

Review

Prospects of alternative cropping systems for salt-affected soils in Ethiopia

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Soil salinization is one of the major constraints in achieving food security and environmental degradation in Ethiopia. Restoration of salt-affected lands into productive lands and protection of newly developed areas from the spread of salinity is therefore of paramount importance. In high salinity areas where technical solutions to soil rehabilitation are expensive and time consuming and growth of normal field crops is restricted, use of bioremediation methods including planting halophytic forages could bring these soils back into production. This paper identifies different causes of salinity and characterizes soils based on severity of salinity levels. The paper suggests that biosaline agriculture is an economical and effective approach to use unproductive lands for growing different food and fodder crops in Ethiopia. This approach, if prudently adapted, can help in improving livelihood of rural and pastoral communities of the salt-affected areas by enhancing feed and fodder production. The paper has recommended many unexplored and unexploited genetic variation that can be harnessed to improve the salt tolerance of field crop species. Productivity of marginal lands can be maximized for field crops and fodder species and varieties that can tolerate soil salinization and poor irrigation water quality.

Key words: Soil salinity, halophytes, biosaline agriculture, food security, salt-tolerance, marginal lands.

INTRODUCTION

Ethiopia is heavily reliant on agriculture sector for its overall economic growth and social sector development because it accounts for 40% of the GDP, 80% of the total employment and 70% of the export earnings (African Economic Outlook, 2015). The development of agriculture sector over the last decade has brought food self-sufficiency in the country with grain production reaching

up to 27 million tons. This was the result of a strong commitment by the government, which allocated more than 15% of the total budget and introduced effective policies and programs for the development of agriculture sector (Yohannes et al., 2017).

The semi-arid and dry sub-humid agro-ecological zones of the country, which account for nearly 47% of the

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country's 113 million ha, are marginal environments for crop production and are highly vulnerable to droughts and a significant proportion of population continues to rely on food aid and safety net programs (Mekonen, 2007). Major causes of low agricultural productivity in these are declining soil fertility and increasing soil salinity, lack of improved crop varieties and lack of irrigation water. The depletion rate for the major plant nutrients is estimated to be 40, 6.6 and 33.2 kg ha⁻¹ year⁻¹ for N, P and K, respectively (Stoorvogel and Smaling, 1990). Other problems related to lower agricultural productivity are limited choice of crop varieties that are tolerant to soil salinity and water stress (Kidane, 1999). The traditional major crops are sorghum, tef, maize and finger millet and lowland pulses. Grain yields of these crops are generally low and varied in different regions (Getachew, 1986).

Soil salinity is one of the major land degradation problems in Ethiopia. It is estimated that salt-affected lands (salinity and alkalinity) cover a total area of 11 million ha, being the highest in any African country (Fantaw, 2007). Most of these soils are concentrated in the plain lands of arid, semi-arid and desert regions of the Rift valley system including Afar, the Somali lowlands, the Denakil plain and valley bottoms throughout the country (Heluf, 1995; Fantaw, 2007). Most of the export crops such as cotton, sugarcane, citrus fruits, banana and vegetables are being produced in the Rift valley. The development of large-scale irrigation projects in Rift valley in the absence of proper drainage systems for salinity control has resulted in increasing severity and rapid expansion of soil salinity and sodicity problems leading to complete loss of land for crop cultivation in these areas.

Despite this alarming situation, attempts to resolve land degradation problems could not get due attention. With a 3% average population growth, future food security as well as the livelihood source for a considerable portion of the population remains a challenge to the governments. The soil salinity problems in Ethiopia stems from use of poor quality water coupled with the intensive use of soils for irrigation, poor on-farm water management practices and lack of adequate drainage facilities (Gebremeskel et al., 2018). Restoration of salt-affected lands into productive lands and protection of newly developed areas from the spread of salinity through improved irrigation and crop management is therefore of paramount importance. In the high salinity areas where growth of normal field crops is restricted, use of bioremediation methods including planting halophytic forages could bring these soils back into production.

There is also a need to identify best adaptation and mitigation practices for salinity management, increasing farmer incomes and improve livelihood of poor rural communities. This is particularly important for Ethiopia considering their large livestock sector. The financial and technical resources needed to reclaim these soils for crop production are beyond the capacity of smallholder

farmers. Therefore, there is every motivation to designate more resources by the government agencies to tackle this problem to ensure future food security and poverty reduction for millions of rural poor. This paper reviews the status and characterization of salt-affected lands in Ethiopia and recommends alternative cropping systems to increase crop productivity and reclamation of these lands.

EXTENT AND CHARACTERIZATION OF SALT-AFFECTED LANDS IN ETHIOPIA

The detailed information on the extent and nature of degraded soils in Ethiopia is either missing or inadequate. The soil classification described by FAO (1984e) is widely used for all practical reasons. According to this classification, the soils in arid and semi-arid areas (typically Regosols, Xerosols and Yermosols) are less developed; tend to be stony and shallow saline (Solonchaks, Solonetz). The soils in the valley bottoms and flat plains are dominantly Vertisols, while in the undulating to gently rolling plateau, Luvisols, Nitosols and Acrisols soil types are more common. The mountains and tarnished landscapes are known as Leptosols and the major alluvial plains are dominantly Fluvisols and Vertisols with saline and sodic phases.

The arid and semi-arid agro-ecologies which account for nearly 50% of the country's land area are regarded as marginal environments for crop production mainly due to soil and water salinity. Low levels of annual rainfall and high daily temperatures have led to high water evaporation rates and consequently contributed to high concentrations of soluble salts in these lowland areas (Sileshi et al., 2015). In Ethiopia, about 44 million ha (36% of the total land area) is potentially susceptible to salinity problems of which 11 million ha have already been affected by different levels of salinity and mainly concentrated in the Rift valley. Ethiopia ranked as 7th in the world in terms of percentage of the total land area affected with salinity. This has resulted in the degradation of natural habitats, ecosystems and agricultural lands. This has threatened the productivity of irrigated lands, which is producing more than 40% of the total food requirement of the country (Mohammed et al., 2015). A map of Ethiopia is as shown in Figure 1.

The soils of the Melka Sedi-Amibara Plain of the Middle Awash Valley are highly saline with EC_e ranging from 16 to 18 dSm⁻¹ (Table 1). Soluble Na⁺, Ca²⁺, Cl⁻, and SO₄²⁻ are the dominant soluble salt constituents throughout the depths of the profile. Accordingly, chloride and sulphate salts of sodium and calcium (mainly NaCl and CaSO₄) are assumed to be the major soluble salts contributing to the very high salinity level of these soils (Auge et al., 2018).

The high salinity and sodicity levels are due to poor drainage conditions in most of the valley. In the Middle



Figure 1. Map of Ethiopia with regional boundaries.

Table 1. Chemical composition of soil profile of Melka Sedi-Amibara Plain of the Middle Awash valley.

Depth (cm)	pH H ₂ O	EC (dS/m)	Soluble cations (me l ⁻¹)				SAR	Soluble anions (me l ⁻¹)			
			Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺		CO ₃ ²⁻	HCO ₃ ⁻	Cl ⁻	SO ₄ ²⁻
0-25	7.2	18.6	59.4	3.7	208.1	15.4	37.0	Nil	1.1	165.8	77.1
25-50	7.2	17.8	55.5	3.3	197.6	14.4	36.4	Nil	1.0	160.2	71.8
50-70	7.2	17.5	53.1	3.7	197.5	14.1	37.0	Nil	1.0	157.0	68.5
70-90	7.2	17.2	51.5	3.4	120.0	13.7	22.9	Nil	1.4	147.0	64.3
90-120	7.2	16.6	47.3	3.1	132.5	10.6	26.4	Nil	1.0	132.4	59.9

Awash Valley of the Rift Valley System, the large state-owned irrigated farms are also fast going out of production due to increasing soil salinity (Fantaw, 2007). The problems of soil salinity are more pronounced in the irrigated areas. The increasing salinity problems in arid and semi-arid regions of Ethiopia have also caused physically and chemically degradation of irrigated lands due to compaction and structural breakdown.

According to the recent estimates, about 80% of Dubti/Tendaho State farm is affected by soil salinity (that is, 27% saline, 29% saline sodic and 24% sodic soils). The historical trend shows that the extent of salt-affected

soils has increased significantly from 1972 to 2014 due to different reasons such as poor irrigation practices, use of poor quality irrigation water and lack of drainage facilities. Sardo (2005) has revealed that increase in groundwater levels due to excessive irrigation has caused salinity development in these soils. In irrigated areas of arid and semi-arid regions, the ascending motion of capillary water is generally greater than the descending motion and it facilitates the buildup of salt in soil profiles due to the large evapotranspiration rates. The changes in the area affected by soil salinity from 1972 to 2014 at Dubti/Tendaho State farm are shown in Table 2.

Table 2. Temporal changes in the area affected by soil salinity at Dubti/Tendaho state farm.

Salinity level	1972		1994		2014	
	Area (ha)	Change (%)	Area (ha)	Change (%)	Area (ha)	Change (%)
Normal soil	3783	35	2930	27	2189	20
Saline-Sodic	2178	20	2423	23	3154	29
Saline	4035	37	4138	38	2929	27
Sodic	797	8	1302	12	2521	24
Total	10,793	100	10,793	100	10,793	100

CAUSES AND EFFECTS OF SOIL SALINITY DEVELOPMENT IN ETHIOPIA

In the saline lands of Ethiopia, agricultural production is increasingly faced with environmental constraints resulting in reduced crop productivity. The variation in crop production in different salinity prone areas is linked to the changes in local environmental, socio-economic and edaphic conditions. Major factors causing salinity development in Ethiopia are summarized in the following.

Water shortage for irrigation

Salt-affected lands in Ethiopia are mainly located in arid, semi-arid and lowland dry areas (60% of total land area of the country), where rainfall is neither sufficient nor reliable for sustainable crop production. In these areas, irrigation is necessary for stabilizing agricultural production. In many areas, farmers used to develop flood-based farming systems, also called as spate irrigation. Spate irrigation is beneficial in mountain catchment border lowlands, where farmers can make use of short duration floods. However, as water comes often either long before or late after the cropping season, crop productivity is severely affected. The success of spate irrigation depends on availability of good infrastructure and cooperation of farmers. Based on the review of the spate irrigation systems in Tigray region, Van Steenberg et al. (2011) listed the following problems with the spate irrigation.

- (1) Upstream and downstream users do not share the flood flow equitably;
- (2) Technical faults in developing local diversion canals generate changes in the river course;
- (3) Improper secondary and tertiary canals leading to in-field scour and creation of gullies in the fields - which reduces available soil moisture.

In the arid lowlands of the country, the option of conventional irrigation is limited to the few perennial rivers, which are in most cases heavily challenged. Other forms of irrigation such as based on temporary flows and floods, have more potential but are not fully developed.

In parts of the lowlands there is a considerable groundwater potential, but it is challenging to exploit this for irrigation due to its existence at deeper depths and lack of drilling facilities.

Declining irrigation water quality

The increasing demand of water for domestic and industrial uses has put enormous pressure on agriculture sector to decrease its share of good quality water use. The hot and dry climates of saline areas require that the irrigation water does not contain soluble salts in amounts that are harmful to the plants or have an adverse effect on the soil properties. Studies done to evaluate the impact of irrigation on soil salinity and crop production in Gergera Watershed, Atsbi-Wonberta, Tigray, Northern Ethiopia have shown potential risk of soil sodification due to the use of surface water for irrigation and suggested the need for adopting alternative water and crop management practices for sustaining crop productivity in these areas (Yeshitela et al., 2012).

Soils of Central Rift valley are naturally sodic in the subsurface horizons and the use of marginal quality groundwater for irrigation has exacerbated the salinity problems. In North Shewa, the widely irrigated areas of the zone are the lowlands of Kewet and Efratana Gidim are also facing growing threats of soil salinity especially in small-scale irrigated farms (Tilaye and Mekonen, 2002). Development of soil salinity in this area is often associated to the use of poor quality water for irrigation from dug wells during the dry season when fresh water availability from the river is not sufficient to meet irrigation demand. The quality of these wells is only marginally fit for irrigation (Yonas, 2005).

Deterioration of water quality along major river streams of the Awash River is also becoming an important ecological concern because water from this river is extensively used for more than 3000 hectares of farm land along the River Basin (EIAR Annual Report, 2015).

Figure 2 shows spatial trend of Awash River water quality at different diversion weir and pump sites along the stream flow. The water quality is deteriorated as we move from upper to lower river streams due to increase in salt concentration over time (Figure 3). This means that the

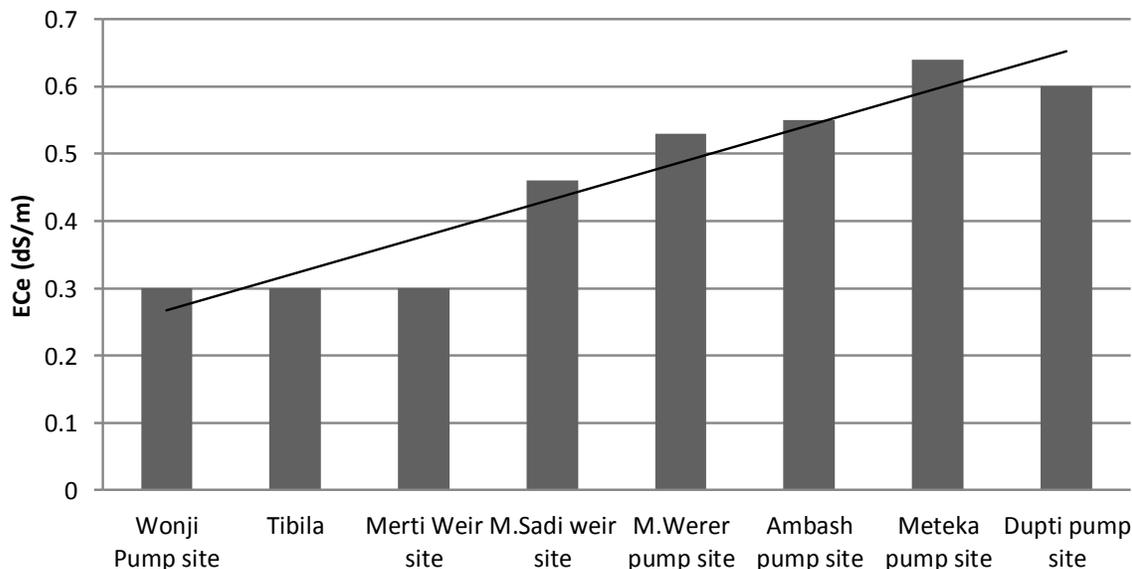


Figure 2. Trends in surface water quality along the Awash River (from upper to lower stream).

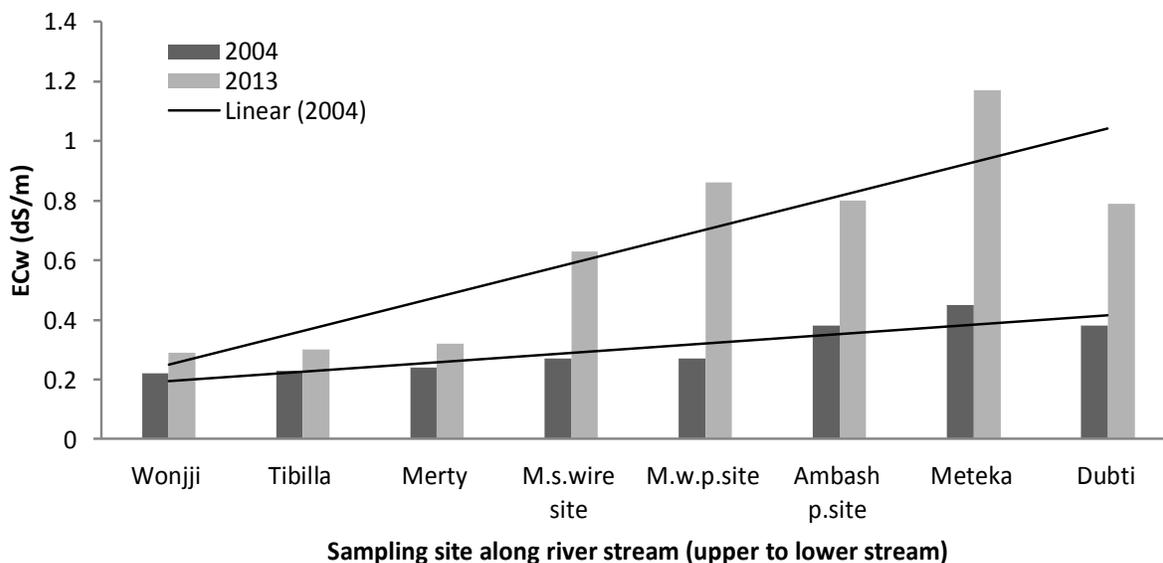


Figure 3. Changes in Awash River water quality from 2004 to 2013.

suitability of Awash River water for irrigation at down streams is continuously deteriorating, which may cause further soil degradation in future.

Waterlogging and soil salinization problems

Salinity problems are increasing in the irrigated areas of arid and semi-arid lowlands of Ethiopia, which is causing huge social (that is, migration and diseases) and economic problems (reduction in crop production and

increase in poverty) for the country. Farmers are increasingly abandoning part of their farms in irrigation schemes due to rising salinity problems. This problem is more acute in arid and semi-arid regions, where salinity strongly limits crop development. In many parts of the country, high salinity and sodicity levels from increasing groundwater levels are threatening the sustainability of irrigated agriculture (Kidane et al., 2003). Increasing secondary salinization and alkalization is preventing farmers to bring more area under cultivation in these arid and semi-arid regions of the country.

Waterlogging and salinity problems have aggravated due to poor drainage facilities and on-farm water management practices that have caused excessive seepage of irrigation water resulting in elevated groundwater levels. The combined effect of waterlogging, salinity and sodicity has emerged as 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, etc. Due to this situation, many farms in these areas have gone out of production leading to increased migration, declining farm incomes and poor living standards. Therefore, for environmentally and socially sustainable development and to produce enough food for the rising population, there is a strong need to bring these salt-affected lands back to their production potential.

POTENTIAL ALTERNATIVE CROPS FOR MARGINALIZED ENVIRONMENTS IN ETHIOPIA

The limited capacity of rainfed agriculture to sustain crop production due to erratic nature of the rainfall has persuaded farmers to look for alternative ways of improving the availability of food (Tesfaye and Fassil, 2011). Due to increasing soil salinity, per capita land availability has reduced to 0.2 ha in Ethiopia (Spielman et al., 2011). Abiotic stresses such as water scarcity, temperature extremes, waterlogging, salinity, and increasing marginality of production systems are the major constraints to enhance productivity at the farm level, resulting in food and nutrition insecurity in many arid and semi-arid regions of the country. Since new agricultural land will be scarce, increasing food production will require utilization of marginal land and water resources.

With a 3% average population growth in Ethiopia, future food security as well as the livelihood source for a significant proportion of the population will remain a challenge to the governments (Ringheim et al., 2009). Increasing the productivity of existing salt-affected lands and protecting newly developed areas from the spread of salinity is therefore of paramount importance. The smallholder farmers in Ethiopia have the potential to increase their agricultural productivity and farm incomes if they get proper guidance on the improved irrigation and salinity management strategies and access to modified salinity-tolerant seeds for crops and forages. Therefore, for millions of farm families in Ethiopia, access to improved knowledge and inputs will be a dividing line between poverty and prosperity.

Saline and sodic soils are marginally productive for commonly grown food crops. Therefore, for sustainable agricultural production, new agricultural practices and cropping systems should be adopted considering changing environmental conditions. One of the approaches for this purpose is to investigate and include

in the cropping system plant species which can tolerate abiotic stresses. Moreover, the competition for fresh water resources will increase in future due to increasing demand from domestic and industrial sectors, leaving agriculture to use low-quality water with adverse effects on agricultural productivity as most of the commonly cultivated crops are salt-sensitive. In this scenario, diversification of production systems based on more salt and water tolerant crops could be an important strategy to sustain agricultural productivity and increase economic returns at the farm level. The potential alternative crops that can be used in salt-affected lands of Ethiopia are summarized in the following.

Salt tolerant field crops

Crop plants differ a great deal in their ability to survive and yield satisfactorily when grown in saline soils. Information on the relative tolerance of crops to a soil environment is of practical importance in planning cropping patterns for optimum returns. The areas of low to moderate salinity levels can be restored by introducing improved irrigation and crop management practices. However, in areas where increased salinity levels have restricted the growth of normal field crops, use of Biosaline approach could be a potential solution. This 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 resilience of small scale crop-livestock farms, particularly in Ethiopia where livelihood of smallholder farmers is largely dependent on the development of livestock sector. Biological approach is one of the easiest approaches of reclamation and management of salt-affected soil; especially for small farmers who do not have the resources to implement costlier corrective measures. The judicious selection of salt-tolerant crops that can grow satisfactorily under moderately to highly saline or sodic soil conditions has merit in most cases.

Barley (*Hordeum vulgare* L.), sorghum, wheat, mustard and oilseeds (safflower and sunflower) are among economically important crops with diverse genetic diversity for better adaptation under saline soil conditions. Barley is among cereal crops widely grown in high land areas of Ethiopia and currently it is about to expand to mid altitude areas as well. Even though barley, among commonly grown cereal crops, has been well described for its potential ability to tolerate stress induced by salinity, its introduction and potential use under marginal environment is not common in the country. For instance, farmers at Zeway Dugda area in Ethiopia used to grow barley instead of maize and other horticultural crops when the soil is getting more salinized.

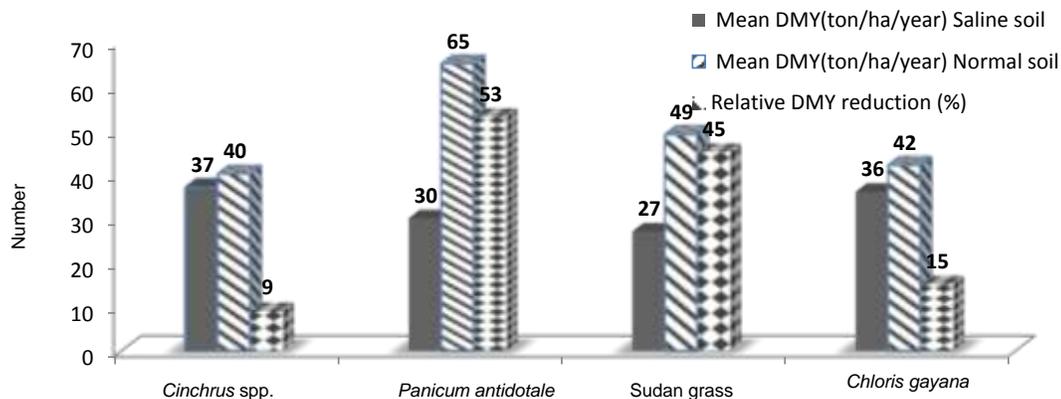


Figure 4. Comparison of mean dry matter yield for different grass species under saline and normal soil conditions.

Existence of genetic variation for salinity stress tolerance among different barley genotypes is well documented in which possibility of improvement of salinity tolerance in barley attains bright future for its wider use potential as alternative crop under salt affected soils. Result from pot trials have shown the potential ability of some sunflower cultivars to high salinity stress level of 19 dS/m with 50% decrease in growth. Safflower is among important multi-purpose oilseed crops with great potential as source of edible oil and feed source. From field plot trials conducted over two seasons to evaluate salinity tolerance of among 52 genotypes using irrigation water of different qualities, it was found that safflower is moderately salt-tolerant and cultivation on salt-affected lands can prove beneficial to farmers (ICBA, 2014)

Prospects for improving salt tolerance in barley, wheat, sorghum and oilseed include, among others, the use of intra-specific variation and screen out resistant varieties that suits to saline areas. Ethiopia being a country of center of origin of barley and wide genetic diversity for sorghum and some oilseed crops have potential for identification of genotype among available gen pool and introduction into cropping system that best suit to salinity stress condition as an alternative to less salinity tolerant crops.

Salt tolerant legumes and forage grasses

Under high saline soil conditions, planting salt-tolerant forage grasses and legume crops is more practical. Field and greenhouse studies have shown that Karnal grass (*Diplachne fusca*), Rhodes grass (*Chloris gayana*), Para grass (*Brachiaria mutica*) and Bermuda grass (*Cynodon dactylon*) are highly salt-tolerant and can be successfully grown in saline and sodic soils. Karnal grass grows extremely well in highly sodic soils (ESP = 80) even when no amendments are applied. In Pakistan, dry matter yields of 7.5 tons per hectare have been reported (Chang

et al., 1994). In trials of the performance of a range of summer grasses on saline soils in Saudi Arabia, Rhodes grass yielded 8.9 tons of dry matter per hectare in 188 days; this was more than double the yield of any other tested species (Rozema, 2013).

Studies done by Werer Agricultural Research Centre in Ethiopia during 2011-2014 have shown promising results in terms of salinity tolerance, biomass yield and ameliorative effects for four forage crop species, that is, *Cinchrus* species, *Panicum antidotale*, Sudan grass and *C. gayana* and 3 legume species *Desmodium triflorum*, *Sesbania sesban* and *Medicago sativa* (Alfalfa). Salt stress levels under which *Cinchrus* spp., *P. antidotale*, Sudan grass and *Chloris gayana* were subjected to contain mean EC_e values of 8.2, 10.4, 12.7 and 17.9 dS/m, respectively. The biomass yields obtained under saline soil conditions were closely comparable with that obtained under normal soil condition (Figure 4) (EIAR annual report, 2016). Under saline stress condition *C. gayana* (Rhodes grass) gave the highest mean fresh biomass yield (127 tons/ha/year), closely followed by *Cinchrus* spp. (118 ton/ha/year). Dry matter yield obtained under saline soil was also higher in *C. gayana* (36 tons/ha/year) and *Cinchrus* spp. (37 tons/ha/year) than both *P. antidotale* (30 tons/ha/year) and Sudan grass (27 tons/ha/year).

Under Ethiopian conditions, effect of salinity stress was less pronounced in *C. gayana* and *Cinchrus* spp. The dry matter forage yield reductions under saline conditions were only 15 and 9%, respectively. However, dry matter yield reduction of *P. antidotale* and Sudan grass under saline conditions was found to be 53 and 45%, respectively. Therefore, for Ethiopian salt-affected areas, *C. gayana* is the most suitable salt-tolerant forage crop as compared to other grass species. These results confirm earlier findings of Deifel et al. (2006) who indicated *C. gayana* as the most salt-tolerant forage grass. In the salt-affected lands of United Arab Emirates, high dry matter yields of *C. gayana* (Rhodes grass) have

also been achieved by applying irrigation water up to 23 dS/m (ICBA, 2014).

The growth of these salt-affected grasses also results in remarkable improvement in soil quality. Soil salinity generally decreased markedly in all grass treatments from a mean E_{Ce} value of 12.3 to 3.7 dS/m in upper 0-30 cm soil layer. Rhodes grass (*C. gayana*) and Blue panic (*P. antidotale*) were reported as promising grasses for sodic soils (Akhter et al., 2003). There was also an improvement in soil pH and bulk density characters resulting from growing of salt tolerant grass species. Thus, growing salt-tolerant grasses will not only provide much needed forage but also improve the soils resulting in increased absorption of rain water, reduced runoff and soil losses due to erosion.

Cultivation of salt-tolerant grasses also helps in restoring soil structure and permeability through penetration of their roots and increased solubility of native-soil CaCO₃, resulting in enhanced leaching of salts. In addition to buildup of biomass, their cultivation and growth can improve the water retention and infiltration characteristics of saline soils because of root penetration and root decay to loosen the otherwise compacted soil. The net result is enhanced leaching of salts to deeper layers and decreased salt concentration in the upper soil layers of the soil profile. This increases the potential of reclamation of salt-affected lands.

Among the tested forage legume species *Susbania susban* has been shown to have excellent potential for its salinity and moisture stress tolerance and remarkable biomass yield. *Susbania*, in addition to its tolerance to salinity requires less water to grow and have a wide range of uses such as feed and fire wood. This makes it promising candidate for legume forage production system and economic use of marginal quality soil and water resources. Alfalfa has also shown proved salinity tolerance with remarkable biomass yield. Alfalfa because of its salinity tolerance, high water use with deep-rooted system would be best alternative crop for the areas where salinity and canal seepage losses are a problem. Both forage and legume crops gave economically reasonable biomass yield indicating their ability to tolerate high level of soil salinity under which no yield is expected from cultivating other field crops.

Bio-drainage to control waterlogging

The recent emphasis on additional sources of energy has demanded that a sizeable fraction of available land resources be diverted to forestry. Due to increasing competition for good land to grow food crops, use of marginal lands for tree plantation is desirable. Plant species such as *Eucalyptus hybrid*, *Prosopis juliflora* and *Acacia nilotica* can successfully be grown on salt-affected soils by creating favorable conditions for seed germination. All major irrigation schemes in Ethiopia face problems of waterlogging and soil salinity which can

partly be tackled by planting trees. The excessive use of water by these trees can help control groundwater table rise to the critical depth, where it can harm the crop growth (Qureshi, 2016). However, this would require that the annual rate of discharge is equal or exceeds the rate of recharge to groundwater. The tree plantation for bio-drainage is suitable where engineering approaches to control groundwater table are not feasible due to economic and technical reasons. The tree plantation for bio-drainage also provides additional economic benefits for farmers.

In the desert area of Rajasthan, India, this technique has successfully been used for lowering groundwater table. The annual evapotranspiration from tree plantations (eucalyptus) with a density of 1900 trees/ha was estimated to be 3446 mm (Dagar, 2009). The annual water use of eucalyptus forest was found to be two times higher than that of agricultural crop such as finger millet. Calder et al. (1994) have also found that fully developed plants like *Eucalyptus camaldulensis*, *A. nilotica*, and *Prosopis cineraria*, with a tree density of 1100 trees/ha or more can be expected to transpire water in a year equal to annual Class A Pan evaporation.

Conversion of marginal lands, that produces low yields or have been abandoned from cropping, to tree plantation is a feasible option because it produces economic benefits for farmers and does not compete with the food crop production. The advantages of bio-drainage as an eco-friendly technique for combating waterlogging and salinity are cost-effective strategies as compared to the expensive conventional drainage systems (Qureshi, 2017). However, to make it attractive for farmers, long-term objectives need to be combined with short term incentives.

Halophytes plantation for highly salt-affected lands

The increasing pressure on land and water resources makes it necessary to make better use of available fresh water resources and to expand agriculture in non-traditional areas where extreme soil and water conditions exist. Under extreme conditions of soil or water salinities where normal agricultural crops cannot be grown, dedicated halophyte plantations for forage production can be practiced. Halophyte plantation may help in rehabilitation of saline lands, landscaping, bioenergy generation, carbon dioxide sequestering and many other useful purposes (Sardo, 2005). The presence of halophytes has long been recognized, however much of the scientific work has been carried out during the last four decades, which has demonstrated unsuspected value of halophytes (Michalk et al., 2013).

Because of their diversity, halophytes have been tested as vegetable, forage and oilseed crops in agronomic field trials. The oilseed halophyte, *Salicornia bigelovii*, yields 2 tons/ha of seed containing 28% oil and 31% protein, like soybean yield and seed quality (Girma et al., 2007).

Halophytic forage and seed products can replace conventional ingredients in animal feeding systems, with some restrictions on their use due to partially high salt content and antinutritional compounds present in some species (Khan and Duke, 2009).

The facultative halophytic species such as Quinoa, with a high protein content and unique amino acid composition can successfully be cultivated in saline lands. Quinoa (*Chenopodium quinoa* Willd.) is an edible seed species of the family Chenopodeaceae, which originates from the Andean region of South America, and has dietary importance due to its richness in proteins, fiber and fat, and gluten free characteristics. Quinoa has considerable resistance to several important stresses including drought, frost and high soil salt content. In recent years, quinoa has received worldwide attention as a multi-purpose agro-industrial crop that can thrive in marginal environments characterized by poor soils and poor-quality irrigation water (ICBA, 2014).

Timothy et al. (2015) suggests that selecting plants tolerant to salinity is an alternative strategy for a sustainable agriculture in saline degraded soil lands. Meanwhile, soil reclamation could be done using bioremediation method through planting halophyte plant which can absorb salt from soil and utilize these plants as fodder. According to Khan and Duke (2001), the use of halophytic plants in pasture and fodder production on saline soils is the best economically feasible solution.

Studies conducted by ICBA (2014) have shown that high salinity tolerance ability of Atriplex makes it useful for use as feed source bioremediation to improve soil salinity. Their finding also indicates that soil salinity was improved by 40% under Atriplex treatment for one-year experiment. ICBA (2014) has also successfully investigated the benefits of growing Atriplex for feed production in highly salt-affected areas and valued as a high-protein animal feed.

In Ethiopia, there is wide area of barren and abandoned marginal lands that are commonly believed useless; on the contrary, a huge research and activity in the last decades has demonstrated their unsuspected value. Research is in progress in Ethiopia with the major aim of collecting and evaluating the potential of local halophytes for wide economic use in arid and semiarid regions in the light of the progressive shortage of fresh water resources and expanding soil salinization. Collection of halophytes made during 2016 from limited salt affected farm area of Middle Awash in Ethiopia indicates widely distributed halophyte species which is of interest because of existence of potential possibility for different economic uses under such environmental stress condition.

CONCLUSION AND FUTURE PERSPECTIVES

This paper suggests that biosaline agriculture is an economical and effective approach to use unproductive lands for growing different food and fodder crops in

Ethiopia. This approach, if prudently adapted, can help in improving livelihood of rural and pastoral communities of the salt-affected areas by enhancing feed and fodder production. This discussion reveals that there is an abundant unexplored and unexploited genetic variation that can be harnessed to improve the salt tolerance of field crop species. Through proper identification of field crop and fodder species and varieties that can tolerate soil salinization and poor irrigation water quality, productivity of marginal lands can be maximized. In Ethiopia, this approach is of special importance because of the following reasons:

(1) Pressing shortage of livestock feed is among major reasons claimed for low productivity gains from this sector. Forage production under saline soil conditions without competition of other farm land for field crops is important for Ethiopia to increase the productivity of livestock sector particularly for pastoral and agro-pastoral communities in the moisture stress dry regions. The aforementioned alternative crops, in addition to their tolerance to salinity and ameliorative effect, require less input to produce which make them promising candidates for the diversification of production system and economic use of marginal quality soil and water resources.

(2) Irrigated agriculture in Ethiopia faces the problems of waterlogging and soil salinization. Engineering solutions to overcome these problems are expensive and technically complex and often cause water pollution and environmental degradation. Therefore, bio-drainage can be a viable option to control the rising groundwater table above critical depth for crop growth. Exploring the possibility of bio-drainage for waterlogged saline lands through the plantation of salt tolerant trees can reduce the volume and cost of drainage.

(3) In Ethiopia, large tracts of agricultural lands have become barren and abandoned due to poor soil and water quality conditions. Since growth of normal crops in these areas has become difficult due to increasing soil salinity, plantation of halophytes can be a viable solution to produce food, fuel, fodder, fiber, essential oils, and medicine. At the same time, halophytes can be exploited as significant and major plant species bearing potential capability of desalination and restoration of saline soils through phytoremediation. By adopting these strategies, unused and marginal lands can be brought under cultivation to improve livelihood of poor rural communities.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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