and Distribution of Salt-Affected Soils

2.1 Characterization of Salt-Affected Soils

The build-up of soluble salts is the most critical factor in forming saline soils in areas where evaporation exceeds precipitation (Cooke et al. 1993). The sources of salts include saline parent materials, fossil salts of former marine and lacustrine deposits, atmospheric deposition, collection of saline sediments in catchment areas, irrigation waters, and fertilization. However, an excessive salt build-up occurs due to the evaporation of irrigation water from the surface and the shallow depths of soils, leaving the salt behind. Based on the USDA classification (US Salinity Laboratory Staff 1954) saline soils are categorized into three main classes, i.e., saline, saline-sodic, and sodic (Table 3).

Saline Soils: Saline soils are more common in irrigated areas of arid and semi-arid regions, where precipitation is much lower than annual evapotranspiration. In humid environments, soluble salts are washed down by percolating rainwater and irrigation water. Saline soils contain excessive sodium chloride (NaCl) and sodium sulfate (Na_2SO_4), which restrict the capacity of roots to extract water from soil resulting in

Table 3 Summary of classification of salt-affected soils

Category	Electrical conductivity of saturation extracts (ECe) (dS m^{-1})	Exchangeable sodium percentage (ESP)	pH
Saline soils	$\geq$4.0	<15	<8.5
Saline-sodic soils	$\geq$4.0	$\geq$15	<8.5
Sodic soils	<4.0	$\geq$15	8.5–10
Non-saline non-sodic soils	<4.0	<15	$\approx$ Neutral

poor crop growth. The presence of white crusts on the soil surface is an indication of saline soils. Saline soils are usually flocculated, well-structured, and well-permeable. The saline soils contain large amounts of Na^+, Ca^{2+}, Mg^{2+} ions, and small amounts of NO_3^- and HCO_3^-. The soluble Na^+ is much lower than the sum of other cations and is thus not adsorbed in the soil.

Saline-sodic soils: These soils have excessive exchangeable sodium (Na^+) that can be detrimental to plant growth and soil structure. Saline-sodic soils hold both saline and sodic soils properties and are described by subsoils impervious to water. The dispersing effect of exchangeable Na^+ may be counterbalanced by the coagulating effect of the soluble salts (electrolyte effect) present in the soil. The saline-sodic soils are generally well-structured and permeable. This is true if soil ECe is higher than 10 dS m^{-1} and ESP is greater than 20. However, if ECe is low and ESP is high (ECe = 6; ESP > 25), saline-sodic soils also act like sodic soil. Therefore, the removal of excess soluble salts from saline-sodic soils by leaching changes them to sodic soils. As a result, the soil becomes strongly alkaline (pH > 8.5), soil particles swell and disperse and translocate to subsoils where they are lodged in conducting pores, restricting the movement of water and air.

Sodic soils: These soils have excessive quantities of exchangeable sodium, destroying the soil structure with subsequent adverse effects on plant growth. They are low in salts but contain large amounts of sodium carbonate (Na_2CO_3), which disperses clay particles in soils or deflocculates by ion exchange processes, resulting in poor soil structure. Sodic soils consist mainly of the anions Cl^-, SO_4^{2-}, HCO_3^-, and CO_3^{2-}. The surface horizons of sodic soils are exceptionally compact and cemented, and puddles of water on these soils are usually turbid, brownish-black in color (Na-humus), and a shiny black crust of film of dry colloidal substance develops on the dry soil surface. The presence of dispersed colloidal clays of smectites group of clay minerals causes soil swelling resulting in low permeability, making tillage operations difficult. Irrigated sodic soils are impervious to water. Since clay soils are sensitive to Na, ESP values as low as 5–10 may reduce infiltration, particularly with good-quality water and swelling clays.

2.2 Causes of Soil Salinity Development in Ethiopia

The natural cause of soil salinity is the weathering process of the parent material of the soil. The salts are brought in by streams draining into the basins. Dissolved sodium accumulates as exchangeable sodium in the B horizon due to vertical or horizontal leaching in humid regions. The salt-affected soils in Ethiopia are affected by climate, soil, and water management practices, and irrigation methods. Low annual rainfall, high temperatures, and shallow groundwater tables in irrigated areas have also added to existing salinity problems. From the very scattered information on the extent and characteristics of salt-affected soils, salinity and sodicity in the region are rapidly increasing, both in irrigated and non-irrigated areas. Four primary sources of the constituents of soil salinity and sodicity {Na^+, Ca^{2+}, Mg^{2+}, K^+ (common metals) and $SO_4{}^{2-}$, Cl^-, $HCO_3{}^-$, $NO_3{}^-$ (common ligands)} are (a) mineral weathering (Na rich feldspars), (b) precipitation or rainfall, (c) fossil salts (marine or lacustrine deposits) and (d) collection of saline sediments in catchment areas. Salts are added through irrigation water or because of fertilization.

In the absence of effective surface irrigation systems, the availability of water for irrigation remains a challenge. For this reason, farmers in many areas have developed a flood-based farming system called 'spate irrigation.' This system is beneficial in mountain catchment border lowlands, where farmers can use short-duration floods to irrigate their lands. However, crop productivity is severely affected as water often comes long before or late after the cropping season. The success of spate irrigation depends on the availability of good infrastructure and the cooperation of farmers. In the arid lowlands of the country, conventional irrigation is limited due to the perennial nature of most rivers.

Development of soil salinity in Kewet and Efratana Gidim areas is associated with the use of poor-quality water for irrigation during the dry season when freshwater availability from the river is insufficient to meet irrigation requirements. The water quality of dug wells is only marginally fit for irrigation (Yonas 2005). In many other lowlands, there is considerable groundwater potential. However, it is challenging to exploit this water source due to its presence at deeper depths, lack of drilling facilities, and associated costs. In other lowlands, the poor quality of groundwater restricts its use for agriculture.

Waterlogging and salinity problems have been exacerbated due to poor drainage facilities and on-farm water management practices. The widespread waterlogging and salinity problems are the major constraint for crop production in Zeway Dugda around Lake Zeway, farms around Gerjele, and Tumuga swampy area, irrigated farm areas of Abaya and Arbaminch. Farmers in these areas tend to over-irrigate their crops (whenever water is available), which results in excessive seepage and rising groundwater levels. Most farmers use flooding and basin irrigation methods on poorly leveled fields, which results in uneven distribution of irrigation water and salts within the same area. Due to technical and financial constraints, the use of soil amendments, the required amounts of fertilizers, and other soil management techniques is limited.

2.3 Effects of Soil Salinity on Soil and Plants

Saline soils negatively affect plant growth due to excessive soluble salts, exchangeable sodium, or both. Plants in saline soils of arid regions grow in a delicate balance because the amount of soluble salts and exchangeable sodium present in these soils is sufficient to produce harmful effects on plant growth. This requires proper management to avoid reduced crop production or, in severe cases, complete crop failure followed by a decline in land value and subsequently abandoned for agricultural use (FAO 1989). When soluble salts occur in excess soil, they limit the availability of water to plants by reducing the osmotic or water potential of the soil. Moreover, soluble salts increase the concentration of specific ions that have toxic effects on plant metabolism.

The sodicity problem is more permanent than the salinity problem because exchangeable sodium remains in the soil profile even after the salts are removed by leaching. The adverse effects of excessive salts and exchangeable sodium on plant and soil properties are summarized in Table 4 (US Salinity Laboratory Staff 1954):

- Excessive salt concentration in soils inhibits plants from extracting water from the soil for their growth due to increased osmotic tension of the soil.
- Specific ions such as boron, chlorine, and sodium affect plant physiological processes.
- The presence of excessive accumulations of specific ions and salts such as Na^+, HCO_3^-, CO_3^{2-}, SiO_3^{2-}, or NaCl and Na_2SO_4 can cause nutritional disorders.
- Changes in soil physical properties finally inhibit water infiltration and movement, air movement, root penetration, and seedling emergence problems.

Salinity threshold: This is the maximum level of soil salinity that does not reduce the potential yield of a specific crop, or it is the salinity (ECe) value where crop yield decline begins. The tolerance levels of salinity and yield reduction of different crops vary according to their physiology. For instance, *Hordeum vulgare* (barley) is salt-tolerant, while *Phaseolus vulgaris* (beans) is highly sensitive to salinity. Differences in salt tolerance exist between crops and different varieties of the same crop.

Table 4 Response of plants to soil salinity at different ECe values

ECe (dS m^{-1})	Plant response
0–2	Negligible salinity effects
2–4	Yields of sensitive crops (Beans, Carrot, Lemon, Orange, Avocado, Pineapple, Peach, Strawberry, Onion, Rose) may be decreased
4–8	Yield of many crops is restricted
8–16	Tolerant crops (Wheat, Grapes, Sorghum, Oats, Mandarin, Soybean, Clover, Sudan grass, Wild rye, Safflower) will survive
>16	Only highly tolerant crops (Barley, Sugar beet, Bermuda grass, Alkali grass, Saltgrass, Cotton, Wheatgrass) will yield satisfactorily

In salty soils, the roots of plants cannot absorb enough water. Thus, as the growth rates of their cells are limited, they have small leaves and closed stomata resulting in low CO_2 fixation (i.e., reduced photosynthesis). However, wilting is often not seen due to the build-up of non-toxic and osmotic substances. Bresler et al. (1982) have described that these plants also show marked differences in their tolerance to exchangeable sodium contents (Table 5).

Crop tolerance to boron: Plants vary in their tolerance to the level of boron in soils. The tolerable boron concentration in different crops is given in Table 6.

Table 5 ESP tolerance of various crops under non-saline conditions

Tolerance to ESP	Crops	Growth (field) response
Extremely sensitive (ESP = 2–10)	Deciduous fruits, Nuts, Citrus (*Citrus spp.*), Avocado (*Persea americana*)	Na^+ toxicity symptoms even at low ESP values
Sensitive (ESP = 10–20)	Beans (*Phaseolus vulgaris*)	Stunted growth at low ESP
Moderately tolerant (ESP = 20–40)	Clover (*Trifolium spp.*), Oats (*Auena sativa*), Tall fescue (*Festuca arundinacea*), Rice (*Oryza sativa*)	Stunted growth due to adverse soil conditions
Tolerant (ESP = 40–60)	Wheat, Cotton, Alfalfa, Barley, Tomatoes, Beets	Stunted growth
Most tolerant (ESP > 60)	Crested and Fairway Wheatgrass, Tall Wheatgrass, Rhodes grass	Stunted growth due to poor soil conditions

Table 6 Crop tolerance limits for Boron in saturation extracts of soil

Tolerant plants	Semi tolerant plants	Sensitive plants
<u>4.0 ppm of Boron</u> Athel (*Tamarix aphylla*) Palm (*Phoenix conariensis*) Date palm (*P. dactylifera*) Sugar beet (*Beta vulgaris*) Alfalfa (*Medicago sativa*) Broad bean (*Vicia faba L.*) Onion (*Allium cepa L.*) Turnip (*Brassica rapa L.*) Cabbage (*Brassica oleracea*) Lettuce (*Lactuca sativa L.*) Carrot (*Daucus carota L.*)	<u>2.0 ppm of Boron</u> Sunflower (*Hellanthus annus*) Potato (*Solanum tuberosum L.*) Cotton (*Gossypium hirsutum*) Tomato (*L. esculentum*) Radish (*Rapharus sativus L.*) Field pea (*Pisum sativum*) Barley (*Hordeum vulgare*) Wheat (*Triticum aestivum*) Corn (*Zea mays*) Sorghum (*Sorghum bicolor*) Oat (*Avena sativa*) Pumpkin (*Cucurbita spp.*) Pepper (*Caspsinum annum*) Sweet Potato (*Ipomoea batatas*)	<u>1.0 ppm of Boron</u> Plum (*Prunus domestica*) Pea (*Pyrus communis*) Apple (*Malus sylvestris*) Grape (*Vitis spp.*) Cherry (*Prunus spp.*) Peach (*Prunus persica*) Orange (*Citrus sinensis*) Avocado (*Persea americana*) Grapefruit (*Citrus P. macfafad*) Lemon (*Citrus lemon*) Apricot (*Prunns americana*) Navy bean (*Phaseolus vulgaris*)

2.4 Extent and Distribution of Saline Soils in Ethiopia

The majority of salt-affected soils are concentrated in the Rift Valley System and Somali lowlands in the Wabi Shebelle River Basin and the Denakil Plains (Mesfin 2001; Heluf and Mishra 2005). The source of salts in the Rift Valley system is weathering. These parent materials undergo intensive disintegration and decomposition when exposed to natural waters. However, the processes liable for salinization and sodication of soils in Ethiopia are more diverse and complicated (Heluf 1985, 1987, 1995; Heluf and Mishra 2005).

It is estimated that the area covered by saline soils in the former Hararghe Administrative Region (eastern region) is 1,159,300 ha, which is 13% of the region's total land area (Girma and Fentaw 1996). Out of 4,000 ha of irrigated lands at Melka Sedi, 40% is saline, 17% is saline-sodic, and only 0.02% is sodic. There is also evidence that farmers have abandoned a large land area due to increasing salinity. Furthermore, about 39% of the Abaya State Farm is also salt-affected.

The Rift Valley Zones and the south-eastern (Somali) country's lowlands are the most valuable agricultural lands as they offer vast potential for multiple cropping. Most of the irrigated State Farms where export crops (i.e., cotton, sugarcane, and fruits) are being grown, are also located in the Rift Valley Zone. However, due to the absence of adequate drainage systems, a substantial proportion of the areas of this zone are turning into saline and saline-sodic soils annually (Heluf and Mishra 2005). Preliminary soil surveys have shown massive salt build-up in the soils of the lower Wabi Shebelle basin of Gode (Somali Region), where small-scale irrigation systems by taking water from the Shebelle River have been introduced. This implies that the development of large-scale irrigation projects in the Wabi Shebelle and other river basins without proper drainage will rapidly expand soil salinity and sodicity problems. A map of soil groups in different parts of Ethiopia is shown in Fig. 1.

2.5 Spatial Distribution of Soil Salinity in Different Regions of Ethiopia

The International Center for Biosaline Agriculture (ICBA) has conducted a detailed survey in the different regions of Ethiopia to characterize salt-affected soils (Qureshi et al. 2021). The spatial variability of soil salinity (ECe) was assessed using the geo-statistical technique. The survey data developed soil characterization, and surface salinity (0–30 cm depth) maps for Afar, Oromia, Amhara, and Tigray regions. The surface salinity was classified as non-saline (<2 dS m^{-1}), low saline (2–5 dS m^{-1}), medium saline (5–10 dS m^{-1}), high saline (10–15 dS m^{-1}) and extreme saline (> 15 dS m^{-1}). The soils were classified according to FAO (2014) soil correlation/classification system and mapped at 1:500,000 scale at the reference group level. The data was also used to develop surface salinity maps.

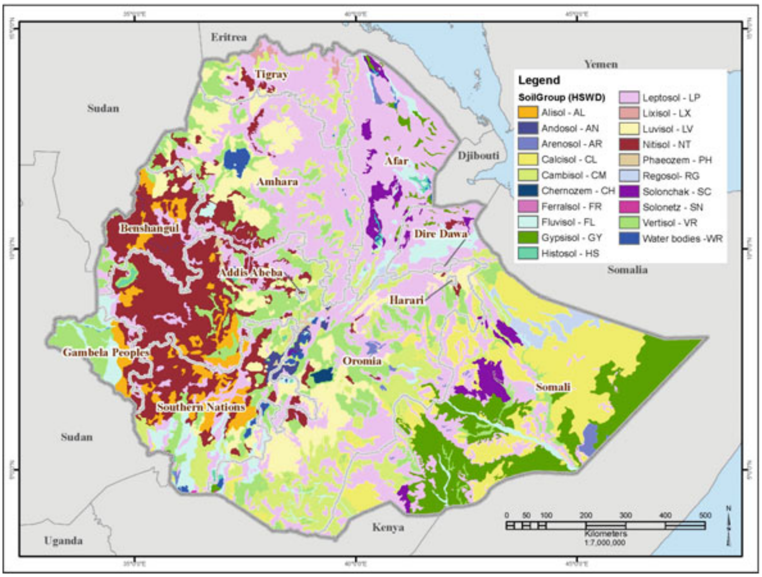

Fig. 1 Soil groups in different regions of Ethiopia

Highly saline soil

Moderately saline and sodic soil

Low salinity and highly sodic soil

Highly sodic soil

Table 7 Area covered by different RSGs in the Afar region

No.	Soil Types	Area		No	Soil Types	Area	
		km^2	%			km^2	%
1	Leptosols	29,821	30.68	9	Gypsisols	2,882	2.96
2	Rockoutcrop/Lava	14,541	14.96	10	Solonetz	2,544	2.62
3	Cambisols	11,108	11.43	11	Calcisols	2,221	2.28
4	Fluvisols	7,870	8.10	12	Luvisols	1,670	1.72
5	Solonchaks	6,882	7.08	13	Durisols	699	0.72
6	Regosols	6,829	7.02	14	Andosols	362	0.37
7	Arenosols	5,108	5.25	15	Water Body	143	0.15
8	Vertisols	4,523	4.65	16	Acrisols	2.38	0.002
Total						97,205	100

Afar region: Sixteen Reference Soil Groups (RSGs) were identified for the Afar region, covering 82% of the area as given in Table 7. The primary identified RSGs include Leptosols (30.68%), Cambisols (11.43), whereas, Fluvisols (8.15), Solonchaks (7.08%), Regosols (7.02%), Arensosols (5.25%), Vertisols (4.65%), Gypsisols (2.96%), Solonetz (2.62%), and Calcisols (2.28%) are minor groups.

The spatial distribution of different soil types is shown in Fig. 2.

The ECe of the surface soils (0–30 cm) in the Afar region ranges from non-saline (<2 dS m^{-1}) to extremely saline (>15 dS m^{-1}). In the Afar region, about 58% of the soils are affected by different salinity levels (Table 8). Low and medium surface soil salinity classes cover 38% of the area and are found in the region's central and southern parts. High and highly saline surface salinity levels cover 20% of the region and spatially cover the northeastern part of the region (Fig. 3). The severity and spatial coverage of subsurface soil salinity are presumed to be higher than the upper 30 cm soil layer. Therefore, it is recommended to properly conduct deep soil profile salinity analysis to select salt-tolerant species for these regions.

Amhara region: Eighteen Reference Soil Groups (RSG) have been identified in the Amhara region, covering 96.6% of the area. The area covered by each RGS is shown in Table 9. Leptosols (38.2%) are dominant in the region followed by vertisols, cambisols, and luvisols.

The surface salinity (0–30 cm) in the Amhara region ranges from non-saline (<2 dS m^{-1}) to extremely saline (>15 dS m^{-1}). About 12% of soils are saline to various degrees. Low and medium surface salinity classes cover 11% of the region and are found in the central, south, southwest, and eastern part of the region. High and extreme soil salinity levels cover only 1% of the area and spatially cover the south and south-eastern part of the region (Fig. 4). Table 10 shows the surface salinity (0–30 cm depth). The surface salinity map of the Amhara region is shown in Fig. 5.

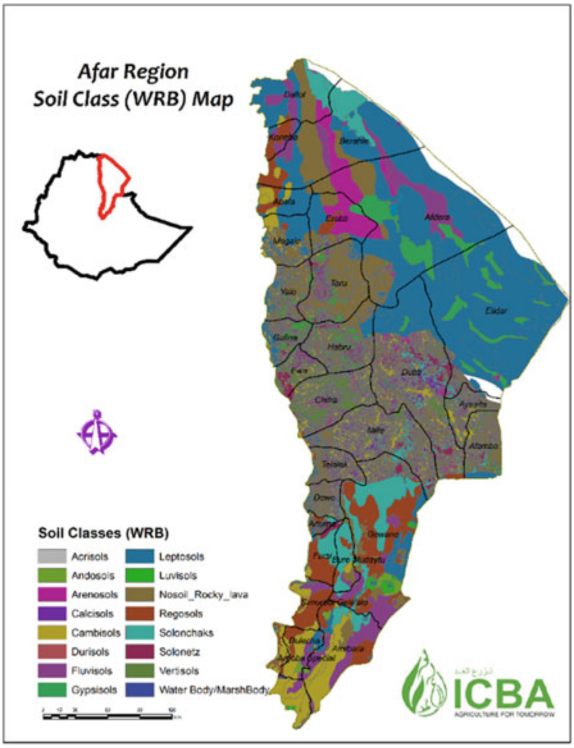

Fig. 2 Dominant RSGs in the Afar region

Table 8 Surface (0–30 cm) soil salinity levels in the Afar region

Soil salinity levels	Area	
	km^2	%
Non-saline/Waterbody/Rockoutcrop (<2 dS m^{-1})	40,787	42
Low saline (2–5 dS m^{-1})	26,916	28
Medium saline (5–10 dS m^{-1})	9,798	10
High saline (10–15 dS m^{-1})	5,618	5
Extremely saline (>15 dS m^{-1})	14,085	15
Total	97,204	100

Oromia region: Fourteen Reference Soil Groups (RSG) have been identified in the Oromia region, covering about 96.55% of the area (Table 11; Fig. 6). The soil survey results indicate that the soil surface salinity (0–30 cm) in the Mahara region ranges from none-saline (<2 dS m^{-1}) to extremely saline (>15 dS m^{-1}). It is estimated that 11.33% of the soils in the region are under various degrees of salinity levels (Table 12). Low (5.33%) and medium (5.29%) surface soil salinity classes cover 10.62% of the region and are in the central, south, and central-eastern parts of

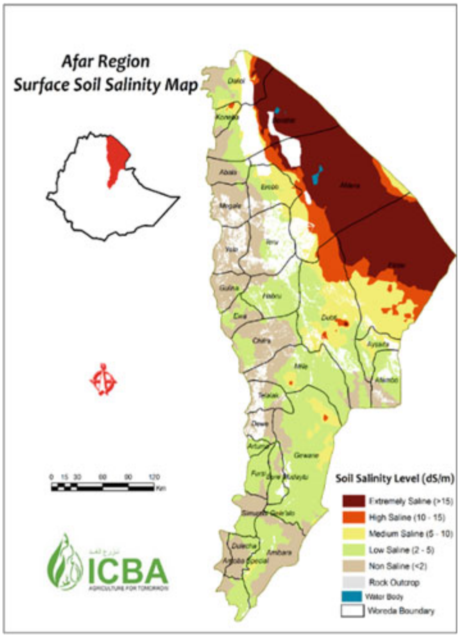

Fig. 3 Surface salinity map of the Afar region

Table 9 Area covered by different RSGs in the Amhara region

No.	Soil Types	Area		No.	Soil Types	Area	
		km^2	%			km^2	%
1	Leptosols	59,635	38.32	10	Fluvisols	908	0.58
2	Vertisols	30,444	19.56	11	Arenosols	472	0.30
3	Cambisols	18,258	11.73	12	Acrisols	431	0.28
4	Luvisols	15,972	10.26	13	Andosols	223	0.14
5	Alisols	12,320	7.92	14	Umbrisols	38	0.02
6	Regosols	5,926	3.81	15	Solonetz	36	0.02
7	Calcisols	4,068	2.61	16	Lava/Rock	34	0.02
8	Nitisols	3,683	2.37	17	Chernozems	8	0.01
9	Water Body	3,180	2.04	18	Gleysols	0.9	0.0006
				19	Phaeozems	0.4	0.0003
Total						155,638	100

the area. Highly saline soils cover only 0.71% of the region (0.49% high and 0.22% extremely saline levels) and spatially cover the south and south-eastern part of the region. Figure 7 shows surface soil salinity ECe (0–30 cm depth) in the Oromia region.

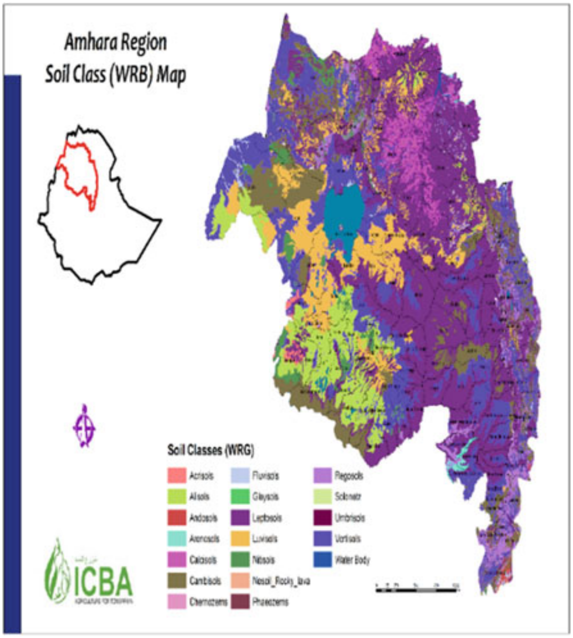

Fig. 4 Dominant RSGs in the Amhara region

Table 10 Surface soil salinity (0-30 cm) in the Amhara region

Soil salinity levels	Area	
	km^2	%
Non-saline/Waterbody/Rockoutcrop (<2)	137,428	88
Low saline (2–5 dS m^{-1})	4,903	3
Medium saline (5–10 dS m^{-1})	11,892	8
High saline (10–15 dS m^{-1})	1,230	0.8
Extremely saline (>15 dS m^{-1})	202	0.2
Total	155,648	100

Tigray region: Eleven Reference Soil Groups (RSG) were identified for the Tigray region covering about 94% of the area. The major groups are leptosols, cambisols, and vertisols (Table 13; Fig. 8). The results of the soil survey indicate that ECe of the surface soils (0–30 cm) ranges from none-saline (<2 dS m^{-1}) to extremely saline (>15 dS m^{-1}). It is estimated that 2.71% of the soils of the region are medium saline and are present in the central, southwest, and eastern parts of the area (Table 14). Figure 9 shows the surface soil salinity classes (0–30 cm) in the Tigray region. The salinity of the deeper layers may be higher due to variations in soil properties.

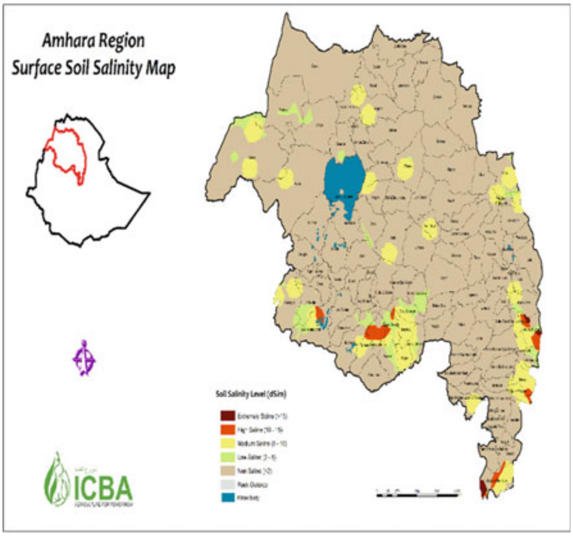

Fig. 5 Surface salinity in the Amhara region

Table 11 Area covered by each RGS in the Oromia region

No.	Soil types	Area		No.	Soil types	Area	
		km^2	%			km^2	%
1	Cambisols	68,891	21.23	13	Regosols	2,388	0.74
2	Leptosols	51,113	15.75	14	Solonchaks	1,854	0.57
3	Nitisols	46,363	14.29	15	Chernozems	1,612	0.50
4	Vertisols	43,883	13.53	16	Phaeozems	1,400	0.43
5	Luvisols	36,091	11.12	17	NosoilRockylava	1,051	0.32
6	Alisols	15,508	4.78	13	Solonetz	982	0.30
7	Fluvisols	12,523	3.86	14	Gypsisols	595	0.18
8	Acrisols	9,504	2.93	15	Planosols	576	0.18
9	Lixisols	6,184	1.91	16	Water Body	456	0.14
10	Calcisols	5,649	1.74	17	Plinthosols	192	0.06
11	Gleysols	5,379	1.66	18	Lake	79	0.02
12	Andosols	5,319	1.64				
Total						324,429	100

Therefore, it is suggested to do a detailed subsurface salinity analysis before offering the best cropping systems for these areas.

Causes of Salinity Development in Ethiopia.

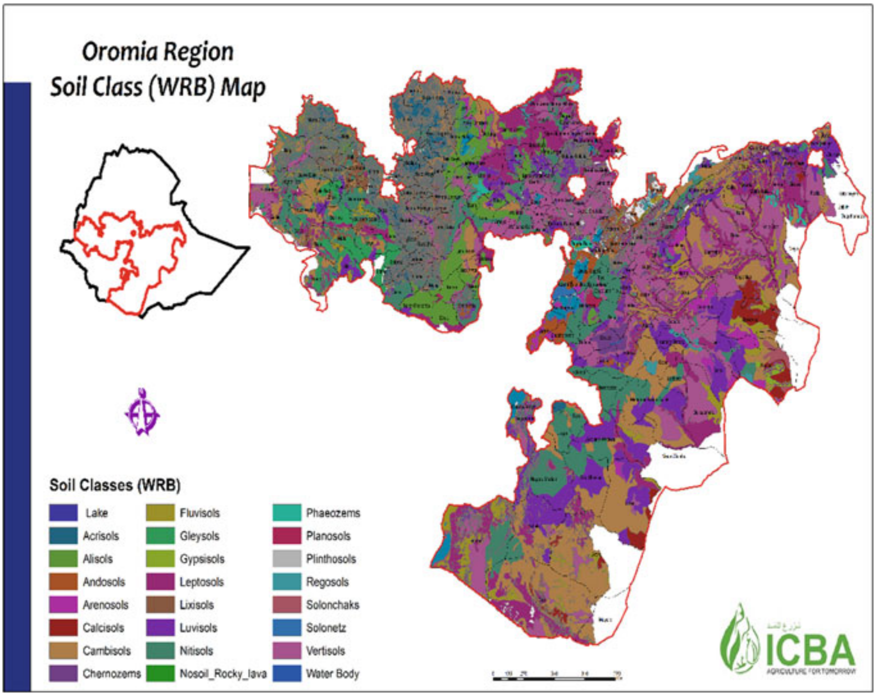

Fig. 6 Soil group types in the Oromia region

Table 12 Surface (0–30 cm) soil salinity in the Oromia region

Soil salinity levels	Area	
	km^2	%
Non-saline/Waterbody/Rock out crop (<2 dS m^{-1})	28,7768.25	88.70
Low saline (2–5 dS m^{-1})	17,292.05	5.33
Medium saline (5–10 dS m^{-1})	17,152.54	5.29
High saline (10–15 dS m^{-1})	1,576.72	0.49
Extremely saline (>15 dS m^{-1})	713.74	0.22
Total	324,428.69	100

2.6 Water Shortage for Irrigation

Ethiopia receives an annual rainfall of 850 mm, or the equivalent of 940 km^3 per year. About 13% of total rainfall is diverted into so-called blue water (river flows and fresh water in lakes). Only 3% is used for rainfed agricultural production, covering 15% of Ethiopia's land area. Regardless of the overall resource potential, the county faces severe water scarcity in the eastern, south-eastern, and north-eastern parts where little

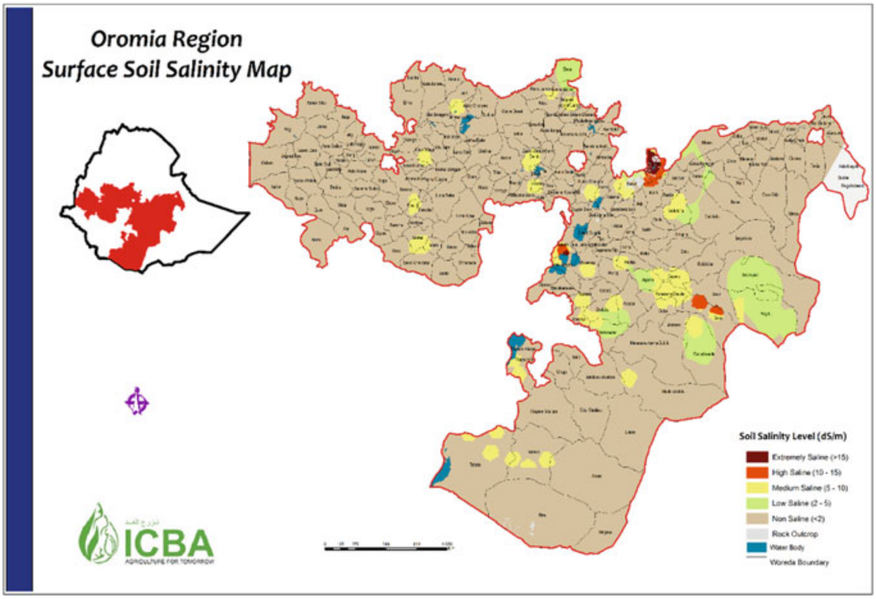

Fig. 7 Surface soil salinity (0–30 cm) map of the Oromia region

Table 13 Area covered by each RGS in the Tigray region

No.	Soil types	Area		No.	Soil types	Area	
		km^2	%			km^2	%
1	Leptosols	28,490	58	8	Calcisols	422	0.85
2	Cambisols	9,307	19	9	Fluvisols	67	0.14
3	Vertisols	7,120	14	10	Regosols	47	0.10
4	Luvisols	1,673	3	11	Rocky Surface	44	0.09
5	Alisols	980	2	12	Nitisols	34	0.07
6	Arenosols	626	1	13	WaterBody/Marsh Land	23	0.04
7	Lixisols	572	1				
Total						49,406	100.00

or no surface water is available. Due to increasing drought incidences, on average, more than four million people face food shortages and need relief assistance in any given year. The development and management of water resources face multiple challenges.

In Ethiopia, about 90% of the crop production is rainfed. The high degree of rainfall variability often creates water scarcity, causing massive damage to productivity in rainfed systems. Therefore, irrigation is vital for sustainable crop production in these

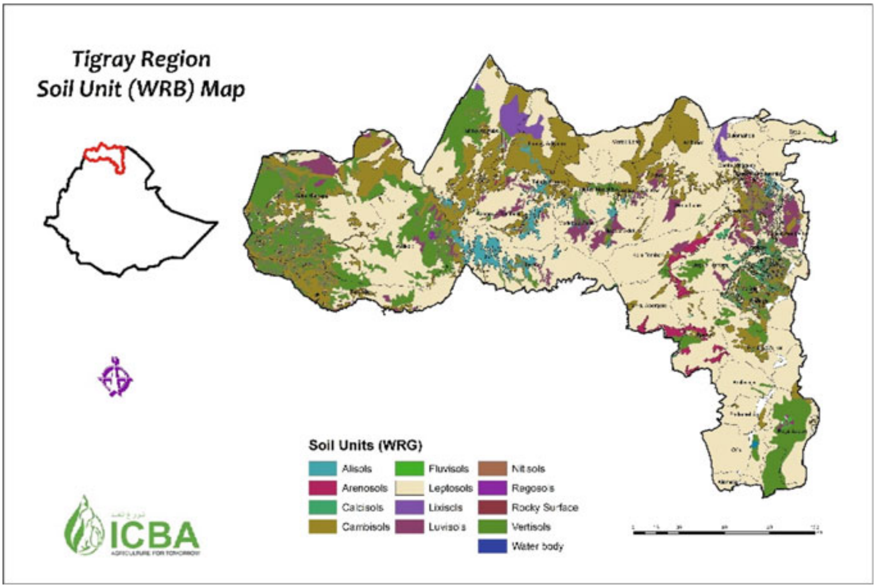

Fig. 8 Soil group types in the Tigray region

Table 14 Distribution of suface (0–30) soil salinity in the Tigray region

Soil salinity levels	Area	
	km^2	%
Non-saline/Waterbody/Rock outcrop (<2)	48,067	97.29
Low Saline (2–5)	0	0
Medium saline (5–10)	1,339	2.71
High saline (10–15)	0	0
Extremely saline (>15)	0	0
Total	49,406	100

areas. Due to multi-faceted and complex issues associated with water resource development, Ethiopia has done little to utilize its water resources. Therefore in Ethiopia, water availability is a limiting factor rather than land to expand irrigated agriculture. The surface irrigation potential of Ethiopia is estimated at 3.7 million ha (Awulachew 2010). However, this focuses on large and medium-scale irrigation developments and does not address the potential effects of small-scale irrigation, including minor river diversions, groundwater irrigation, and rainwater harvesting. An additional one million ha of land can be irrigated from groundwater and 0.5 million ha from rainwater harvesting. The total irrigation potential, thus, was estimated to be about 5.3 million ha (Awulachew and Ayana 2011).

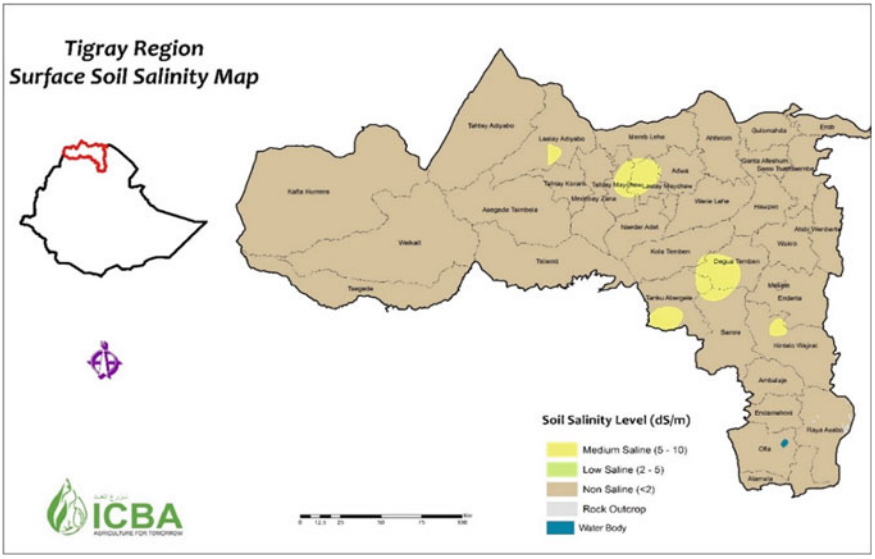

Fig. 9 Surface soil salinity (0–30 cm) map of the Tigray region

2.7 Declining Irrigation Water Quality

Salt-affected soils should be irrigated with good-quality water to avoid salt build-up to the extent that it becomes harmful to plant growth. The soils of Gergera Watershed, Atsbi-Wonberta, Tigray, and Northern Ethiopia have shown signs of increasing sodicity due to excessive use of poor-quality water for irrigation (Fig. 10). Therefore, it is proposed to adopt advanced crop and water management practices for sustaining crop productivity in these areas (Yeshitela et al. 2012). The use of poor-quality groundwater for irrigation has also increased the salinity problems in the Central Rift valley. The small-scale irrigated farms of Kewet and Efratana Gidim areas also face widespread salinity problems (Tilaye and Mekonen 2002) due to the use of poor-quality water for irrigation from dug wells during the dry season. The water quality of these dug wells is marginally fit for irrigation (Yonas 2005). The declining water quality of tributaries of the Awash River is also becoming a serious concern because this water is used for more than 3000 ha of farmland along the River Basin (EIAR 2015).

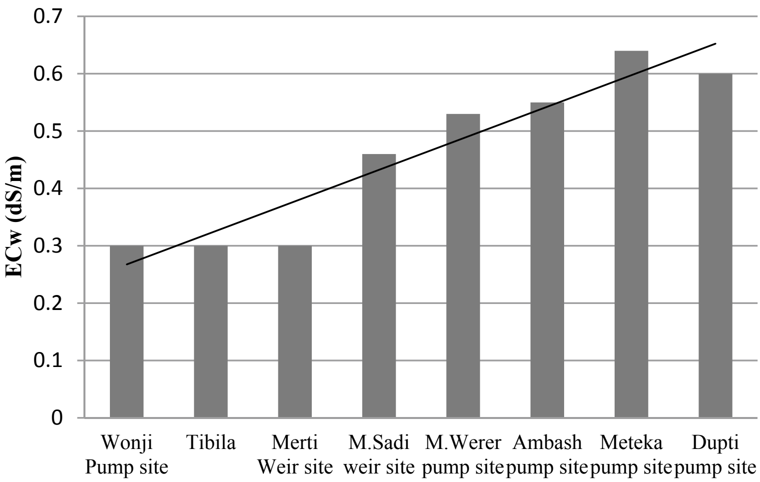

Fig. 10 Surface water quality along the Awash River (from upstream to downstream)

2.8 Waterlogging and Soil Salinization Problems

The increasing soil salinity and waterlogging problems have forced farmers to abandon their agricultural lands and migrate to nearby cities to seek off-farm jobs. This situation has reduced crop production and increased household poverty, which has affected the country's overall economy. The case is more alarming in arid and semi-arid regions. High salinity and sodicity levels from rising groundwater levels threaten irrigated agriculture's sustainability in many parts of the country (Kidane 2003). The waterlogging problems are associated with the lack of drainage facilities and poor on-farm irrigation practices. The Zeway Dugda, irrigated areas of Gerjele and Tumuga swampy area, and farm areas of Abaya and Arbaminch are the most affected areas. Many agricultural farms in these areas have gone out of production, reducing farm incomes and increasing poverty. Therefore, to produce sufficient food for the increasing population and ensure sustainable economic development of the country, these salt-affected lands need to be reclaimed.

2.9 Problems in Traditional Reclamation

The rehabilitation of salt-affected lands by installing appropriate drainage systems and chemical amendments is a costly, time-consuming, and laborious task. Under the current socio-economic conditions of the country, this doesn't seem practical in the near future. In addition, the reclamation of these soils is beyond the technical and financial capacity of smallholder farmers. They need external input and guidance on salinity management strategies and access to salt-tolerant crops. Therefore the adoption of the 'biosaline approach' would be an attractive solution. This approach involves growing salt-tolerant food and feed crops irrigated with marginal quality water integrated with livestock and suitable crop management systems. These integrated crop-livestock systems can increase the resilience of farmers who are dependent on the livestock sector development.

3 Potential Alternative Crops for Salt-Affected Soils in Ethiopia

The soil salinity problem in Ethiopia has been causing devastating effects on farms in Ethiopia. Farmers are experiencing substantial crop losses, while many farms have gone out of production over the last decades. The salinity problems in Ethiopia are spread over a range of landscapes, irrigated lands, rainfed farming areas, and rangelands in the country. In Ethiopia, the arid and semi-arid agro-ecologies, which account for nearly 50% of the country's land area, are considered marginal environments (Qureshi 2018). While soil salinity levels are steadily increasing, the lack of awareness by the farmers on the causes and remedies to the problem is regarded as one of the crucial factors for uncontrolled expansion. The growing salinity problems will have severe consequences on the country's economic development and food security.

Farmers of rainfed areas in Ethiopia are looking for alternate cropping systems to improve the productivity of their lands due to the unpredictable nature of rainfall (Tesfaye and Fassil 2011). Due to widespread salinity problems in irrigated and rainfed areas, land availability in Ethiopia has reduced to 0.2 ha per capita (Spielman et al. 2011). As the development of new agricultural lands will be difficult, owing to economic constraints, increasing the productivity of existing lands to ensure future security for the increasing population will be a potential option (Ringheim et al. 2009). This requires proper education to smallholder farmers about advanced water and salt management strategies and the provision of salt-tolerant crops. The potential alternative crops suitable for salt-affected lands of Ethiopia are summarized below.

3.1 Salt Tolerant Field Crops

The excess salts in the soil cause poor and spotty stands of crops, uneven and stunted growth, and poor yields. The primary effect of salinity is that it reduces water available to plants through roots as a result of the increased osmotic pressure of the soil solution. In addition, excessive concentration and absorption of individual ions may cause toxicity to the plants and restrict the absorption of other plant nutrients (FAO 1988). There is no crucial point of salinity where plants fail to grow. With the increase in salinity, plant growth decreases until plants become chlorotic and die. On the other hand, plants differ widely in their ability of salt tolerance. Salt tolerance of plants is based on yield reduction on salt-affected soils compared with yields on similar non-saline soils (FAO 1988). Under field conditions, saline soils can be recognized by the spotty growth of crops and often by white salt crusts on the surface.

Knowing the relative tolerance of crops to soil salinity is of paramount importance in selecting appropriate cropping patterns under different salinity environments. In highly saline areas where the growth of regular crops is restricted, salt-tolerant crops and halophytes can be potentially grown. This salinity management approach is called *Biosaline agriculture.* This approach is especially suitable for smallholder farmers as they cannot afford costly reclamation measures. The success of this approach lies in the appropriate selection of salt-tolerant crops that can grow under highly saline or sodic soil conditions.

The crops with diverse genetic diversity that can grow satisfactorily under saline soil conditions include barley, sorghum, wheat, mustard, and oilseeds. Barley is a widely grown cereal crop in the highlands of Ethiopia and is now expanding to mid-altitude areas. However, its use in marginal environments is still not very common. For instance, farmers in the Zeway Dugda area replaced barley with maize and other horticultural crops when the soil got more salinized. Over the past three decades, several salt-tolerant genotypes of barley have been developed that can be successfully grown in various environmental conditions. Studies have shown that sunflower cultivars can be grown up to a salinity level of 19 dS/m with a 50% decrease in growth. Similarly, safflower is an essential multi-purpose oilseed crop with great potential to grow under saline conditions. A study of 52 genotypes using marginal-quality water has shown that safflower is moderately salt-tolerant (ICBA 2014).

To increase the salt tolerance of field crops such as barley, wheat, sorghum, and oilseed, intra-specific variation and screening out resistant varieties that suit saline areas are needed. Therefore, more research is required to develop genetic diversity for barley, sorghum, and oilseed crops since Ethiopia is a large country with diversified climatic conditions. The introduction and adoption of modified genotypes of food crops that best suits salinity stress conditions can help increase crop production in marginal areas, raise farm incomes, and reduce household poverty. This will have a direct impact on the economic development of the country.

3.2 Salt-Tolerant Legumes and Forage Grasses

Ethiopia has extensive livestock resources, including cattle, sheep, goats, and camels. However, it faces an acute shortage of fodder resulting in low livestock productivity. There is little use of improved varieties to increase fodder production in the country. There is a strong need for modified forage varieties resistant to common diseases to improve livestock productivity. Planting salt-tolerant forage grasses and legume crops are more practical in highly saline areas. Studies done in Ethiopia have shown that Karnal grass (*Diplachne fusca*), Rhodes grass (*Chloris gayana*), Para grass

(*Brachiaria mutica*), and Bermuda grass (*Cynodon dactylon*) can be successfully grown in highly saline and sodic soils. Even when no amendments are applied, the Karnal grass grows exceptionally well in sodic soils having ESP up to 80. The dry matter yields of 7.5 tons per ha for Karnal grass have been reported in Pakistan (Chang et al. 1994). In Saudi Arabia, Rhodes grass produced 8.9 tons per ha of dry matter in 188 days; this was more than double the production of any other fodder species (Rozema et al. 2013).

Ethiopia's studies have shown promising results in salinity tolerance and biomass yield for four forage species, i.e., *Cinchrus spp., Panicum antidotal, Sudangrass, Chloris gayana*, and three legume species*; Desmodium triflorum, Sesbania sesban, and Medicago sativa (Alfalfa). Cinchrus Spp, Panicum antidotale, Sudangrass, and Chloris gayana* were subjected to salt stress levels of 8.2, 10.4, 12.7, and 17.9 dS/m, respectively. The biomass yields obtained under saline soil conditions were compared with those obtained under normal soil conditions (Fig. 11) (EIAR 2015). *Chloris gayana* (Rhodes grass) gave the highest fresh biomass yield (127 tons/ha/yr), followed by *Cinchrus* spp. (118 ton/ha/yr).

The Chloris gayana was less affected by salinity compared to *Cinchrus grass* under high salinity conditions. The dry matter yield reductions were 15% and 9% for *Cinchrus and Chloris gayana*, respectively. On the other hand, dry matter yields of *Panicum antidotale* and *Sudangrass* were reduced to almost half under similar salinity conditions. Therefore, Chloris gayana is the most suitable salt-tolerant forage crop for Ethiopian salt-affected areas compared to other grass species. These findings agree with Deifel et al. (2006), who reported that *Chloris gayana* is the most salt-tolerant grass. Studies in the United Arab Emirates also showed that *Chloris gayana* produced

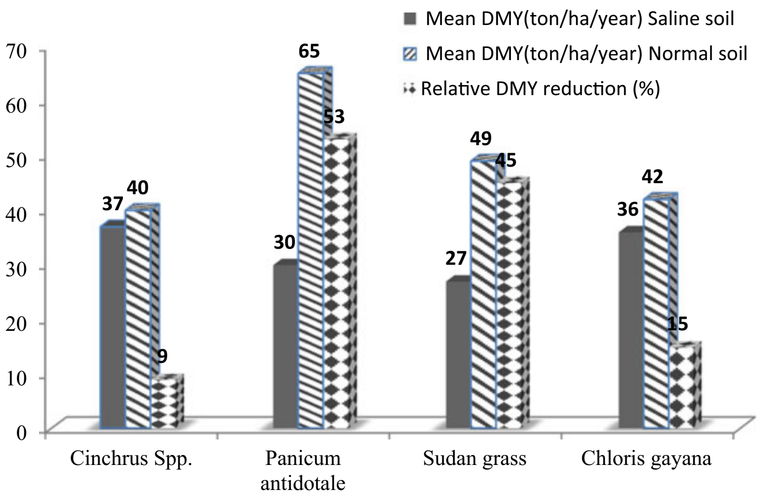

Fig. 11 Comparison of mean dry matter yield for different grass species under saline and normal soil conditions

high dry matter yields when water up to 23 dS m^{-1} was applied for irrigation (ICBA 2014).

These grasses also significantly improve the pH and bulk density of the soil. The surface soil salinity was decreased in all grass treatments from a mean ECe value of 12.3–3.7 dS m^{-1}. Rhodes grass (*Chloris gayana*) and *Panicum antidotale* have also shown promising results for sodic soils (Akhter et al. 2003). This indicates that growing these salt-loving grasses can help increase forage production, improve soil permeability, and enhance native-soil solubility $CaCO_3$, resulting in enhanced leaching of salts to deeper layers and decrease salt accumulation in the upper soil layers.

The forage legume species *sesbania susban* showed excellent salinity tolerance, moisture stress, biomass yield, and high water use efficiency. The *sesbania susban* can be used as a feed and firewood. This makes it the most favorable forage for marginal-quality soil and water resources. Other grasses such as alfalfa have also shown tolerance against salinity with excellent biomass yield. Since alfalfa is a water-demanding grass with a deep rooting system, it is more suitable for areas where soil salinity and high groundwater table due to canal seepage are a problem.

3.3 Bio-Drainage to Control Waterlogging

Most of the major irrigation schemes in Ethiopia face waterlogging problems due to over-irrigation and a lack of appropriate drainage systems. Over the last three decades, tree plantation for bio-drainage has got the attention of the farming community. This technique is suitable in areas where the installation of drainage systems to control groundwater table are not viable due to economic and technical reasons. For bio-drainage, trees with high evapotranspiration rates are selected. The excessive use of water by these trees restricts groundwater table rise to a critical depth, which is harmful to crop growth (Qureshi 2016). Plant species such as *Eucalyptus hybrid*, *Prosopis juliflora*, and *Acacia nilotica* have shown the potential for bio-drainage purposes as their annual discharge rate is equal to or exceeds the rate of recharge to groundwater. The tree plantation for bio-drainage is also economically beneficial for farmers.

In many areas of the world, this technique has successfully been used for lowering groundwater tables. In the Rajasthan region of India, the annual evapotranspiration from eucalyptus trees with a density of 1900 trees/ha was estimated to be 3446 mm (Dagar 2009). The annual water use of the eucalyptus forest was two times higher than that of crops such as finger millet. Calder (1994) have also shown that the fully-developed *Eucalyptus Camaldulensis*, *Acacia nilotica*, and *Prosopis Cineraria* plants, with a tree density of 1100 trees/ha, can transpire water equal to annual Class A Pan evaporation. In marginal environments where land productivity is low due to soil salinity and waterlogging, tree plantation is a potential option because it helps soil reclamation and generates economic benefits for the farming communities. Bio-drainage is an environment-friendly and cost-effective technique to overcome the problems of waterlogging (Qureshi 2017). However, long-term objectives need to be combined with short-term incentives to make it attractive for farmers.

3.4 Halophytes Plantation for Highly Salt-Affected Lands

Halophytes can be successfully planted in marshes, estuaries, cliffs, and dunes because they can tolerate high soil and water salinity. They help protect habitat, maintain ecological stability, carbon dioxide sequestering, and reclamation of salt-affected soils (Sardo 2005). Halophytes tend to remove salts from soils through salt excluding, excreting, or accumulating by their morphological and physiological adaptations at their cellular level (Michalk et al. 2013). They are suitable for coastal and inland soils of arid and semi-arid areas where evapotranspiration exceeds precipitation. The productivity of salt-affected lands can be maintained up to a salinity level of 70 dS m^{-1} by planting halophytes if root zone salinity is maintained through effective leaching (ICBA 2014).

Halophytes have been tested as a vegetable, forage, and oilseed crops in field trials. The oilseed halophyte, *Salicornia bigelovii*, yields 2 tons/ha of seed and contains 28% oil and 31% protein, like soybean yield and seed quality (Girma and Awulachew 2007). Halophytic forage and seed products have been used to replace conventional ingredients in animal feeding systems. However, there are certain restrictions on their use because they contain high salt content and anti-nutritional compounds (Khan and Duke 2001).

The facultative halophytic species such as Quinoa can successfully be grown in salt-affected lands. Quinoa (*Chenopodium quinoa* Willd.) is an edible seed species with rich proteins, fiber and fat, and gluten-free characteristics. It has substantial resistance to drought, frost, and salinity. Quinoa has got global attention as an agro-industrial crop that can succeed in highly saline areas and poor-quality irrigation water (ICBA 2014).

Selecting salt-resistant plants is essential for sustainable agricultural production in saline lands (Flowers and Muscolo 2015). Soil reclamation through the plantation of halophyte plants in pasture and fodder production is a beneficial strategy (Khan and Duke 2001). Halophytic plants such as *Atriplex* can successfully be used to improve soil salinity. Studies have shown that *Atriplex* treatment improved soil salinity by 40% for a one-year experiment and is considered a high-protein animal feed (ICBA 2014).

4 Conclusions and Recommendations

Despite vast salt-affected areas, research and development endeavors to alleviate salinity problems have been minimal in Ethiopia. The extent and causes of salt-affected soils in Ethiopia are not precisely known. The economic implications of the salinity problem are not well-documented, and there are no autonomous institutions to take responsibility for solving salinity problems in the country. Therefore, there is a strong need to develop short-term and long-term strategies and plans to mitigate salinity and sodicity in Ethiopia. This indicates the urgent need to embark on a sustained research endeavor to characterize saline soils, quantify the extent of damage, and develop technologies to reclaim and halt further expansion of soil salinity in the country. The most common short-term and long-term strategies for the reclamation of salt-affected soils are discussed below.

4.1 Short-Term Strategies for Soil Reclamation

For the reclamation of salt-affected soils and to curtail the future expansion of salinity in irrigated areas, recommendations should be made based on detailed studies, investigation, and thorough analysis of factors affecting salt built-up and their practical management, including reclamation and intended utilization. Under the prevailing conditions of Ethiopia, the combination of two or more of the following methods may be practiced for controlling and/or minimizing salinity and sodicity problems. Nonetheless, it should be noted that the practice may not always be successful because the suggested methods are based on the results of studies and investigations made elsewhere and experience in other countries. The following measures could help address salinity and sodicity problems.

- Install proper drainage systems to prevent groundwater tables from rising to the surface—control over-irrigation to avoid excessive percolation of water to groundwater.
- Practice surface mulching to reduce soil evaporation and increase deep percolation to facilitate deep leaching and reduce salt accumulation.
- Perform pre and post-plant leaching to remove stored salts from the root zone.
- Maintain water available in the root zone during critical crop growth stages.
- Select appropriate planting methods to optimize plant density to ensure good crop growth. Eradicate weeds to avoid nutrient and water competition with other crops.
- Select suitable lands for crop cultivation. The areas with high groundwater tables and poor soil structure may create perch groundwater by impeding drainage.
- Avoid bringing sub-soil with high sodium and salt accumulation to the surface during land leveling. If needed, spread a uniform layer of salt-free soil on the surface after land leveling.
- Use lined canals or salt-free conveyance or waterways for primary and secondary irrigation canals crossing soil layers with high salt accumulation.
- Avoid mixing drainage water with irrigation water and avoid direct drainage water use for irrigation because it may contain higher salt content.

The adverse effects of soil salinity and sodicity can also be reduced by adopting suitable agronomic practices as given below:

- Grow crops or crop species, which are salt-tolerant.
- Grow ameliorating crop species and perennial forage grasses where the latter in turn may initiate livestock farming, such as cattle fattening.
- Grow salt-tolerant crops, forages, legumes, etc. This practice is more feasible for soils having high salt concentrations.
- Adverse effects of excessive salts and exchangeable sodium on plant growth can be minimized by increasing the availability of plant nutrients through the application of less available elements such as P, K, Fe, Mn, Zn, Cu, and in some cases, Ca and Mg, due to the high $CaCO_3$ content, high exchangeable sodium, and alkaline soil reactions.
- Initiate reclamation of saline and sodic soils through chemical amendments where calcium sources such as gypsum ($Ca\ SO_4 \cdot 2H_2O$) are available.
- Promote and uphold proper soil, water, and crop management practices and enforce rules and regulations regarding the use of salt-affected soils.
- Monitor, evaluate, and regulate the expansion of irrigated farms in all parts of the country, especially in dry areas.

4.2 Long-Term Strategies for Soil Reclamation

The reclamation of salt-affected soils, halting future expansion, and proper management of soil and water resources require a profound knowledge of resources and their optimum utilization. One of the most cardinal problems of soil reclamation and management in arid and semi-arid regions is the lack of locally amendable technologies. For technology development, an in-depth investigation is required to get quantitative and qualitative information on the dynamic nature of soil and water resources. This scientific knowledge will help us understand the complex physical environment. Thus, a continuous search into the truth and accumulation and dissemination of knowledge and technology is needed. Hence, focused research is vital for generating science and technologies that will change the lives and livelihoods of millions living in marginal environments.

The research priorities for the management of saline and sodic soils are given below.

- Observational and diagnostic studies must be made in salt-affected areas.
- The physical, chemical, biological, environmental, and socio-economic factors influencing soil salinity need to be investigated.
- Field and laboratory studies should be conducted to characterize salt-affected soils.
- Research findings related to environmental, hydro, and agrotechnical, socio-economic factors responsible for the development of salt-affected soils must be implemented.
- Create awareness among farmers and develop preparedness plans to combat salinity and sodicity problems.

- Map salt-affected soils at zonal, regional, and national levels through reconnaissance and a large-scale survey of irrigated and dryland areas.
- Study the effects of saline soils and irrigation water on soil fertility, and productivity, and monitor the impact on plant growth and land value.
- Introduce suitable management practices for irrigation, drainage, leaching, and soil and crop management to control salinity and sodicity.
- Introduce agronomic methods that can be used to reclaim and manage salt-affected soils. These may include appropriate salt-tolerant crops, forages, grasses, and tree species.
- Evaluate different reclamation techniques for saline and sodic soils. These may include the rate of gypsum to be applied, soil amendments, leaching requirements, and irrigation management strategies.
- Prepare soil and water quality maps indicating the areas where immediate action is required.
- Identify and characterize representative watersheds to develop proper water management and drainage plans.
- Propagate available soil reclamation technologies to the end-users.
- Develop agricultural water management manuals, bulletins, and flyers to improve soil and water management.
- Impact on the environment and socio-economic aspects must be assessed to establish a system to sustain agricultural production and protect the environment.

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