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Project Report 6

FIELD EVALUATION OF SALT-TOLERANT FOOD AND FODDER CROPS IN ETHIOPIA AND SOUTH SUDAN

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REHABILITATION AND MANAGEMENT OF SALT-AFFECTED SOILS TO IMPROVE AGRICULTURAL PRODUCTIVITY (RAMSAP) IN ETHIOPIA AND SOUTH SUDAN

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Rehabilitation and management of salt-affected soils to improve
agricultural productivity in Ethiopia and South Sudan

INTERNATIONAL CENTER FOR BIOSALINE AGRICULTURE DUBAI – 2021

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This project is led by the International Center for Biosaline Agriculture (ICBA). It is being implemented with the Ministry of Agriculture, Ethiopia, Ethiopian Agricultural Research Institute (EIAR), and Directorate of Research and Training (DRT), South Sudan. The authors are highly grateful to Dr. Tarifa A. Alzaabi, Acting Director-General-ICBA, for her overall leadership and Ms. Seta Tutundjian, Director of Programs-ICBA, for her guidance during the execution of this project. We are thankful to H.E. Dr. Kaba Urgessa, State Minister of Agriculture, Ethiopia, Mr. Tefera Solomon, Director of Soil Fertility, Ministry of Agriculture, Ethiopia, and Dr. Victor Bennet, Director General, DRT-South-Sudan for their support during the execution of this project. The hard work and dedication of the research and field staff in South Sudan is highly appreciated.

ACRONYMS

ADF	Acid Detergent Fiber
ANOVA	Analysis of Variance
CEC	Cation Exchange Capacity
CP	Crude Protein
CRD	Completely Randomized Design
ECe	Electrical Conductivity of Soil Extract
ESP	Exchangeable Sodium Percentage
ETc	Crop Evapotranspiration
ETo	Reference Evapotranspiration
FAO	Food and Agricultural Organization
FTC	Farmers Teaching Center
GI	Germination Index
ICBA	International Center for Biosaline Agriculture
ILRI	International Livestock Research Institute
IvDMDC	invitro Dry Matter Digestibility Content
ME	Metabolizable Energy
MGT	Mean Germination Time
MoARC	Mekhoni Agricultural Research Center
MRS	Mekhoni Research Station
NDF	Neutral Detergent Fiber
RCBD	Randomized Complete Block Design
REST	Relief Society of Tigray
USSLS	United Stated Soil Laboratory Staff
WARC	Werer Agricultural Research Center
WRS	Werer Research Station

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EXECUTIVE SUMMARY

The Soil salinization has threatened the sustainability of crop production in the arid and semi-arid regions of Ethiopia, where livestock production is commonly practiced. Approximately 11 million hectares of land (i.e.,9% of the country's total landmass and 13% of the irrigated area) are salinized. The growing occurrence of salt-affected soils is affecting the productivity of irrigated lands and farm and livestock productivity. This problem directly or indirectly affects the livelihood of poor rural communities and the national economy. To meet future food security challenges, the introduction of salt-tolerant food and feed crops is becoming essential in most country areas because of salt accumulation on soil, restrictions on groundwater use, and saltwater intrusion into groundwater.

To meet food security challenges, transforming salt-affected soils into productive lands and preventing the spread of salinity in other areas is paramount in Ethiopia. In the low to moderate saline areas, excessive leaching and installing effective drainage systems can improve the degraded soils. Crop plants differ significantly in their ability to survive 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. In the high saline areas where the growth of regular field crops is problematic, soil reclamation can be done using chemicals and/or growing salt-tolerant plant species (bioremediation approach).

The Biosaline approach is based on adaptable technology packages composed of salt-tolerant fodders and halophytes integrated with livestock and appropriate management systems (irrigation management, soil fertility, etc.). These integrated crop-forage-livestock feeding systems can increase the resilience of smallscale crop-livestock farms, particularly in Ethiopia, where the livelihood of smallholder farmers is mainly dependent on the development of the livestock sector. The biological approach is one of the most straightforward approaches to reclamation and management of salt-affected soil, especially for smallholder farmers who do not have the resources to implement costlier corrective measures.

ICBA-RASMAP project has generated and disseminated sustainable integrated crop-livestock packages to diversify incomes of smallholder farmers through the sale of animal products and forages to local markets, thus making the production systems economically feasible. However, salt-tolerant forage plants are variable in biomass production and nutritional value. Most of the available salt-tolerant forages have not been selected or managed for improved livestock production. For this reason, they need to be tested locally for their (a) edible biomass production (kg/ha/year); (b) nutritional value of edible biomass (i.e., the response in animal production per unit of voluntary feeding intake), and (c) the use of micronutrients and nutraceutical properties. Under this project, more than 25 genotypes of different crop and forage genotypes have been tested to evaluate their suitability for salt-affected lands of Ethiopia. These include Barley, Cowpea, Lablab, Pearl Millet, Sorghum, Quinoa, Sesbania, Rhoades grass, Panicum, etc. The experiments have been conducted in four regions of Ethiopia (Amhara, Afar, Oromia, and Tigray), both under control environment and field conditions. This report presents the results of these trials for extension workers and farmers to choose the right crop for their soils and climatic conditions.

Adaptations have also been shown at the Farmers Training Centers (FTCs) and volunteer farmers' plots in collaboration with the national partners. A representative number of farms solely managed by women were also selected for field trials. These trials were also used for demonstration purposes before scaling up. These trials focus on the critical question of which soil constraints most limit plant growth. Comparisons are made between the growth and productivity of a range of salt-tolerant germplasms of different economically feasible salt-tolerant forage species. The project team has jointly selected and implemented the best management practices for salinity control at the farm level.

01

INTRODUCTION

Salt-affected soils are becoming a serious threat to crop production in the arid and semi-arid irrigated areas of the world (Frew et al., 2015). To meet food security challenges, transforming salt-affected soils into productive lands and preventing the spread of salinity in other areas is vital. In less saline areas, excessive leaching and installing effective drainage systems can improve the degraded soils. Plants differ significantly in their ability to survive when grown in saline soils. Information on the relative tolerance of crops to a soil salinity is of practical importance in planning cropping patterns for optimum returns. In the high saline areas where the growth of regular field crops is problematic, soil reclamation can be done using chemicals and/or growing salt-tolerant plant species (bioremediation approach) (Singh et al., 1999).

Agriculture is an important sector both in Ethiopia and South Sudan, like many other Sub-Sahara African countries. In Ethiopia, this sector supports 80 percent of the workforce, whereas 85 percent of the total population living in rural areas is directly or indirectly dependent on agriculture for their food security and livelihood. The 7 million smallholder farmers of Ethiopia are responsible for producing more than 95 percent 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 large livestock capital i.e., cattle, sheep, goats, and camels (Ahsenafi and Bobe, 2016). Despite this high biodiversity and distinctive ecosystems, food shortages are widespread, and there have been recurrent droughts and subsequent food crises almost every decade since the 1970s. However, drought was not the only cause of recent suffering and famine in the country. Other factors such as high population growth, lack of technological changes, and accelerating the environment's degradation also led to stagnation or even decline in crop yields.

In South Sudan, agriculture account for 36 percent of the non-oil GDP, with 80 percent of the population living in rural areas largely dependent on subsistence farming and 75 percent of the households consuming cereals as a central part of their daily diet. Despite abundant water supplies, only 5 percent of the total 30 million ha arable land is cultivated. Crop yields are meager, which negatively affects the incomes and livelihood of poor farmers. Lack of agricultural inputs such as seed and fertilizer, low advisory services, and inefficient irrigation management are considered major barriers. Although South Sudan has the highest livestock per capita globally, with 23 million head of cattle, sheep, and goats, there is little use of improved varieties of seed for livestock breeding. There is a strong need for new, improved forage varieties that are resistant to common diseases. The salt-affected lands in South Sudan are in the White Nile irrigation schemes. These areas' agricultural potential has not been utilized despite freshwater availability from the Nile River. Furthermore, low groundwater quality around Malakal and isolated regions also cause salinity.

With a 3% average population growth in these countries, future food security and the livelihood source for a considerable portion of the population remains a challenge to the governments. 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 can increase their agricultural productivity and farm incomes if their technical and financial capacity is enhanced. They need guidance on the improved irrigation and salinity management and access to modified salt-tolerant seeds for crops and forages.

The areas of low to moderate salinity levels can be restored by improving 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 of salt-tolerant fodders and halophytes integrated with livestock and appropriate management systems. These integrated crop-forage-livestock feeding systems can increase resilience of smallholder farmers who are largely dependent on the livestock sector.

Ethiopia stands first in Africa in the extent of salt-affected soils, with an estimated 11 million ha (Mha) of land exposed to salinity (FAO, 1988). This corresponds to 9% of the total landmass and 13% of irrigated area of the country (Birhane, 2017). These soils are concentrated in the Rift Valley, Wabi Shebelle River Basin, the Denakil Plains, and other lowlands and valleys, where 10% of the population lives (Sileshi, 2015). The Awash Valley and the lower plains are dominated by salt-affected soils (Tena, 2002). For example, soil salinity has caused substantial desertion of banana plantations and showed a dramatic spread to the adjacent cotton plantation of Melka Sadi Farm (Hailay et al., 2000). A study by Kidane et al. (2006) also indicates that, of the entire Abaya State Farm, 30% has already been affected by salinity.

The problems of soil salinization in Ethiopia and South Sudan are expected to be severe in the years to come. Under the prevailing situation, there is a tendency to introduce and implement large-scale irrigated agriculture to increase agricultural productivity (Tekalign et al., 1996). In the absence of efficient irrigated water management, the salt build-up is inevitable. The growing prevalence of these soils is undermining the sustainability of irrigated agriculture, reducing natural biodiversity and farm and livestock productivity in the country (Singh, 1989).

In the Ethiopian Rift valley agricultural system, the primary sources of salts are shallow groundwater levels, natural saline seeps, and marine origin. The development of large irrigation schemes at middle and lower Awash Valley without appropriate drainage systems and poor irrigation management practices have resulted in the gradual rise of saline groundwater. The high evapotranspiration rates in many areas cause secondary salinization (Frew et al., 2015). If the current irrigation practices continue, salinity problems will further exacerbate. Therefore, there is a need to take measures to control the spread of soil salinity. The possible solution is either using physical practices (irrigation frequency and leaching, irrigation methods, cyclic use of multi-quality waters, fertility management, and amendments) or biological practices (attainment of salt-tolerant species and cultivating through biological approaches) (Gupta and Minhas, 1993).

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 can increase the resilience of small-scale crop-livestock farms, particularly in Ethiopia and South Sudan, where the livelihood of smallholder farmers is mainly dependent on the development of the livestock sector. The biological approach is one of the most simple and low-cost approaches for the reclamation of salt-affected soil, especially for smallholder farmers who do not have the resources to adopt expensive measures. However, the success of bioremediation approaches depends on selecting suitable genotypes that have the potential to tolerate abiotic stresses. In addition to this, improvement of degraded soil can be achieved either by using different chemicals, using appropriate drainage systems, or growing salinity-alkalinity resistant plants (Garg, 1998). Salt-affected lands can also be utilized and ameliorated through the cautious use of plant species.

ICBA-RASMAP research project has been mindful of the magnitude of the current problem and its potential contribution to the development by solving the constraint through research, development of technology to control and mitigate salt-affected soils. Currently, the research project is working on addressing these urgent and pressing problems of natural resources degradation, especially salt-affected areas, on a sustainable basis. The introduction of salt-tolerant forage grasses can increase fodder production in the marginal lands because they can prevent salinity development by creating a mulching layer on the soil surface. This mulching layer prevents capillary movement of water upward, forcing plants to use water from lower soil layers through their rooting systems. This study was designed to evaluate the salt tolerance, biomass production, and nutrient composition of selected food and forage crops.

The project is intended to generate and disseminate sustainable integrated crop-livestock packages to diversify incomes of smallholder farmers through the sale of animal products and forages to local markets, thus making the production systems economically feasible. However, salt-tolerant forage plants are variable in biomass production and nutritional value. Most of the available salt-tolerant forages have not been utilized for improved livestock production. For this reason, they need to be tested locally for their (a) edible biomass production (kg/ha/year); (b) nutritional value of edible biomass (i.e., the response in animal production per unit of voluntary feeding intake), and (c) the use of micronutrients and nutraceutical properties.

Under this project, more than 20 genotypes of different crop and forage genotypes have been tested to evaluate their suitability for salt-affected lands of Ethiopia. These include Barley, Cowpea, Lablab, Pearl Millet, Sorghum, Quinoa, Sesbania, Rhoades grass, Panicum, etc. The experiments have been conducted in four regions of Ethiopia (Amhara, Afar, Oromia, and Tigray), both under control environment and field conditions. The experiments this report presents the results of these trials for extension workers and farmers to choose the right crop for their soils and climatic conditions.

The project has adopted a participatory approach to conduct field trials in different parts of Ethiopia to test the suitability of local and imported genetic resources (crop and forage species) to rehabilitate salt-affected soils. Adaptations have also been conducted at the Farmers Training Centers (FTCs) and volunteer farmers' plots in collaboration with the national partners. A representative number of farms (depending on the situation) solely managed by women have also been selected for field trials. These trials are also being used for demonstration purposes before scaling up. These trials focus on the critical question of which soil constraints most limit plant growth and when they have the most significant adverse effects on growth. Comparisons are made between the growth and productivity of a range of salt-tolerant germplasms of different economically feasible salt-tolerant forage species. The project team has jointly selected and implemented the best management practices for salinity control at the farm level.

02

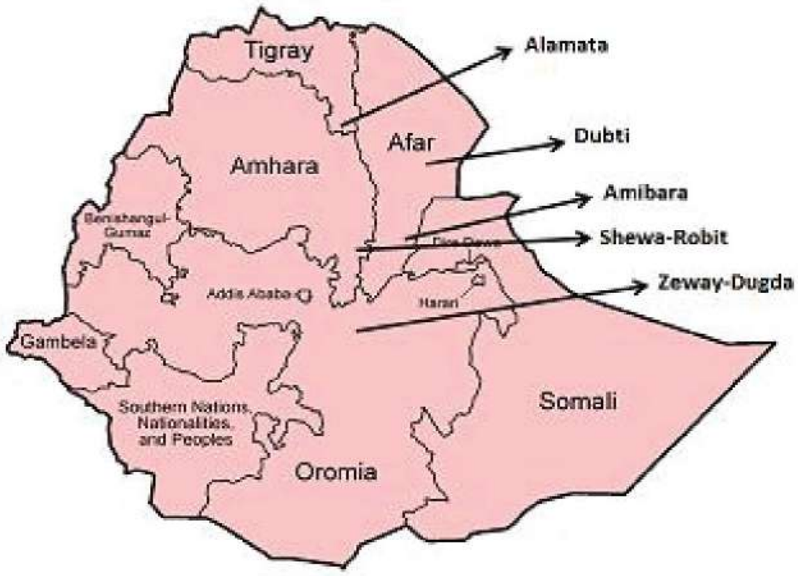
FIELD EVALUATIONS IN ETHIOPIA

2.1 Trial sites in Ethiopia

For Ethiopia, five locations were selected to establish field trials under this project, as shown below. These locations were chosen after due consultation with the representatives of the Ministry of Agriculture, research organizations, and research scientists. The selected areas include:

1. Amibara and Dubti in Afar regional state,
2. Zeway-Dugda in Oromiya regional state,
3. Shewa-Robit in Amhara regional state and
4. Alamata in Tigray regional state.

These sites are located within the East African Rift-Valley system representing different agro-climatic zones, which offer various options to test and grow potential salt-tolerant crops, forages, and cereals. The Land and Water Resources Research Institute conducted baseline surveys such as collecting water and soil samples for salinity analyses and undertaking socio-economic surveys to collect information on current farming systems and agricultural constraints conducting adaptation trials. Three Agricultural Research Centers of the EIAR, namely Werner, Debre-Zeit, and Mekhoni are responsible for conducting field trials.



These sites have been selected based on the following criterion.

- Marginal degraded lands with low due to poor agronomic and water management practices.
- Characterized by poor farm-households including rare cattle's and small ruminants
- Accessibility of the selected sites
- Availability of local partners and state government staff on the ground
- Availability of surface water and groundwater resources
- Overgrazing and deforestation have affected the soil structures of some of these sites.

The trials were conducted at the Werer Agricultural Research Center (WARC), Amibara district of the Afar region, and Mekhoni Agricultural Research Center (MoARC), Raya-Alamata district of the Tigray region. (Figure 1). WARC is located at an altitude of 740m above mean sea level between 9°12'80" N latitude and 40°15' 2" E longitude, While MoARC is situated at an altitude of 1520 meter above sea level between 12° 15' 11" and 12° 56' 54" Northing latitudes and 39° 14'35" and 39° 53' 25" Easting longitudes. The experiments were conducted

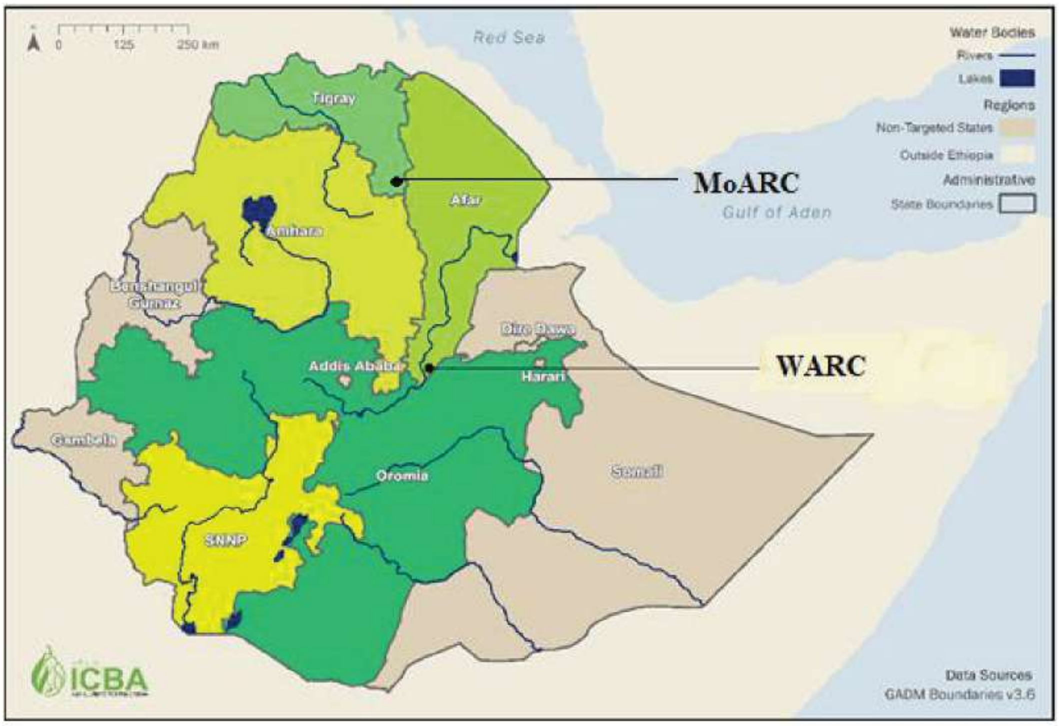


Figure 1. Map of Ethiopia with regional boundaries.

The field trial site (WARC) is semi-arid, with mean annual temperatures ranging between 19°C and 34°C (Figure 2). The mean yearly Class A pan evaporation is 2800mm, five times higher than the mean annual rainfall (570mm). The area consists of an extensive alluvial plain, which was historically formed by the deposits of the Awash River. The site has a flat topography with a slope gradient of 1–2%. The predominant soil types are weak-structured Vertisols and Fluvisols. The Vertisols are silty clay to clay, whereas Fluvisols are sandy loam to silty loam in texture. The constituents of Fluvisols are muscovite/illite clay minerals while Montmorillonite clay minerals dominate Vertisols.

Similarly, the MoARC is classified as dry land climates of semi-arid and arid types (REST, 1996). The annual rainfall, minimum and maximum temperatures collected from NMSA (1997-2016) show that it is 663.12 mm, 14.70 °C, and 28.17°C, respectively. The quaternary sediments vary widely in grain size and are dominantly deposited as fluvial processes (Tenalem et al., 2013). The primary soil types found in the district are Cambisols, Fluvisols, Leptosols, and Vertisols. Each soil covers 22.4, 19.8, 21.3, and 28.0% of the area, respectively (Amanuel et al., 2015).

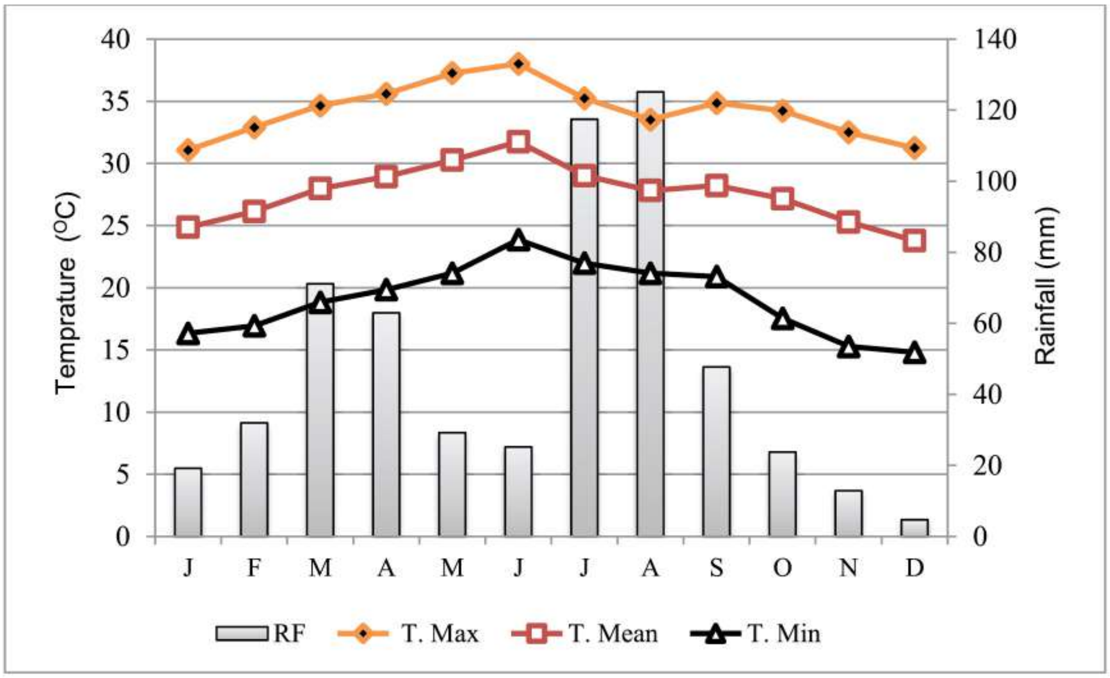


Figure 2. Mean monthly rainfall and temperatures at the field trial site.

2.2 Pot trials in a Lathouse

The pot trials under controlled conditions were conducted to generate more detailed information on the salt-tolerance level of different genotypes. Treatments include two factors: food and forage genotypes and salt stress levels. Four salt stress treatments were prepared by mixing 7.28 14.57, 21.43, and 29.14 g of NaCl into 6 kg of soil packed per pot to produce 5, 10, 15, and 20 dSm-1 salinity treatments. Genotypes of four food crops (Barley: 2 genotypes, Sorghum: 3 genotypes, two pear millet genotypes, and five Quinoa genotypes) and two forage crops (Cowpea: 3 genotypes and Sesabinia: 3 genotypes) were evaluated during these experiments to evaluate their tolerance under different soil salinity conditions. Treatments were factorial combined and arranged in a completely randomized design with three replications. Irrigations were applied according to crop evapotranspiration (ETc = ETo x Kc) values plus 10% for leaching requirements using good quality canal water (EC = 0.2 dSm-1). The reference evapotranspiration (ETo) was calculated with the modified Penman-Monteith equation (FAO-56) using climatic data collected from the field trial site. The crop coefficient (Kc) values were taken from the FAO-56 publication.

Five seeds of each selected forage and food crop were planted in each pot. Since the soils of the study area are good in nutrients, no fertilizer was used for these experiments. Emerged seedlings were counted at 5, 10, and 15 days after planting, and Mean germination time (MGT) and Germination Index (GI) were calculated according to the equation of Ellis and Roberts (1981) and Association of Official Seed Analysts (1983), respectively. Selected agronomic and physiologic traits which are highly affected by salinity were measured and recorded. At optimum harvesting time, seed grain yield and biomass yield were harvested and recorded. Chlorophyll (SPAD units) content was also measured. The plant samples were dried and grounded for analyzing crude protein (CP), neutral-detergent fiber (NDF), acid detergent fiber (ADF) and ash content using standard procedures (Van Soest et al., 1981; Kitcherside et al., 2000).

2.3 Field Trials

At Amibara, field trials were conducted in soils with ECe values ranging from 14.39-32.89 dSm-1, and ESP ranges from 15.45 to 24.28%. In contrast, in Field trials, the Raya-Alamata and Fentale district of Oromia was conducted at the soil with ECe values of 7 to 12 dSm-1 and ESP >15. A plot size of 3m x 4m was used for field experiments. Treatments were laid out in randomized complete block design (RCBD) with three replications. ICBA and locally available seeds of different crops were sown. Application of irrigation water and other agronomic practices were implemented following recommendations of the local research stations. After harvesting. agronomic and physiologic traits affected by salinity were measured and recorded.

Soil samples were collected from the experimental plots at a soil depth of 0-30 and analyzed for the different salinity and sodicity parameters. The soil bulk density was determined according to the methods described by (Blake, 1965). Soil pH and ECe were determined from saturated paste extract following the procedures described by FAO (1999). The exchangeable bases (Ca, Mg, Na, and K) were selected from neutral standard ammonium acetate extraction, Ca, and Mg from EDTA titration method. At the same time, K and Na were determined by a flame photometer. All exchangeable bases were expressed as cmol (+) kg-1 soil. According to the percolation tube procedure, the soils' cation exchange capacity (CEC) was determined by the neutral standard ammonium acetate method (Van Reeuwijk, 1992). ESP was computed as the percentage of the exchangeable Na to the CEC of the soil (USSLS, 1954).

2.4 Experimental design for field trials

The following information from field trials was collected for screening genotypes of various crops.

- Information about soil salinity/sodicity levels in the potential areas
- Water salinity/sodicity levels (irrigation water)

Steps for the screening trials and data collection

Step 1: *Set up of field trial of selected genotypes*

- The site selection and preparation (leveling, making beds, etc.) are based on the experimental design as suggested below.
- Selected field trial sites with different salinity levels, e.g., ECe of 3, 6, and 9 or 2, 4 and 8
- Record salinity (ECe) of the experimental plot up to a depth of 1 m (15, 30, 60, 90 cm depths).
- Arrangement of water and set up of irrigation system
- Sowing of seeds of different genotypes
- Apply recommended doses of fertilizers (NPK) – band placement

Step 2: *Water application*

- Calculate evapotranspiration (ET) of the crop/plant for different plant growth stages using standard methods and apply irrigation water based on these ET values
- Develop irrigation schedules and irrigate crops according to this schedule
- Measure each irrigation (discharge, time of application, source of water)
- Note down the date and volume of each irrigation.
- Note down the quality of irrigation water applied (freshwater, saline water----ECw)

Step 4: *Agronomic parameters*

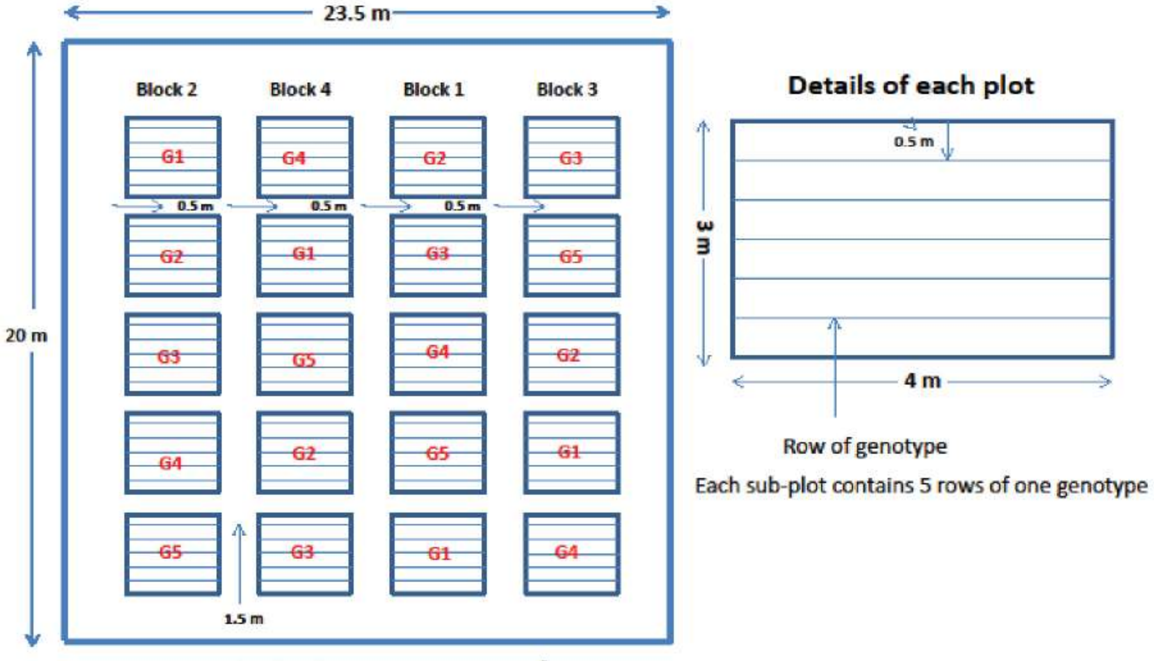
- Record sowing date, harvesting date, soil preparation records, amounts and timing of fertilizer and seed application, soil amendments if any, etc.)
- Record plant growth parameters (tillers, height) on a regular interval (e.g., after every 15 days)
- After harvesting, record fresh and dry biomass and weight of grains

Step 5: *Economics of experiment*

- Record total cost of establishing field trail. This should include soil preparation, costs of fertilizer, cost of irrigation application, labor costs, land rent if any, etc.
- Record also running cost of field experiment (labor needed for weeding, harvesting, fencing etc.)
- At the end, we will perform benefit/cost analysis

For each genotype, a plot size of 3m x 4m was prepared. There were five rows of genotype plants in each sub-plot. A Completely Randomized Block Design (CRBD) with three replications was used for the field trials. Each subplot was separated by 0.5 m distance, and each row of sub-plots was separated by 1.5 m to minimize the influence of different treatments.

Genotype screening experiment layout



Main plot size = 23.5 x 20 = 470 m^2
Sub=plot size = 4 x 3 = 12 m^2

ICBA provided the seeds of the salt-tolerant food and fodder crops for testing under local soil and climatic conditions before being recommended for scaling up. These salt-tolerant varieties and accessions are already tested in other marginal farming systems (e.g., the MENA region).

Common name	Scientific name	ID	Origin
Barley	*Hordium vulgare*	CM72	Egypt, Ethiopia, Tibet
Barley	*Hordium vulgare*	58/1A	Egypt, Ethiopia, Tibet
Cowpea	*Vigna unguiculata*	TVU9716	Africa, Latin America, South Asia
Cowpea	*Vigna unguiculata*	ILRI-9643	Africa, Latin America, South Asia
Cowpea	*Vigna unguiculata*	ILRI-9334	Africa, Latin America, South Asia
Cowpea	*Vigna unguiculata*	ILRI-12713	Africa, Latin America, South Asia
Sesbania	*Sesbabia sesban*	ILRI 9643	Tropical Africa and Asia
Sesbania	*Sesbabia sesban*	ILRI 1178	Tropical Africa and Asia
Sesbania	*Sesbabia sesban*	ILRI 1198	Tropical Africa and Asia
Sorghum	*Sorghum bicolar*	ICSV700	Northeastern Africa
Sorghum	*Sorghum bicolar*	ICSR93034	Northeastern Africa
Pearl Millet	*Pennisetum glauccum*	IP13150	Sahel zone of West Africa
Pearl Millet	*Pennisetum glauccum*	IP19586	Sahel zone of West Africa
Quinoa	*Chenepodium quinoa*	ICBA-Q1	Latin America
Quinoa	*Chenepodium quinoa*	ICBA-Q2	Latin America
Quinoa	*Chenepodium quinoa*	ICBA-Q3	Latin America
Quinoa	*Chenepodium quinoa*	ICBA-Q4	Latin America
Quinoa	*Chenepodium quinoa*	ICBA-Q5	Latin America

addition to the above crop varieties, two genotypes of Sesabinia Sesban (ILRI-1198; ILRI-1178), three genotypes of Rhoades grass (CV-Massaba; ILRI-6633; ILRI-7384), and three genotypes of Lablab purpuerus (Local cultivar; ILRI-184T; ILRI-6529T) were also introduced and tested in the field. The salt-tolerant grasses such as Cenchrus ciliaris and Blue Panicum were also demonstrated to farmers through the establishment of the farmer field days.

2.5 Statistical Analysis

addition to the above crop varieties, two genotypes of Sesabinia Sesban (ILRI-1198; ILRI-1178), three genotypes of Rhoades grass (CV-Massaba; ILRI-6633; ILRI-7384), and three genotypes of Lablab purpuerus (Local cultivar; ILRI-184T; ILRI-6529T) were also introduced and tested in the field. The salt-tolerant grasses such as Cenchrus ciliaris and Blue Panicum were also demonstrated to farmers through the establishment of the farmer field days.

03

RESULTS OF FIELD TRIALS

3.1 Barley genotype screening under control conditions

The increasing salt stress delayed the mean germination time (MGT) of all genotypes. The highest MGT for both genotypes was observed at 20 dSm-1 at Werer Research Stations (WRS). However, the MGT of CM-58/1A genotype was less affected under high salt stress conditions in the Mekhoni Research Station (MRS). Salt stress also negatively affects the Germination Index (GI) of both barley genotypes (Table 1). The reduction was more pronounced at the higher salinity levels (20 dSm-1). Kaya et al. (2008) and Khan et al. (2009) have reported

Table 3. Typology of irrigation based on the size of the irrigated area.

Parameters	Genotypes	NaCl salinity level (dSm^{-1})					LSD $(p \leq 0.05)$	CV (%)
		0	5	10	15	20		
		Werer Research Station (Amibara)						
TGP (%)	CM-72	93.33	86.67	83.33	63.33	50.00	7.63	8.66
	CM-58/1A	86.67	86.67	66.67	56.67	53.33		
MGT (days)	CM-72	3.61	4.83	6.72	7.44	8.77	0.69	9.51
	CM-58/1A	3.77	4.27	5.33	7.56	7.86		
GI	CM-72	2.86	2.01	1.32	0.92	0.67	0.21	12.34
	CM-58/1A	2.34	1.84	1.05	0.81	0.69		
		Mekhoni Research Station (Raya-Alamata)						
TGP (%)	CM-72	80.00	-	70.00	60.00	53.33	21.3	4.66
	CM-58/1A	76.67	-	70.00	60.00	60.00		
MGT (days)	CM-72	5.58	-	7.33	7.50	7.33	10.60	6.21
	CM-58/1A	5.67	-	7.17	7.75	8.00		
GI	CM-72	1.44	-	0.97	0.79	0.67	30.84	8.54
	CM-58/1A	1.42	-	0.93	0.84	0.73		

TGP= Total Germination Percentage; MGT= Mean Germination Time; GI= Germination Index

Results indicate a decrease in plant height with increasing salinity levels. In control, plant height varied between 62.67cm for CM-72 to 58.50cm for CM-58/1A at both locations. At higher salt concentration (20 dSm-1), plant height of CM-72 genotypes (30.17cm) was higher than CM-58/1A genotype (27.23cm) at WRS (Table 2).

Table 2. Effects of salinity on plant height on two Barley genotypes.

Parameters	Genotypes	NaCl salt level (dSm^{-1})					LSD $(p \leq 0.05)$	CV (%)
		0	5	10	15	20		
		Werer research Station (Amibara)						
Plant Height (cm)	CM-72	62.67	57.73	51.80	43.47	30.17	4.09	7.09
	CM-58/1A	58.50	55.93	49.03	39.17	27.23		
		Mekhoni research Station (Raya-Alamata)						
Plant Height (cm)	CM-72	38.00	-	31.00	28.33	25.00	2.18	15.07
	CM-58/1A	33.33	-	33.00	33.33	33.00		

However, at MRS, CM-58/1A genotype performed better than the CM-72 genotype at higher salt concentration (20 dSm-1). These results agree with the findings of Ashraf et al. (2005, 2006).

Increased salt stress reduced fresh biomass yield in both barley genotypes, although the decrease was smaller in the CM-72 genotype. The highest reduction in fresh biomass yield per unit increase in salinity (1 dSm-1)was recorded in CM-58/1Agenotype at WRS (Figure 3: A, B). Thehighest reduction in fresh biomass per unit increase in salinity (1 dSm-1) for the CM-72 genotype was recorded at MRS (Figure 3: C, D). This was probably because the high salt concentration in the nutrient medium causes stunted growth in plants (Cherian et al., 1999; Takemura et al., 2000; Ashraf et al., 2005). The increased soil salinity causes a reduction in leaf area expansion (Wang and Nil, 2000), which results in decreased fresh and dry weights of the shoot, leaves, and roots

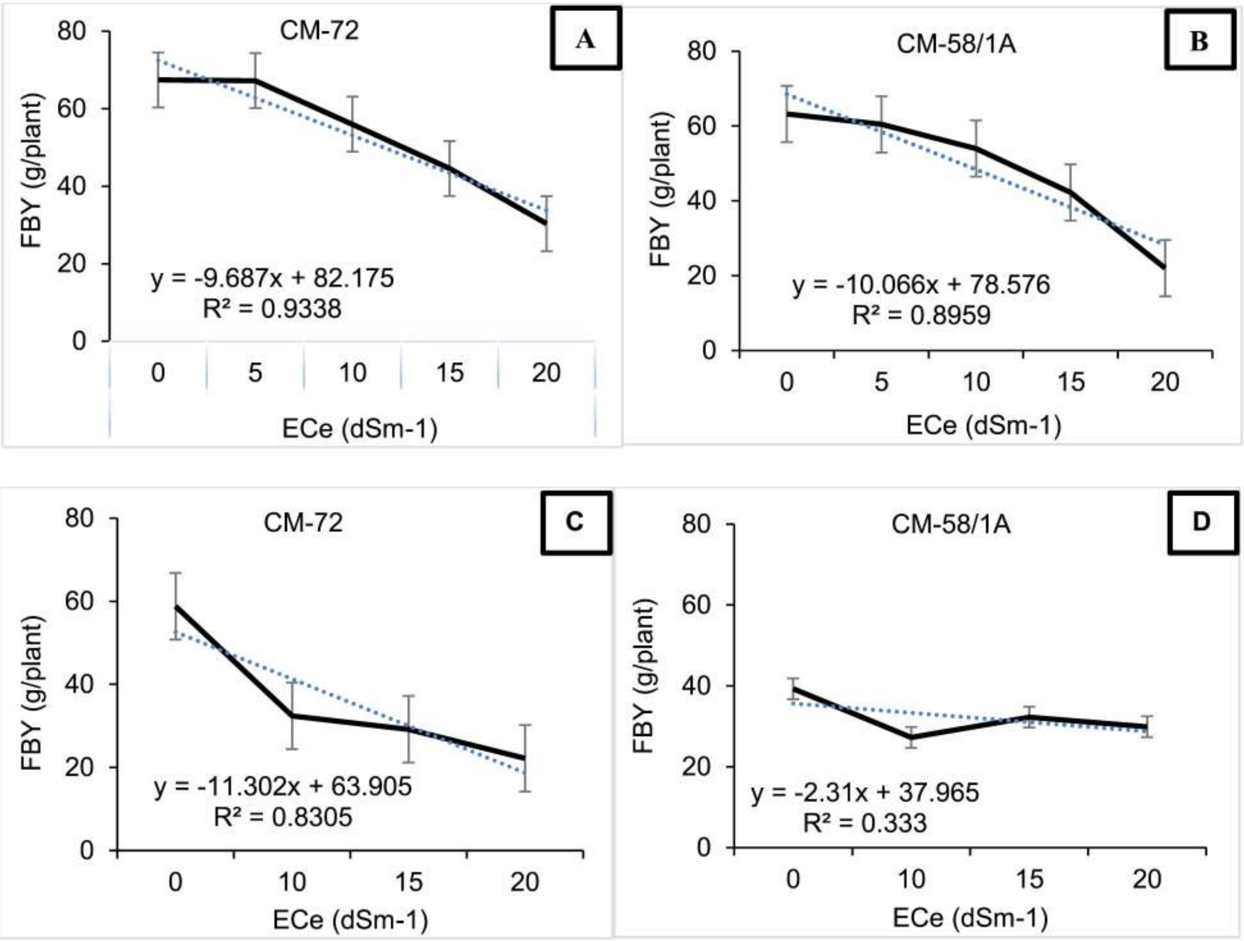


Figure 3. Effects of salinity on FBY of two Barley genotypes (A & B – WRS; C & D – MRS).

The effect of salinity on grain yield of two barley genotypes at WRS is shown in Figure 4. The grain yields were not collected from the Mekhoni research station. The yield reduction was more pronounced at higher salt concentrations. The decrease in grain yield per unit increase in salinity (1 dSm-1) was lower in CM¬58/1A genotype compared to the CM-72 genotype.

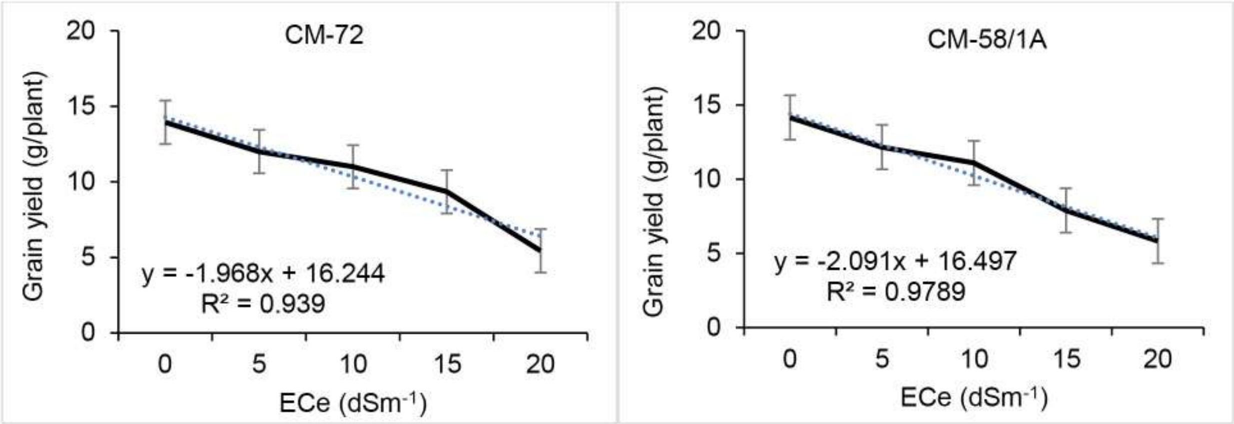


Figure 4. Effects of salinity on grain yield of two Barley genotypes at WRS.

3.2 Barley genotypes screening under field conditions

Under field conditions, barley genotypes showed significant differences in grain yield, dry biomass yield, and spike length. However, differences in days to 50% emergency, days to 50% maturity, number of tillers per plant, and plant height were non-significant (Table 3). The CM-72 genotype performed superior in terms of grain yield compared to CM-58/1A. However, the highest dry biomass yield was recorded in CM-58/1A. Both genotypes performed better at MoARS compared to WRS. This shows that these genotypes are suitable for the less saline and wet region than dry, hot, and saline areas. The physio-chemical properties of the soils of the field trials site at WRS are given in Table 4.

Table 3. Field evaluation of salt-tolerant barley genotypes.

Barley genotypes	DE (days)	DM (days)	PH (cm)	NT (#)	SL (cm)	DBY (tha^{-1})	GY (Kgha^{-1})
Werer Research Station (Amibara)							
CM-58/1A	9.33	84.33	72.33	4.67	6.80^{b}	4.23^{a}	0.70
CM-72	7.67	93.67	76.26	6.00	8.07^{a}	3.54^{b}	1.16
LSD ($P<0.05$)	NS	NS	NS	NS	1.24	0.44	NS
CV (%)	14.80	10.20	14.58	13.57	7.65	9.14	13.18
Mekhoni Research Station (Raya-Alamata)							
CM-58/1A	8.00	87.95	32.50	6.00	3.00	52.50	1.49
CM-72	9.00	99.50	32.00	3.00	5.25	23.95	3.36
LSD ($P<0.05$)	NS	NS	NS	4.75	6.42	5.20	5.11
CV (%)	9.60	10.04	12.68	22.22	17.45	24.15	24.90

DE= Days to 50% Emergency; DM= Days to 50% Maturity; NT = No. of Tillers per plant; PH = Plant Height; SL = Spike Length; DBY= Dry Biomass Yield; GY= Grain Yield.

Table 4. Physio-chemical properties of the soil at the field trial site of WRS

Barley varieties	Soil depth	pH	ECe (dSm^{-1})	Exchangeable bases (cmol (+) Kg^{-1})			CEC (cmol $_{(+)}$ Kg^{-1})	ESP (%)	BD (g cm^{-3})
				Ca+Mg	Na	K			
CM-58/1A	0-30	7.8	17.35	37.94	8.04	0.94	42.06	19.12	1.37
CM-72	0-30	7.9	16.84	38.62	8.98	0.87	43.57	20.61	1.36

Barley field trials on the salt-affected lands of Ethiopia

3.3 Quinoa genotypes screening under control conditions

For all genotypes of Quinoa, increasing salinity significantly affected seed germination percentage (GP), mean germination time (MGT), and germination index (GI). The GP of ICBA-Q1 and ICBA-Q2 genotypes were affected more under higher salt concentration levels (Table 5). The highest increase in MGT was observed in ICBA-Q1 at 20 dSm-1, whereas the lowest was recorded in ICBA-Q3 at 0 dSm-1. Salt stress also affected the GI of Quinoa genotypes in the Mekhoni research station (Table 6). The reduction was more pronounced at the higher salinity levels (20 dSm-1). The salinity inhibits germination of seeds in one of two ways: (1) preventing germination without loss of viability at higher salinities; and (2) delaying germination of seeds at higher salinity stress (Gulzar et al., 2001).

Table 5. Effects of salinity on TGP, MGT, and GI of five Quinoa genotypes at WRS

Parameters	Genotypes	NaCl salt level (dSm^{-1})					LSD ($p \leq 0.05$)	CV (%)
		0	5	10	15	20		
Total Germination Percentage (%)	ICBA-Q1	36.67	23.33	10.00	16.67	10.00	6.00	17.93
	ICBA-Q2	16.67	16.67	13.33	20.00	16.67		
	ICBA-Q3	83.33	80.00	63.33	53.33	33.33		
	ICBA-Q4	83.33	83.33	56.67	60.00	40.00		
	ICBA-Q5	83.33	86.67	63.33	53.33	36.67		
Mean Germination Time (days)	ICBA-Q1	2.67	3.27	5.88	8.33	13.05	0.52	11.28
	ICBA-Q2	3.11	3.33	5.66	8.50	12.33		
	ICBA-Q3	2.61	3.83	5.27	5.77	10.27		
	ICBA-Q4	3.00	4.33	5.61	7.22	10.94		
	ICBA-Q5	3.16	4.33	5.67	8.07	10.27		
Germination Index (GI)	ICBA-Q1	1.01	0.45	0.23	0.24	0.10	0.22	26.84
	ICBA-Q2	0.31	0.21	0.19	0.23	0.24		
	ICBA-Q3	2.38	2.17	1.57	0.95	0.72		
	ICBA-Q4	2.02	2.32	2.01	1.10	0.76		
	ICBA-Q5	2.59	2.51	1.92	1.25	0.94		

Table 6. Effects of salinity on TGP, MGT and GI of five Quinoa genotypes at MoARS.

Parameters	Quinoa genotypes	NaCl salt level (dSm^{-1})				LSD ($p \leq 0.05$)	CV (%)
		0	10	15	20		
Total Germination Percentage (%)	ICBA-Q3	76.67	70.00	63.33	60.00	18.50	5.11
	ICBA-Q4	80.00	70.00	60.00	60.00		
	ICBA-Q5	73.33	70.00	60.00	56.67		
Mean Germination Time (days)	ICBA-Q3	5.83	7.00	7.00	7.42	10.11	4.41
	ICBA-Q4	6.00	7.08	7.08	7.42		
	ICBA-Q5	5.83	7.08	7.08	7.58		
Germination Index (GI)	ICBA-Q3	1.40	1.03	0.79	0.73	39.31	7.57
	ICBA-Q4	1.37	1.02	0.78	0.73		
	ICBA-Q5	1.40	1.02	0.78	0.71		

Results also indicate a decreasing trend in the plant height with increased salinity for all Quinoa genotypes. In control (0 dSm-1), plant height varied between 92.67cm (ICBA-Q3) and 70.00cm (ICBA-Q5) at WRS and between 55.33cm (ICBA-Q3) and 48.33cm (ICBA-Q4) at MoARS. At the highest soil salinity (20 dS m-1), the maximum plant height was observed in ICBA-Q3 (54.66cm) and (37.0cm) at WRS MoARS, respectively. The lowest plant height was found in ICBA-Q5 and ICBA-Q4 at both experimental sites (Table 7). These findings agree with Jeannette et al. (2002) and Kagan et al. (2010), who reported a significant reduction in plant height

Table 7. Effects of salinity on plant height of five Quinoa genotypes.

Parameters	Genotypes	NaCl salt level (dSm^{-1})					LSD ($p \leq 0.05$)	CV (%)
		0	5	10	15	20		
Werer Research Station (Amibara)								
Plant height (cm)	ICBA-Q1	78.67	77.00	77.67	71.67	52.47	4.01	8.05
	ICBA-Q2	68.33	67.67	67.33	63.67	48.33		
	ICBA-Q3	92. 67	84.00	74.67	63.00	54.66		
	ICBA-Q4	92. 33	85.00	69.47	59.33	51.00		
	ICBA-Q5	70.00	65.33	60.67	56.00	45.67		
Mekhoni Research Station (Raya-Alamata)								
Plant height (cm)	ICBA-Q3	55.67	-	50.00	44.00	37.00	15.03	8.71
	ICBA-Q4	48.33	-	39.33	34.67	25.33		
	ICBA-Q5	50.33	-	41.67	36.67	31.33		

Increased salt stress level also reduced the dry biomass yield in five Quinoa genotypes, although the reduction was less in ICBA-Q1 and ICBA-Q5 at both research stations. The highest reduction in dry biomass yield per unit (1 dSm-1) salinity increase was found in ICBA-Q3 at Werer and ICBA-Q5 at Mekhoni research station (Figures 5 and 6). This was probably due to the stunted growth of plants caused by high salinity in the nutrient medium (Cherian et al., 1999; Takemura et al., 2000). The higher salt stress causes a reduction in the rate of leaf surface expansion (Wang and Nil, 2000), which results in a considerable decrease in the fresh and dry weights of the shoot, leaves, and roots (Chartzoulakis and Klapaki, 2000; Ashraf et al., 2005).

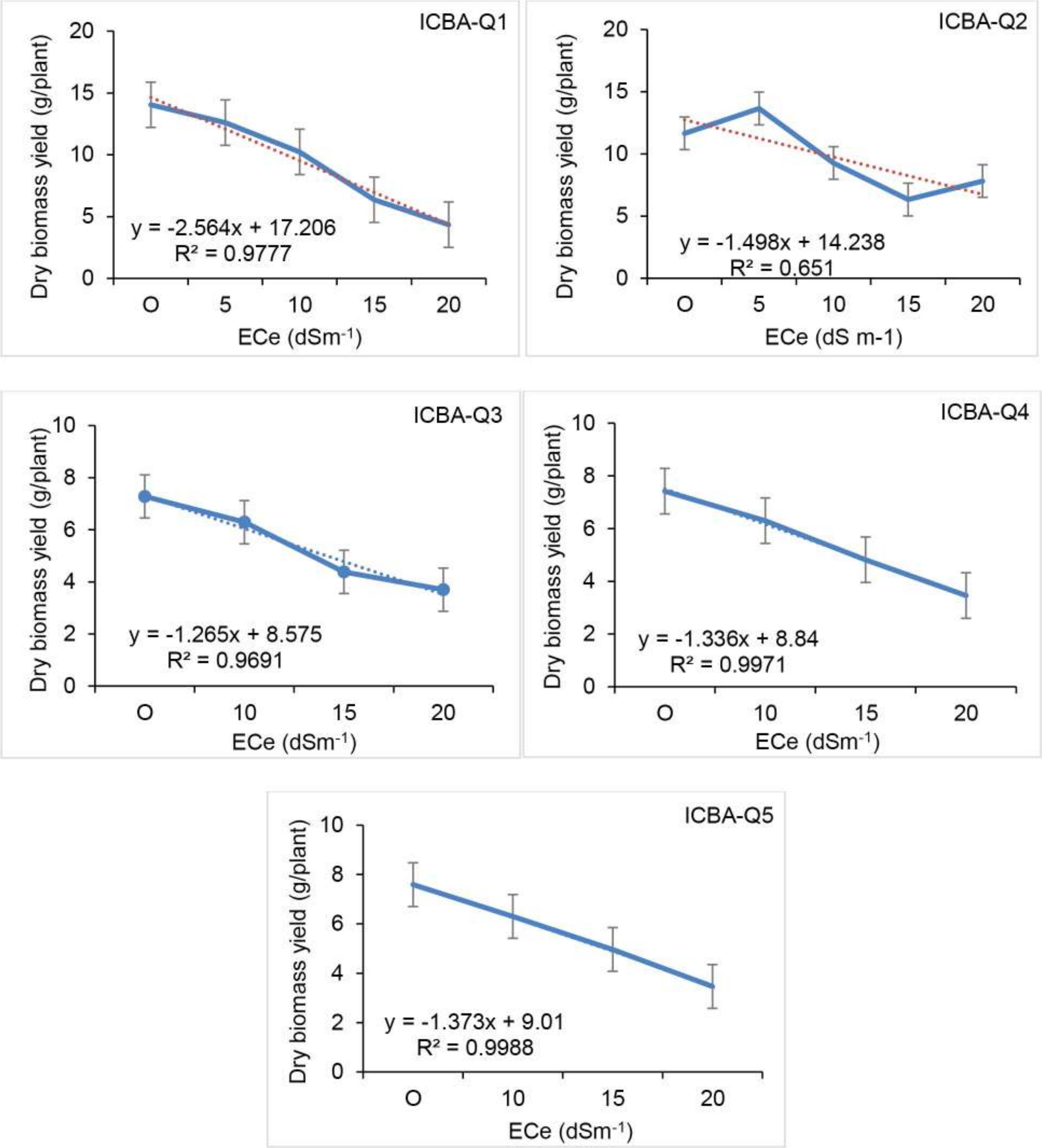


Figure 5. Effects of salinity on dry biomass yield of Quinoa genotypes at MRS.

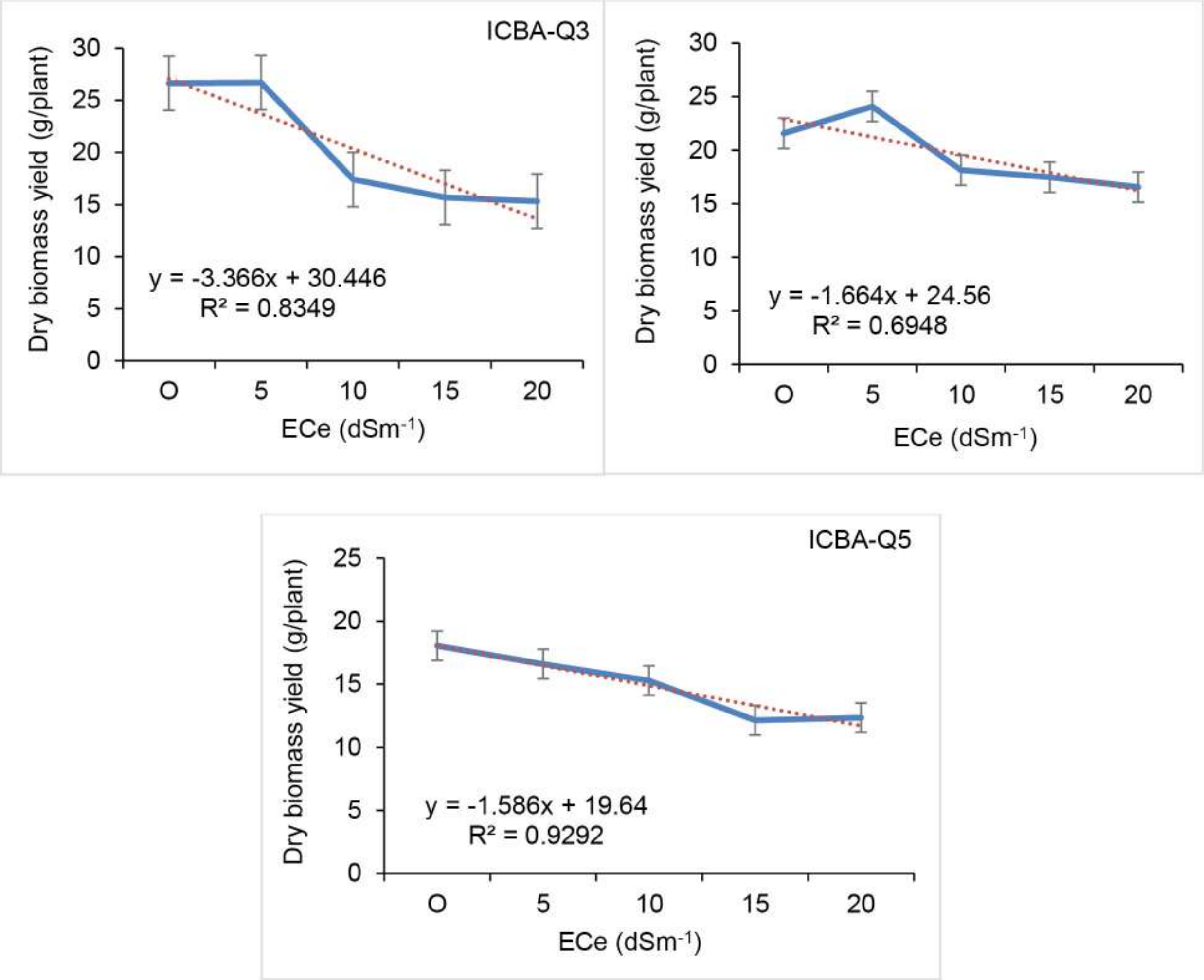


Figure 6. Effects of salinity on dry biomass yield of Quinoa genotypes at WRS.

Increased salinity levels reduced the grain yield in five Quinoa genotypes at the Werer research station. In contrast, the grain yield of Quinoa genotypes was not collected from the Mekhoni research station. However, the influence became pronounced with higher salt concentrations. Since ICBA-Q1 and ICBA-Q2 genotypes have poor germination, this implies low yielder genotypes; this lowest reduction per increase of 1 dSm-1 salt stress in grain yield was recorded. The highest reduction per increase of 1 dSm-1 salt stress in grain yield was recorded at ICBA-Q3 genotype followed by ICBA-Q4 genotype (Figure 7). Yet, ICBA Q3 high grain yielder genotype followed by ICBA-Q4 genotype than other ICBA Quinoa genotypes. These results agreed with those reported by (Jeannette et al., 2002 and Kagan et al., 2010).

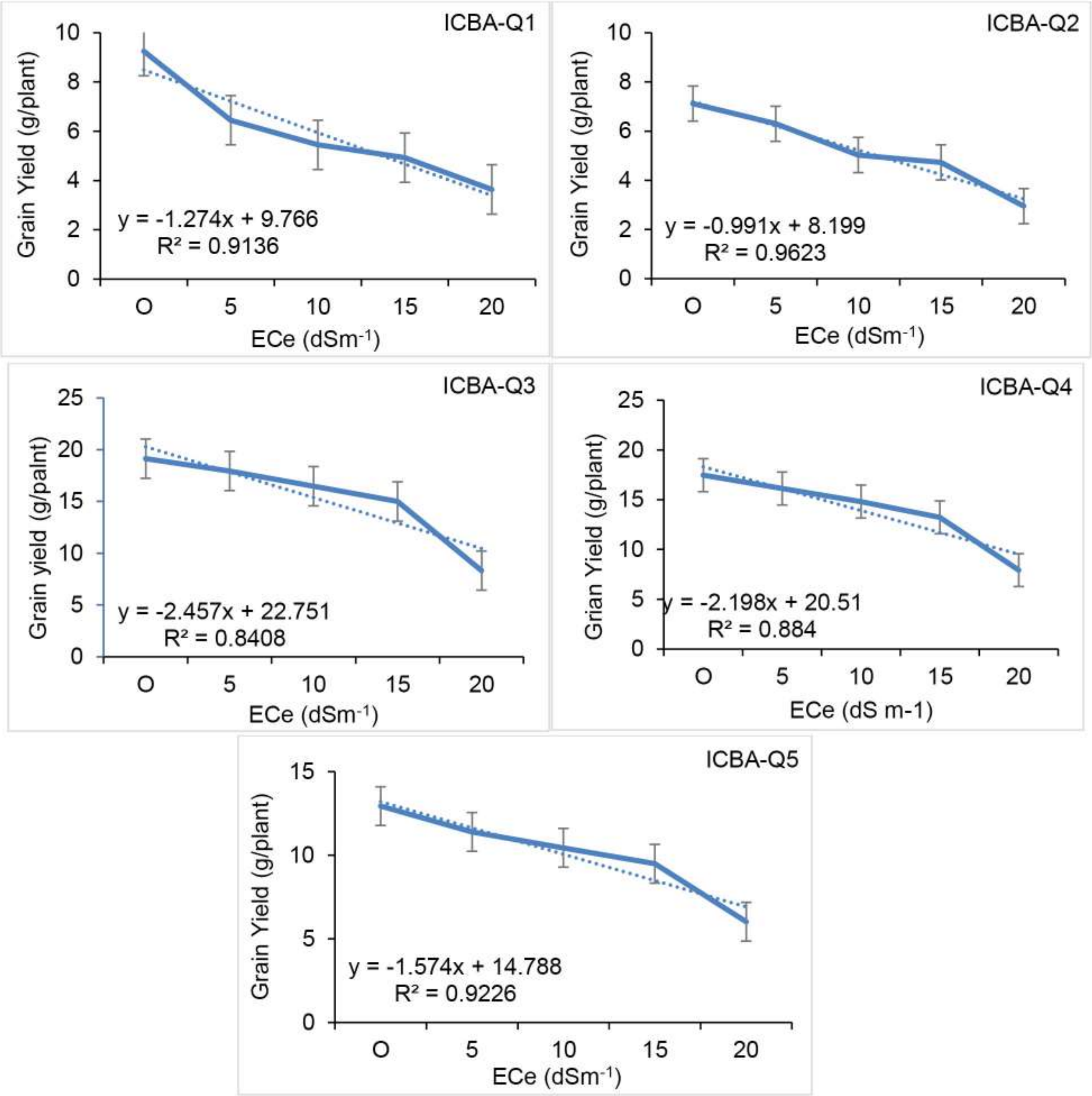


Figure 7. Effects of salinity on grain yield of Quinoa genotypes at WRS.

3.4 Quinoa genotypes screening under field conditions

The Quinoa genotypes showed a statistically significant difference in grain yield and other biophysical parameters at WRS. Among the newly introduced Quinoa genotypes, ICBA-Q3 gave higher grain and dry biomass yield, followed by ICBA-Q4 (Table 8). Other genotypes did not perform well. This was probably due to the limited supply of metabolites to young growing tissues because metabolic production occurs within the leaves and is significantly perturbed at high salt stress either due to the low water uptake or the toxic effect of NaCl concentration (Hassen et al., 2014). This implies that increasing salinity negatively affected the growth of Quinoa genotypes. At both research stations, ICBA-Q3 produced a higher grain yield compared to other genotypes. However, the grain yield produced by ICBA-Q3 at the Werer station was about 75% higher than the Mekhoni research station.

Table 8. Field evaluation of 5 salt-tolerant Quinoa genotypes.

Quinoa genotypes	DE (days)	DM (days)	PH (cm)	NPPP (days)	NDMS (days)	NDPG (days)	DBY (tha^{-1})	GY (kgha^{-1})
Werer Research Station (Amibara)								
ICBA-Q1	12.33	93.00	138.60	8.00	80.00	90.67	1.239	464
ICBA-Q2	12.00	94.33	148.77	8.00	78.33	89.67	1.291	499
ICBA-Q3	9.00	86.33	144.00	11.67	72.33	84.00	7.211	2965
ICBA-Q4	8.67	89.00	152.13	10.00	75.67	88.00	5.885	1644
ICBA-Q5	8.67	86.00	156.13	9.00	71.33	78.66	4.023	1559
LSD ($P<0.05$)	1.49	3.94	NS	1.41	NS	6.68	0.572	152
CV (%)	7.85	12.33	23.61	8.06	16.85	14.11	8.61	15.67
Mekhoni Research Station (Raya-Alamata)								
ICBA-Q3	8.66	84.66	110.67	8.33	71.00	84.00	5.444	1696
ICBA-Q4	10.00	91.00	118.67	7.33	77.67	89.33	4.185	1044
ICBA-Q5	9.66	78.33	93.00	9.00	69.33	79.00	3.556	1326
LSD ($P<0.05$)	NS	2.35	NS	NS	NS	NS	NS	80.70
CV (%)	9.34	5.98	22.00	23.63	8.23	8.76	39.45	11.72

DE = Days of 50% Emergence; DM = Days of 50% Maturity; PH = Plant Height; NPPP= No. of Panicles per Plant; NDMS = No. of days to Milky Stage; NDPG= No. of Days to Pasty Grain; DBY= Dry Biomass Yield; GY= Grain Yield.

The grain yields and dry biomass yield of ICBA-Q4 and ICBA-Q5 genotypes were comparable at both experimental stations. ICBA-Q3 was found to be superior for dry biomass and grain yield (Table 8).

Table 9. Soil physio-chemical properties of Werer field trial site.

Quinoa genotypes	Soil depth (cm)	pH	ECe (dSm^{-1})	Exchangeable bases (cmol $_{(+)}$ Kg^{-1})			CEC (cmol $_{(+)}$ Kg^{-1})	ESP (%)	BD (gcm^{-3})
				Ca+Mg	Na	K			
ICBA-Q1	0-30	7.9	19.32	36.94	8.00	1.04	41.16	19.44	1.38
ICBA-Q2	0-30	7.8	20.34	43.02	7.68	0.96	44.21	17.37	1.36
ICBA-Q3	0-30	8.0	20.01	38.83	9.67	1.01	39.83	24.28	1.37
ICBA-Q4	0-30	8.1	18.76	37.91	9.01	0.98	41.78	21.57	1.39
ICBA-Q5	0-30	7.9	17.98	38.02	8.98	0.87	43.57	20.61	1.36

Evaluation of Quinoa genotypes in salt-affected soil conditions of Werer research station, Ethiopia

3.5 Sorghum genotypes screening under control conditions

The increasing salinity reduced germination percentage and delayed mean germination time in Sorghum genotypes, although the extent varied between different genotypes. The highest and lowest MGT was observed in Melkam at 20 dSm-1 (8.67 days) and ICSR-93034 at 0 dSm-1 (4.43 days), respectively at WRS (Table 10). Similar trends were observed for Germination Index for 3 Sorghum genotypes in WRS MoARS. The reductions were more pronounced at the higher salt stress (20 dSm-1).

Table 10. Effects of salinity on TGP, MGT, and GI of three Sorghum genotypes.

Parameters	Genotypes	NaCl salt level (dSm^{-1})					LSD	CV
		0	5	10	15	20	($p \leq 0.05$)	(%)
		Werer Research Station (Amibara)						
TGP (%)	Melkam	56.67	36.67	26.67	26.67	23.33	9.87	18.63
	ICSR-93034	90.00	86.67	70.00	60.00	50.00		
	ICSV-700	80.00	76.67	53.33	50.00	36.67		
MGT (days)	Melkam	5.11	6.33	7.00	7.85	8.67	0.84	13.53
	ICSR-93034	4.43	5.16	6.44	6.72	7.66		
	ICSV-700	4.66	5.72	5.83	6.98	7.83		
GI	Melkam	1.67	1.05	0.99	0.96	0.87	0.30	18.73
	ICSR-93034	3.11	2.95	2.27	1.57	1.30		
	ICSV-700	2.71	2.01	1.33	1.23	0.97		
		Mekhoni Research Station (Raya-Alamata)						
TGP (%)	Melkam	80.00	-	66.67	66.67	56.67	4.97	9.22
	ICSR-93034	76.67	-	66.67	56.67	56.67		
	ICSV-700	80.00	-	70.00	66.67	63.33		
MGT (days)	Melkam	5.88	-	6.95	6.74	8.38	5.65	9.71
	ICSR-93034	5.55	-	6.86	6.50	8.14		
	ICSV-700	5.88	-	7.02	7.14	8.10		
GI	Melkam	1.30	-	0.88	0.73	0.68	55.55	6.66
	ICSR-93034	1.24	-	0.83	0.60	0.61		
	ICSV-700	1.26	-	0.82	0.65	0.65		

TGP= Total Germination Percentage; MGT= Mean Germination Time; GI= Germination Index

Table 11. Effects of salinity on plant height of three Sorghum genotypes.

Parameters	Genotypes	NaCl salt level (dSm^{-1})					LSD	CV
		0	5	10	15	20	($p \leq 0.05$)	(%)
		Werer Research Station (Amibara)						
Plant height (cm)	Melkam	98.33	96.33	73.33	77.33	65.00	12.32	13.91
	ICSR-93034	121.66	90.67	83.00	91.67	70.00		
	ICSV-700	131.33	115.33	98.00	85.00	79.00		
		Mekhoni Research Station (Raya-Alamata)						
Plant height (cm)	Melkam	36.67	-	39.33	36.67	39.00	NS	20.78
	ICSR-93034	36.67	-	34.00	34.00	31.67		
	ICSV-700	40.67	-	31.33	33.00	29.00		

Plant height varies with an increase in the salinity level for the three Sorghum genotypes. In control, plant height varied between 131.33cm (ICSV-700 genotype) and 98.33cm (Melkam genotype) at the Werer research station. Similar observations were recorded at the Mekhoni research station (Table 11). At the highest salt concentration (20 dSm-1), maximum plant height was observed in the ICSV-700 genotype (79cm) and the lowest in Melkam genotype (65cm) at the Werer research station. The opposite observation was recorded at Mekhoni station.

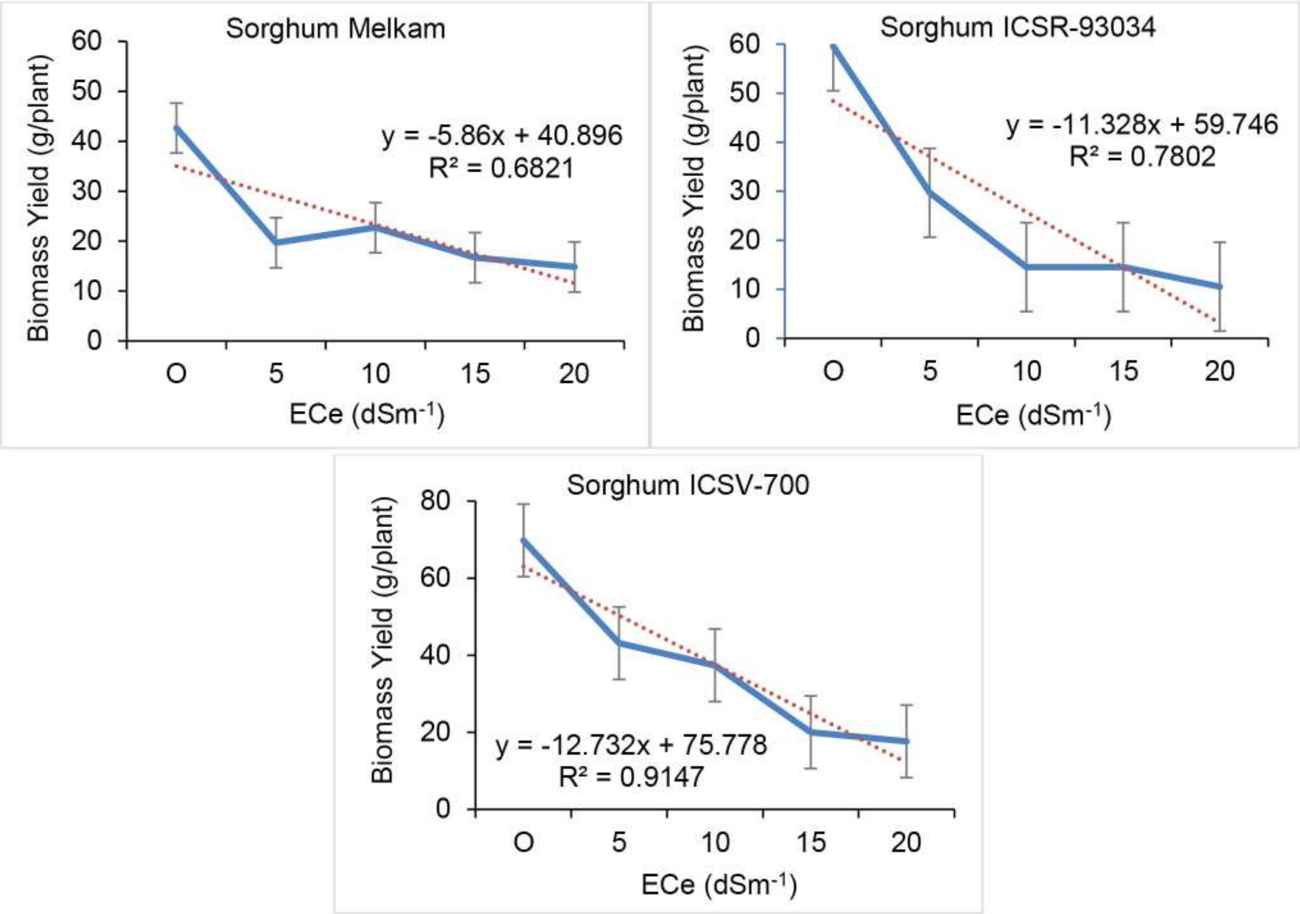


Figure 8. Effects of salinity on biomass yield of Sorghum genotypes at WRS

Fresh and dry biomass yields are considered important stress-responsive determinants to evaluate salt tolerance in controlled conditions (Kingsbury and Epstein, 1984; Saqib et al., 2002). Increased salt stress level also reduced the production of dry biomass yield in three Sorghum genotypes, although the reduction was less in the Melkam genotype (Figure 8 and 9). The highest reduction in fresh biomass yield was recorded in ICSV-700 with a unit increase (1 dSm-1) in salinity stress at the WRS (Figure 8). This was because the high salt concentration in the nutrient medium causes stunted growth in plants (Ashraf et al., 1999; Cherian et al., 1999; Takemura et al., 2000). The immediate response of salt stress is the reduction in the rate of leaf surface expansion (Wang and Nil, 2000). This causes a considerable decrease in shoots, leaves, and roots (Chartzoulakis and Klapaki, 2000; Ashraf et al., 2005).

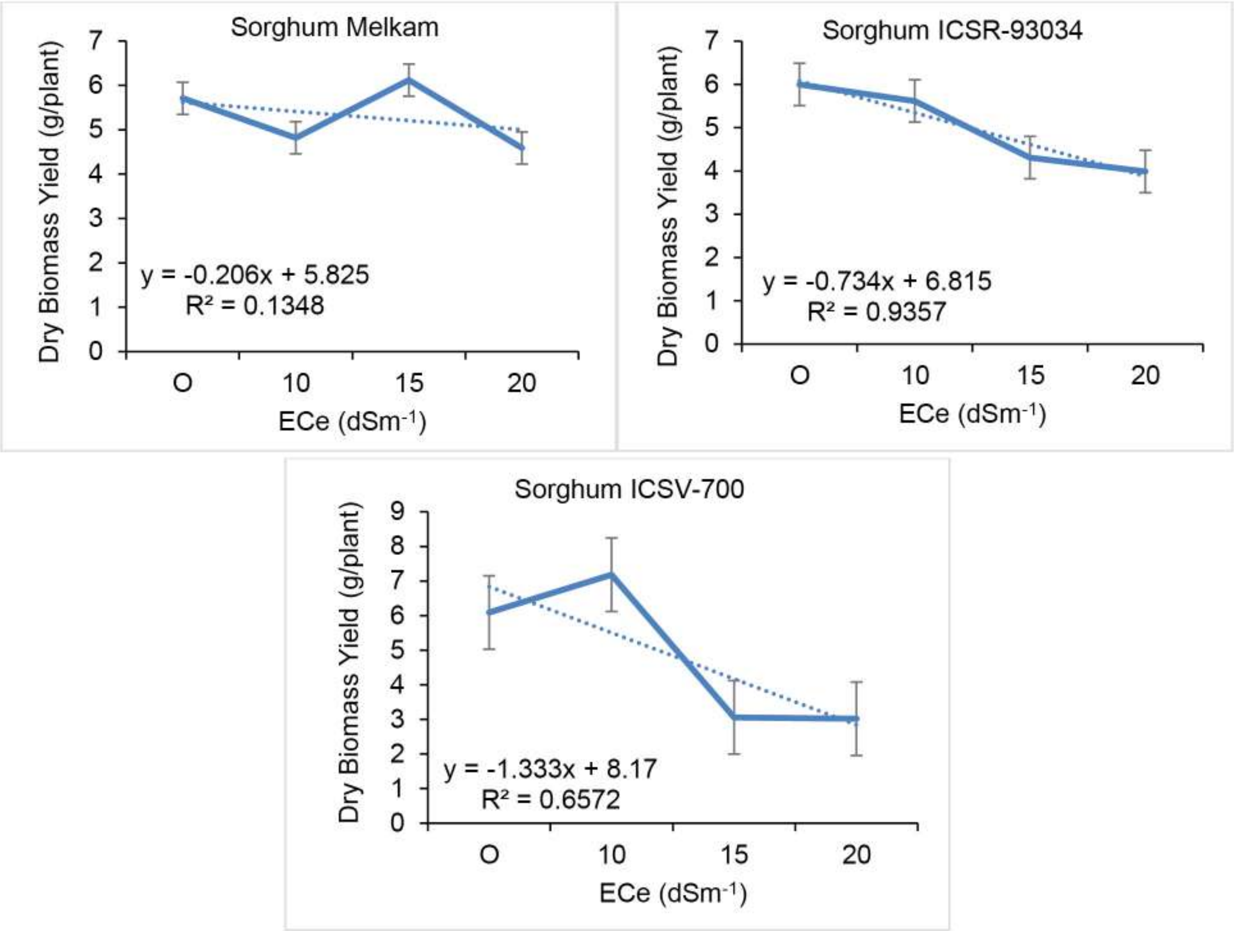
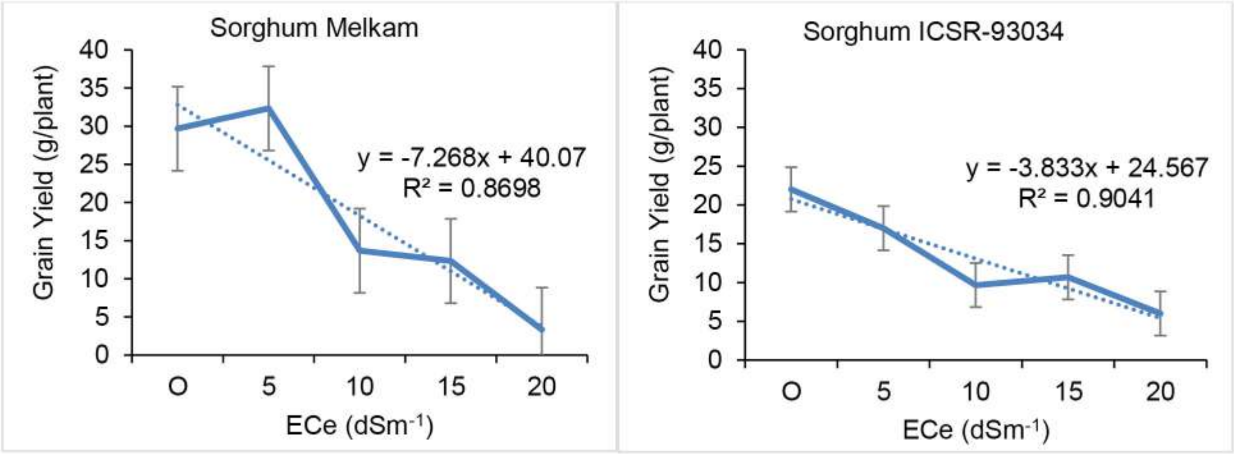


Figure 9. Effects of salinity on dry biomass yield of Sorghum genotypes at MoARS.

Every salinity level reduced the production of grain yield in three Sorghum genotypes at the Werer research station. Due to early harvest, the grain yield data for Sorghum genotypes could not be collected at the Mekhoni research station. However, the influence of salinity became more pronounced with higher salt concentrations. The less grain yield per unit increase (1 dSm-1) in salt stress was recorded at ICSR-93034 followed by ICSV-700 sorghum crop (Figure 10). These results agree with those reported by (Ramesh et al., 2005; Krishnamurthy et



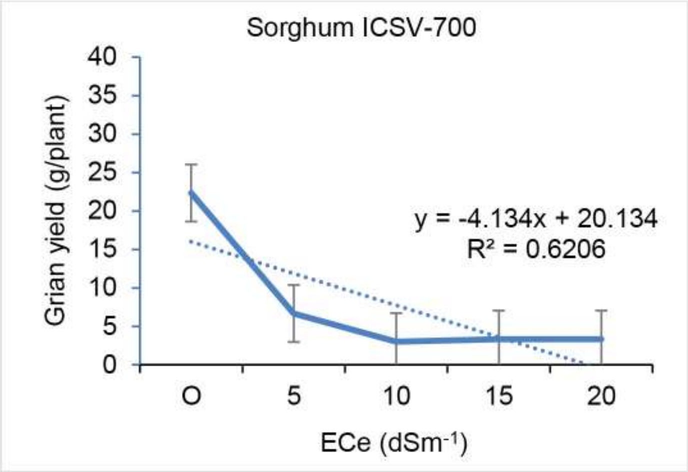


Figure 10. Effects of salinity on grain yield of three Sorghum genotypes at WRS.

3.6 Sorghum genotypes screening under field conditions

Sorghum genotypes also showed significant differences in all parameters except panicle length in both studied areas. The soil physio-chemical properties of the trial site are given in Table 12. All genotypes were affected more at high salt stress. A similar result was observed from the report by (Reddy et al., 2010). Among the newly introduced sorghum genotypes, Melkam was superior in terms of grain yield than ICSR¬93034 and ICSV-700. However, ICSR-93034 and ICSV-700 genotypes produced a higher dry matter than the Melkam genotype (Table 13). This made them highly attractive for animal feeds. Farmers prefer these two varieties because they produce reasonable grain yields and significantly higher biomass.

Table 12. Soil physio-chemical properties of trial site.

Sorghum varieties	Soil depths (cm)	pHe	ECe (dSm^{-1})	Exchangeable bases (cmol $_{(+)}$ Kg^{-1})			CEC (cmol $_{(+)}$ Kg^{-1})	ESP (%)	BD (gcm^{-3})
				Ca+Mg	Na	K			
Melkam	0-30	8.2	25.67	44.62	8.68	1.36	43.21	15.45	1.36
ICSR-93034	0-30	8.1	30.90	41.09	8.58	1.87	42.07	20.39	1.39
ICSV-700	0-30	8.3	31.23	39.62	7.97	1.04	39.57	21.79	1.40

Table 13. Field evaluation of salt-tolerant Sorghum genotypes at WRS.

Sorghum genotypes	DF (days)	DM (days)	PH (cm)	PL (cm)	DBY (ton/ha)	1000 seed wt (gm)	GY ($Kgha^{-1}$)
Melkam	73.00	97.33	146.07	26.86	10.56	36.30	3286.7
ICSR-93034	91.33	123.67	184.51	20.28	18.37	29.33	2327.5
ICSV-700	94.67	125.67	202.53	19.72	20.84	30.63	1948.6
LSD (P<0.05)	4.13	4.59	50.23	NS	7.70	6.35	415.15
CV (%)	12.11	17.54	12.46	20.71	22.02	8.68	7.26

DF= Days to 50% Flowering; DM= Days to 50% Maturity NT = No. of Tillers per plant; PH = Plant Height; SI = Spike Length; DBY= Dry Biomass Yield; GY= Grain Yield.

Evaluation of Sorghum genotypes in salt-affected soil condition of Werer research station, Ethiopia

3.7 Pearl Millet genotypes screening under control conditions

For all the genotypes, there was a decrease in germination percentage with increasing salt stresses level. However, the extent of the effect of salt stress on germination varied between different genotypes. Increasing salinity significantly delayed mean germination time (MGT) for all genotypes. The highest and lowest MGT was observed in the IP-13150 genotype at 20 dSm-1 (9.73 days) and 0 dSm-1 (3.05 days), respectively (Table 14). Salt stress had shown a significant effect on the germination index of IP-13150 and IP-19586. The reduction was exceptionally high at the highest level of salt stress (20 dSm-1). Similar results were reported by Kaya et al. (2008) and Khan et al. (2009). Sharma et al. (2011) also found that salinity causes severe damage in the seedling emergence stage than in any other stages in pearl millet.

Table 14. Effects of salinity on TGP, MGT, GI, and PH of two Pearl Millet genotypes.

Parameters	Genotypes	NaCl salt level (dSm^{-1})					LSD ($p \leq 0.05$)	CV (%)
		0	5	10	15	20		
TGP (%)	IP-13150	96.67	86.67	83.33	70.00	76.67	10.14	10.72
	IP-19586	96.67	93.33	96.67	36.67	43.33		
MGT (days)	IP-13150	3.05	6.39	7.61	8.00	9.73	0.92	10.81
	IP-19586	3.33	5.66	8.72	8.50	9.67		
GI	IP-13150	3.55	2.37	2.18	1.17	1.27	0.36	14.97
	IP-19586	3.55	2.42	2.41	0.61	0.69		
Plant height (cm)	IP-13150	113.33	110.10	112.03	101.67	89.67	22.26	17.75
	IP-19586	122.10	109.07	94.10	100.83	80.90		

TGP= Total Germination Percentage; MGT= Mean Germination Time; GI= Germination Index

Results indicate a decrease in plant height with increasing salinity level for the two pearl millet genotypes. In control, plant height varied between 122.10cm (IP-19586) and 113.33cm (IP-13150) (Table 14). At the highest salt concentration (20 dSm-1), the maximum plant height was observed in IP-13150 (89.67cm) and the lowest in IP-19586 (80.90cm). These results agreed with those reported by Ashraf et al. (2006).

Increased salt stress also reduced the dry biomass yield in both pearl millet genotypes. The outcome was poorer in IP-9586. The highest reduction in dry biomass yield per unit increase in salinity (1 dSm-1) was recorded in IP-13150 (Figure 11). The high salt concentration in the nutrient medium causes stunted growth in plants (Cherian et al., 1999; Takemura et al., 2000). The increased salt stress causes a reduction in the rate of leaf surface expansion (Wang and Nil, 2000), resulting in a significant decrease in the fresh and dry weights of shoots, leaves, and roots (Chartzoulakis and Klapaki, 2000; Ashraf et al., 2005).

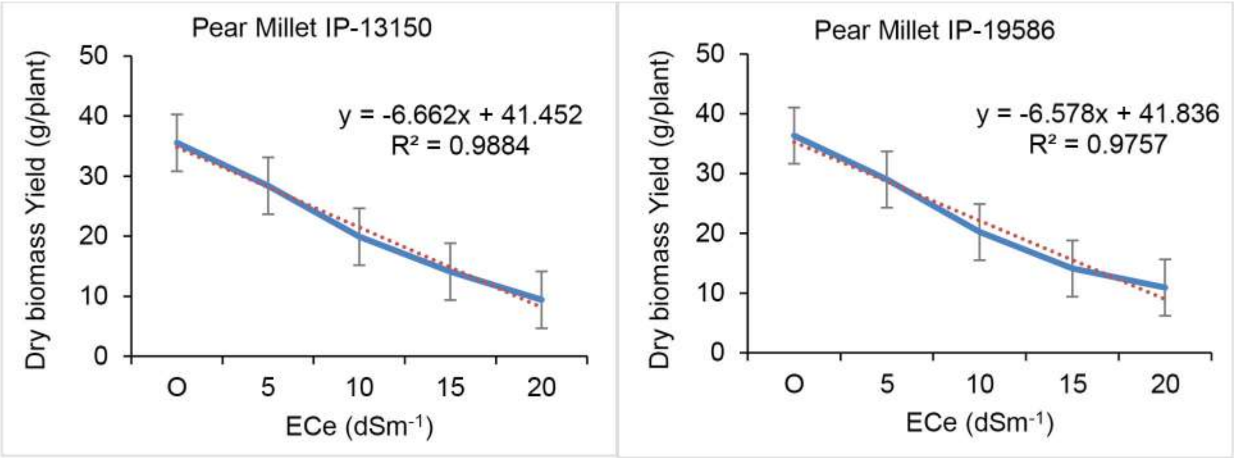


Figure 11. Effects of salinity on dry biomass yield of two Pearl Millet genotypes.

Increasing salinity also reduced the grain yield of both pearl millet genotypes at the Werer research station. The reduction in grain yield was minimal up to 5 dSm-1, but it becomes more pronounced at higher salinity levels. The lowest reduction in grain yield per unit of increase in salinity (1 dSm-1) was recorded in the IP¬13150 genotype, followed by the IP-19586 genotype (Figure 12). This is due to limited root water uptake by plants due to salinity. Higher salinity increases osmotic potential in the soil and high concentrations that may cause physiological

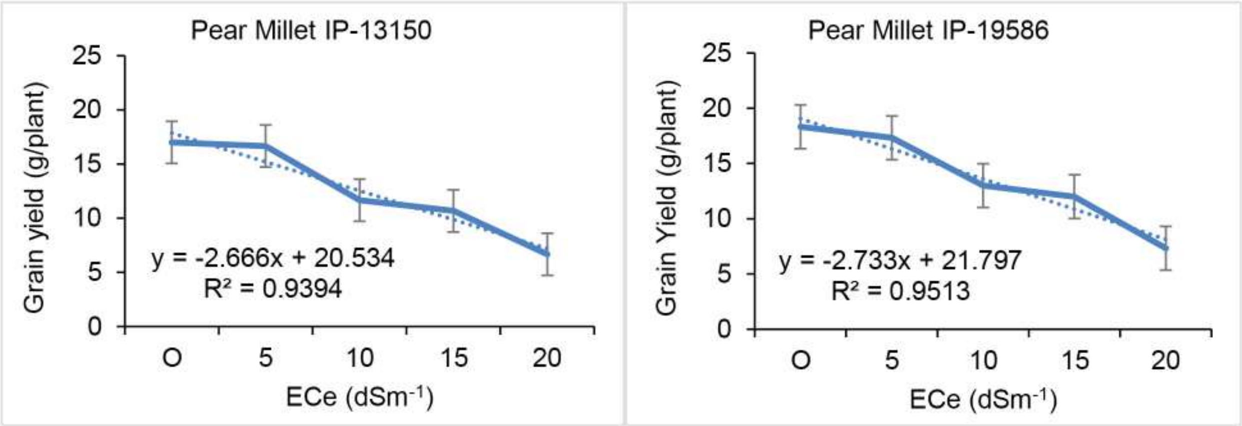


Figure 12. Effects of salinity on grain yield of two Pearl Millet genotypes.

3.8 Pearl Millet genotypes screening under field conditions

Under field conditions, pearl millet genotypes showed a statistically significant difference in days of 50% flowering, panicle length, dry matter biomass, and grain yield. However, no significant differences were found in days of 50% physiological maturity, the number of tillers per plant, dry biomass yield, and 1000 seed weight. The IP-13150 genotype performed superior grain and dry biomass yields than the IP-19586 genotype (Table 15). The highest dry biomass yield was recorded in IP-13150, which is very important for animal feeds.

Table 15. Field evaluation of salt-tolerant Pearl Millet genotypes

Pearl Millet Varieties	DF (days)	DM (days)	PH (cm)	NT (#)	PL (cm)	DBY (tha^{-1})	1000 seed wt. (g)	GY (kgha^{-1})
Werer research station								
IP-13150	96.67	127.33	163.86	5.33	21.12	11.72	11.58	1200
IP-19586	102.75	131.67	175.86	4.67	14.97	9.46	11.62	1042
LSD (P<0.05)	2.89	NS	15.01	NS	4.97	NS	NS	101.5
CV (%)	14.52	13.10	14.09	21.60	14.01	13.95	13.71	10.54
Fentale farmers field (Oromia)								
IP-13150	92.09	129.67	198.90	5.96	26.60	11.43	13.29	1136
IP-19586	103.04	136.67	188.90	4.40	16.06	8.467	12.25	1008
LSD (P<0.05)	3.21	NS	NS	NS	5.92	NS	NS	137.8
CV (%)	14.52	13.10	12.31	19.97	7.90	13.95	3.37	3.65

DF = Days of 50% Flowering; DM = Days of 50% Maturity; PH = Plant Height; PL= Panicle Length; RL= Root Length; DBY= Dry Biomass Yield; GY= Grain Yield.

The field data shows that highly saline field conditions (Table 16) and pearl millet varieties produce more than 1.0 tha-1 grain yields and around 10 tha-1 dry biomass yields. These are very encouraging results for the highly saline areas of Ethiopia. This shows that these two ICBA introduced pearl millet varieties can successfully be grown to improve the productivity of saline lands in Ethiopia. The soils of the Werer research station are also high in ESP, which means that these pearl millet genotypes can also survive in alkaline soils. Therefore, these varieties should be introduced to farmers of saline and saline-sodic areas.

Table 16. Soil physio-chemical properties of Werer research station.

Pearl Millet Varieties	Soil depth	pH	ECe (dSm^{-1})	Exchangeable bases (cmol (+) Kg-1)			CEC (cmol $_{(+)}$ Kg^{-1})	ESP (%)	BD (gcm^{-3})
				Ca+Mg	Na	K			
IP-13150	0-30	7.8	29.78	41.39	7.98	0.87	42.37	18.83	1.37
IP-19586	0-30	8.0	32.89	37.62	7.06	1.01	39.05	16.35	1.35

Evaluation of Pearl Millet genotypes in salt-affected soil condition of Werer research station, Ethiopia

3.9 Cowpea genotypes screening under control conditions

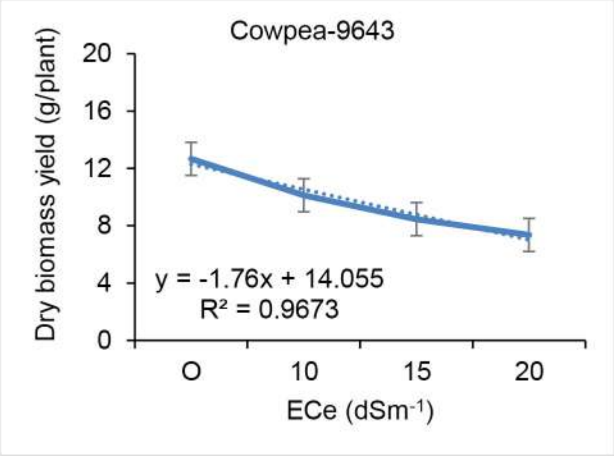
The results showed that salt stress treatments significantly affected seed germination and germination percentage for all genotypes. However, the extent of the effect of salt stress on germination varied between different genotypes. Increasing salinity significantly delayed mean germination time in cowpea genotypes. The highest and lowest MGT were observed ILRI-9643 and ILRI-12713 genotypes at 20 dSm-1 (8.25 days) and 0 dSm-1 (5.58 days), respectively (Table 17). Salt stress also showed a negative effect on the GI of cowpea genotypes. The reduction gets higher at the higher salinity (20 dSm-1). Similar results were reported by Kaya et al. (2008) and Khan et al. (2009) working on hot pepper.

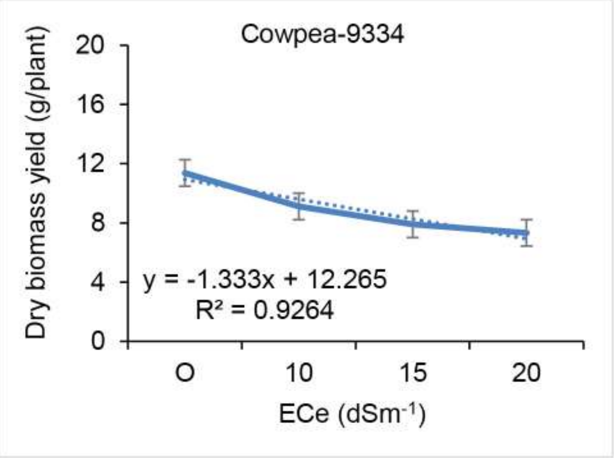
Table 17 shows that plant height was reduced with an increase in salinity for the three cowpea genotypes. In control, plant height was 86cm for ILRI-12713 and 40.33cm for ILRI-9643 at Mekhoni research station. At the highest salinity (20 dSm-1), the maximum plant height was observed in ILRI-12713 (44.33cm) and the lowest in ILRI-9643 (23.67cm). These results agreed with those reported by Ashraf et al. (2005).

Table 17. Effects of salinity on TGP, MGT, GI, and PH of three cowpea genotypes.

Parameters	Cowpea cultivars	Soil salinity levels (dSm^{-1})				LSD ($p \leq 0.05$)	CV (%)
		0	10	15	20		
TGP (%)	ILRI-9643	76.67	70.00	63.33	56.67	5.05	9.40
	ILRI-9334	73.33	66.67	56.67	53.33		
	ILRI-12713	76.67	70.00	66.67	53.33		
MGT (days)	ILRI-9643	5.67	6.92	7.17	8.25	6.35	8.13
	ILRI-9334	5.67	7.08	7.00	8.00		
	ILRI-12713	5.58	7.08	7.33	7.42		
GI	ILRI-9643	1.42	0.97	0.77	0.77	30.01	8.54
	ILRI-9334	1.43	1.02	0.79	0.73		
	ILRI-12713	1.44	1.03	0.82	0.66		
Plant height (Cm)	ILRI-9643	40.33	36.67	33.33	23.67	7.96	21.60
	ILRI-9334	83.33	65.67	51.67	37.33		
	ILRI-12713	86.00	65.67	54.67	44.33		

TGP= Total Germination Percentage; MGT= Mean Germination Time; GI= Germination Index.





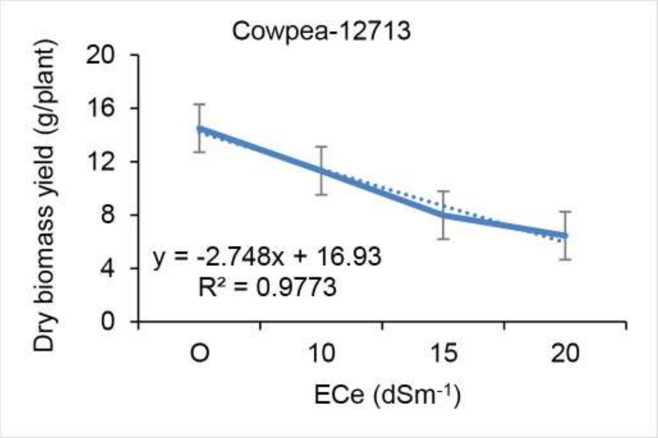


Figure 13. Effects of salinity on dry biomass yield of three Cowpea genotypes.

Increased salinity reduced dry biomass yield (DBY) in all cowpea genotypes, although the reduction was relatively less in ILRI-9334. The highest DBY at control was in the ILRI-12713 compared to the other two genotypes (Figure 13). However, the highest reduction in DBY per unit increase in the salinity was recorded in the ILRI-12713 genotype. The higher salt concentration in the nutrient medium causes stunted growth in plants (Cherian et al., 1999; Takemura et al., 2000). The immediate response of salt stress is the reduction in the rate of leaf surface expansion (Wang and Nil, 2000), which results in a considerable decrease in the fresh and dry weights of the shoot, leaves, and roots (Chartzoulakis and Klapaki, 2000; Ashraf et al., 2005).

3.10 Cowpea genotypes screening under field conditions

The cowpea genotypes showed significant differences in all growth parameters at the Fentale district. However, in the Mekhoni research station, differences were non-significant except for dry biomass yield. The ILRI-9643 genotype produced superior grain and biomass yield than the other two genotypes at both locations. The grain and dry biomass yields were higher in MoARS compared to WRS (Table 18). This shows that these cowpea varieties are suitable for high lands with lower temperatures and higher rainfall.

Table 18. Field evaluation of salt-tolerant cowpea genotypes.

Genotypes	DF (days)	DM (days)	PH (cm)	DBY (tha^{-1})	GY ($kgha^{-1}$)
		Mekhoni research station			
ILRI-9643	67.67	97.67	42.67	29.55	2345
ILRI-9334	70.67	97.67	36.00	22.16	2318
ILRI-12713	71.67	93.33	42.33	24.55	2297
LSD (P<0.05)	NS	NS	NS	1.25	NS
CV (%)	5.05	2.27	7.91	9.43	11.35
		Fentale farmer field (Oromia)			
ILRI-9643	75.67	76.33	64.96	17.30	1047
ILRI-9334	75.67	95.33	55.40	12.72	582
ILRI-12713	55.33	95.33	63.13	12.53	754.4
LSD (P<0.05)	0.77	1.31	8.74	4.44	154.9
CV (%)	0.48	0.64	6.30	13.81	8.59

DF = Days of 50% Flowering; DM = Days of 50% Maturity; PH = Plant Height; PL= Panicle Length; RL= Root Length; DBY= Dry Biomass Yield; GY= Grain Yield.

3.11 Sesabinia sesban genotypes screening under control conditions

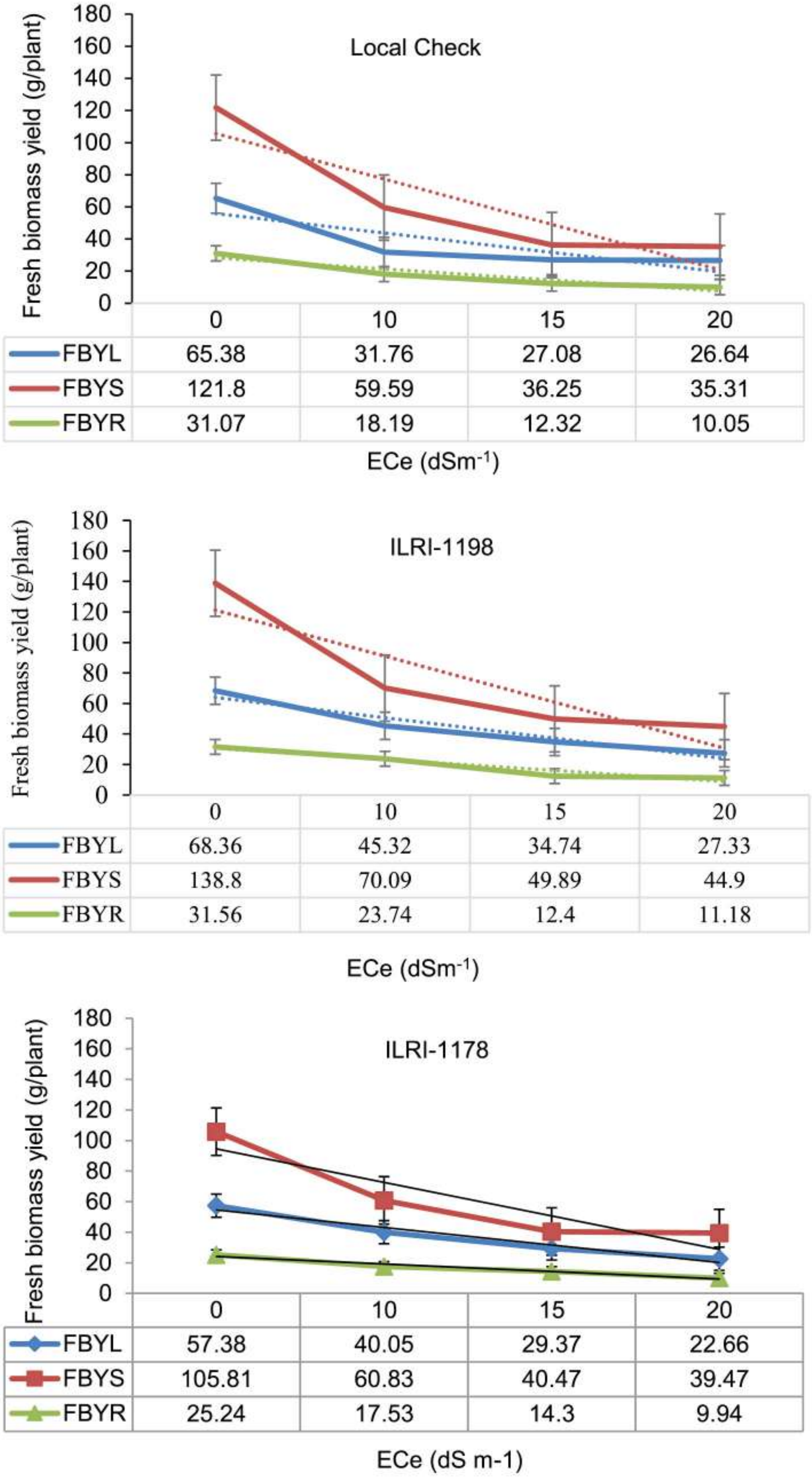
The different levels of salinity have a significant effect on Sesabinia sesban seed germination. In all genotypes, there was a decrease in germination percentage when the salt stresses increased. Different Sesabinia sesban genotypes had a different response to the increasing salinity levels. The highest and lowest MGT was observed in ILRI-1198 and local genotype at 20 dSm-1 (8.44 days) and 0 dSm-1 (3.17 days), respectively (Table 19). Increased salt stress shows significant adverse effects on the Germination Index of Sesabinia sesban. The higher reductions were recorded at 20 dSm-1. Similar results were reported by Kaya et al. (2008) and Khan et al. (2008) and Khan et al. (2009) working on hot pepper.

Table 19. Effects of salinity on TGP, MGT, GI, and PH of three Sesabinia sesban genotypes.

Parameters	Cultivars	NaCl salt level (dSm^{-1})				LSD ($p \leq 0.05$)	CV (%)
		0	10	15	20		
TGP (%)	Local	96.67	70.00	50.00	36.67	9.98	14.82
	ILRI-1198	100.00	83.33	66.67	56.67		
	ILRI-1178	93.33	66.67	60.00	46.67		
MGT (days)	Local	3.17	3.22	5.44	7.61	0.78	15.03
	ILRI-1198	4.05	5.50	6.39	8.44		
	ILRI-1178	3.67	4.33	4.38	7.50		
GI	Local	1.88	1.30	0.60	0.54	0.23	19.84
	ILRI-1198	2.30	1.42	1.14	0.87		
	ILRI-1178	1.92	0.91	0.80	0.71		
Plant height (cm)	Local	124.00	112.67	103.53	73.00	12.69	11.98
	ILRI-1198	125.67	105.13	101.00	99.50		
	ILRI-1178	126.67	125.00	107.33	103.63		

TGP= Total Germination Percentage; MGT= Mean Germination Time; GI= Germination Index

Increased salt stress levels also reduced the production of fresh biomass yield in leaf, stem, and root for all genotypes, with the highest reduction in the ILRI-1198 genotype. The maximum decrease in fresh weight in leaf, stem, and roots was observed when salinity reached 20 dSm-1. The highest dry weight of leaf, stem, and roots was observed for the ILRI-1178 genotype (Figure 14).



Local Check

	0	10	15	20
FBYL	65.38	31.76	27.08	26.64
FBYS	121.8	59.59	36.25	35.31
FBYR	31.07	18.19	12.32	10.05

ILRI-1198

	0	10	15	20
FBYL	68.36	45.32	34.74	27.33
FBYS	138.8	70.09	49.89	44.9
FBYR	31.56	23.74	12.4	11.18

ILRI-1178

	0	10	15	20
FBYL	57.38	40.05	29.37	22.66
FBYS	105.81	60.83	40.47	39.47
FBYR	25.24	17.53	14.3	9.94

Figure 14. Effects of salinity on FYB of leaf stem and root of Sesabinia sesban genotypes.

3.12 Sesabinia sesban genotypes screening under control conditions

Salinity stress affected plant height of Sesabinia sesban genotypes with varying magnitude. A significant difference ($p < 0.05$) in plant height was recorded for both harvesting times between tested Sesabinia sesban species. The ILRI-1178 was relatively taller (379.67 cm) than the Local genotype (366.50cm) and ILRI-1198 genotype (324cm) at first harvesting (Table 20). A similar observation was made at the second harvesting. The highest dry biomass yield was recorded for the local check than ILRI genotypes.

Table 20. Plant height, fresh biomass yield and dry biomass yield of three Sesabinia sesban genotypes.

Genotypes	Plant height (cm)		Biomass Yield (tha^{-1})			
			Fresh		Dry	
	1st harvesting	2nd harvesting	1st harvesting	2nd harvesting	1st harvesting	2nd harvesting
Local	366.00ba	357.00a	143.69ba	139.93	44.45	45.72a
ILRI-1198	324.00b	321.00b	141.29b	138.69	43.11	39.56
ILRI-1178	379.67a	366.33a	148.16b	137.48	42.39	43.19
LSD ($P<0.05$)	45.72	33.76	6.01	NS	NS	3.71
CV (%)	15.65	14.27	15.28	7.11	12.28	13.82

Table 21. Soil physio-chemical properties of the trial site of WRS.

Genotypes	Soil depth (cm)	pH	ECe (dSm^{-1})	Exchangeable bases (cmol (+) Kg^{-1})			CEC (cmol $_{(+)}$ Kg^{-1})	ESP (%)	BD (gcm^{-3})
				Ca+Mg	Na	K			
Local	0-30	7.7	17.80	38.90	5.46	0.93	37.68	15.81	1.33
ILRI 1198	0-30	7.9	14.39	45.78	6.89	1.09	41.32	16.67	1.35
ILRI 1178	0-30	8.0	19.40	41.33	3.28	0.67	34.85	20.88	1.38

Evaluation of Sesabinia sesban genotypes at the salt-affected salts in Ethiopia

3.13 Rhoades grass genotype screening under control conditions

Five seeds of each genotype were planted in each pot. Seeds that produce full radicles were considered as germinated. The mean germination time, percentage, number of tillers per plant, and plant height were collected from all pots. Chloris gayana grasses were sustained up to 75 days after planting. At the time of harvesting, shoot and root dry matter weight was recorded. The first germination count was done after five days on the plantation. Because saline environment often causes a delay in seed germination, seedlings counting was also done on the 10th and 15th day after plantation.

The results indicate that the increased salinity negatively affected the germination percentage (GP) and mean germination time (MGT) of three Rhoades grass (Chloris gayana) genotypes. The GP showed a decreasing trend with the increasing salinity and ranged between 68.3-71.7 percent in control, 63.2-67.0 percent at 5 dSm−1, 53.3-56.7 percent at 10 dSm−1, 50.0–51.7 percent at 15 dSm−1, and 45.0-48.3 percent at 20 dSm−1 (Figure 15). The highest GP at each salinity level was obtained for ILRI-6633, followed by ILRI¬7384, except for higher salinity of 20 dSm-1 where CV-massaba performed better than ILRI-7384.

The germination of all three genotypes was delayed with the increasing salinity, i.e., from 8 days in control (0 dSm−1) to more than 12 days for higher salinity (20 dSm−1) (Figure 15). The local genotype CV-massaba germinated faster than the other two genotypes under all salinity levels. This shows that CV-massaba is more tolerant to salinity as far as germination is concerned. On average, delay in MGT was 4, 13.3, 21.7, and 39.1% at 5, 10, 15, and 20 dSm−1, respectively. The average MGT for all genotypes was 7.2 days in control, with ILRI-6633 being the maximum (7.9 days) and CV-massaba the minimum (6.8 days). At the highest salinity (20 dSm-1), the average MGT for ILRI-7384 was 12.2 days, followed by 12.1 days for ILRI¬6633 and 11.2 days for CV-massaba. This shows that although CV-massaba germinated faster, its germination percentage was lower than the other two genotypes.

The crop genotypes that can effectively germinate under salt stress conditions do not necessarily qualify for good seedling growth. In our case, ILRI-6633 and CV-massaba genotype showed promising results not only in terms of germination percentage and mean germination time but also in seedling growth. Studies have shown that the crops with higher germination percentages can establish themselves effectively on moderate to high saline soils (ECe = 5–12 dSm-1). Although it is challenging to generalize pot results for field conditions, ILRI-6633 and CV-massaba genotypes can potentially germinate and establish in moderate to high saline areas. This will help produce high biomass because yield losses due to poor germination and inadequate crop stand establishment will be minimal.

Plant height, number of tillers, and Chlorophyll SPAD value

Plant growth is affected by salinity due to many factors, including osmotic stress, ionic toxicity, lack of minerals, and physiological and biochemical responses. This study reveals a significant reduction in plant height, number of tillers per plant at the seedling stage, and plant fresh and dry matter weight of three Chloris gayana genotypes with the increasing salinity levels. However, high chlorophyll content (SPAD value) was detected in salt-tolerant genotypes. These higher chlorophyll values can be ascribed to an improved photosynthetic rate and higher dry matter production. The reduction in chlorophyll contents under marginal environments has been observed in many previous studies.

The plant height and the total number of tillers of three Chloris gayana genotypes at different salinity levels are given in Table 22. A linear decrease in plant height with increasing soil salinity was observed for all genotypes. The plant height of Chloris gayana genotypes ranged between 93.0-120.8cm at 0 dSm−1), 92.5¬117.8cm at 5 dSm−1, 81.4–103.6cm at 10 dSm−1, 60.3–78.3cm at 15 dSm−1 , and 52.0–69.0cm at 20 dSm−1 .

The average plant height for all Chloris gayana genotypes at 0 dSm-1 was 105 cm, with ILRI-6633 highest (120.8cm). Likewise, the average plant height for all genotypes at the highest salinity level (20 dSm-1) was 61.6cm, with ILRI-6633 taking the lead (68.9cm). The highest decrease in plant height with an increase in salinity level from 0 to 20 dSm-1 was noted in ILRI-6633 (51.8cm) followed by ILRI-7384 (41.0cm) and CV¬massaba (37.5cm).

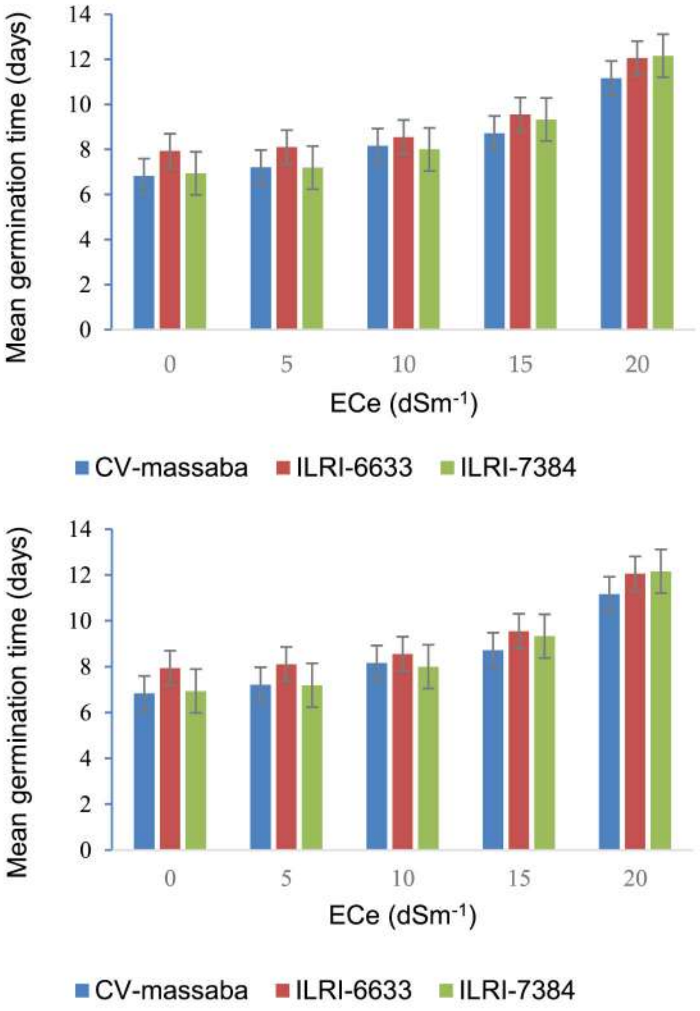


Figure 15. Effect of different salinity levels on GP and MGT of three Chloris gayana genotypes

Table 22. Plant height and number of tillers of three selected Chloris gayana genotypes.

Parameters	Genotypes	Salinity level (dSm^{-1})					LSD ($p \leq 0.05$)	CV (%)
		0	5	10	15	20		
Plant height (cm)	CV-massaba	101.3	100.3	97.0	76.3	63.8	7.3	9.0
	ILRI-6633	120.8	117.8	103.6	78.3	68.9		
	ILRI-7384	93.0	92.5	81.4	60.3	52.0		
Total tillers (#)	CV-massaba	6.9	6.8	6.3	5.2	5.5	1.1	17.6
	ILRI-6633	5.4	5.3	5.0	4.7	3.1		
	ILRI-7384	9.4	9.3	8.4	8.0	5.9		

The number of tillers per plant is one of the most important agronomic traits because it determines the biomass yield of the forage grasses. The results indicate that higher salinity conditions significantly affect tiller production at maturity. The average number of tillers per plant was 7.2, 7.1, 6.6, 5.9, and 4.8 at 0, 5, 10, 15, and 20 dSm-1, respectively (Table 22). At 0 dSm−1, ILRI-7384 gave a maximum number of tillers per plant (9.4), followed by CV-massaba (6.9) and ILRI-6633 (5.4). A similar pattern was observed at higher salinity conditions (20 dSm−1) where the maximum and the minimum number of tillers per plant was recorded in ILRI-7384 (5.8) and ILRI-6633 (3.1), respectively. These results coincide with the earlier findings, which show that morphological and physiological traits of plants such as plant height, number of tillers per plant, and fresh and dry biomass yields tend to decrease with the increasing salinity levels.

Figure 16 shows the chlorophyll content (SPAD value) of three Chloris gayana genotypes. The SPAD values were found to be consistent up to a salinity level of 10 dSm-1. However, a significant reduction in SPAD values at salinity levels of 15 dSm-1 and 20 dSm-1 was observed. For all salinity levels, the highest SPAD values were found in ILRI-6633 followed by ILRI-7384 and CV-massaba. The highest SPAD value (63.6) was recorded in ILRI-6633 at a moderate salinity level (10 dSm-1). However, for 20 dSm-1, SPAD values decreased significantly for all three genotypes except for ILRI-6633. Similar trends of chlorophyll content reductions with the increasing salinity have also been observed for different crops.

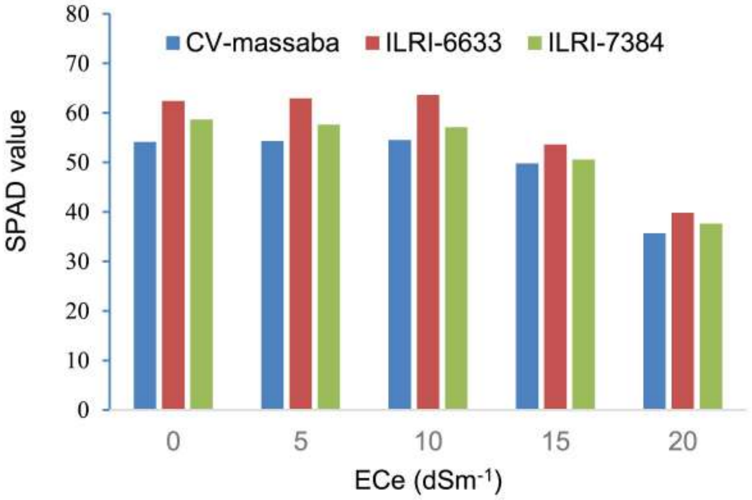


Figure 16. Chlorophyll content (SPAD value) of three selected Chloris gayana genotypes.

Root and shoot dry matter

Figure 17 shows the impact of different salinity levels on shoot and root dry matter of three Chloris gayana genotypes. The highest shoot dry matter (71.2 g/pot) was obtained in ILRI-6633, whereas the lowest (60.3 g/pot) was recorded in ILRI-7384. The reduction in dry shoot matter was more pronounced at salinity levels of 15 dSm-1 and 20 dSm-1. Overall reduction in dry shoot matter from 0 to 20 dSm-1 was 18.0 g/pot for ILRI-6633, 21.5 g/pot for ILRI-7384, and 27.5 g/pot for CV-massaba. This demonstrates that the ILRI-6633 genotype has the lowest reduction in dry shoot matter with increasing salinity. The root dry matter ranged between 10.4–17.4 g/pot at 0 dSm-1, 14.2–18.4 g/pot at 5 dSm−1, 12.5–18.3 g/pot at 10 dSm−1, 12.2–16.4 g/pot at 15 dSm−1, and 10.0–12.2 g/pot at 20 dSm−1 (Figure 17).

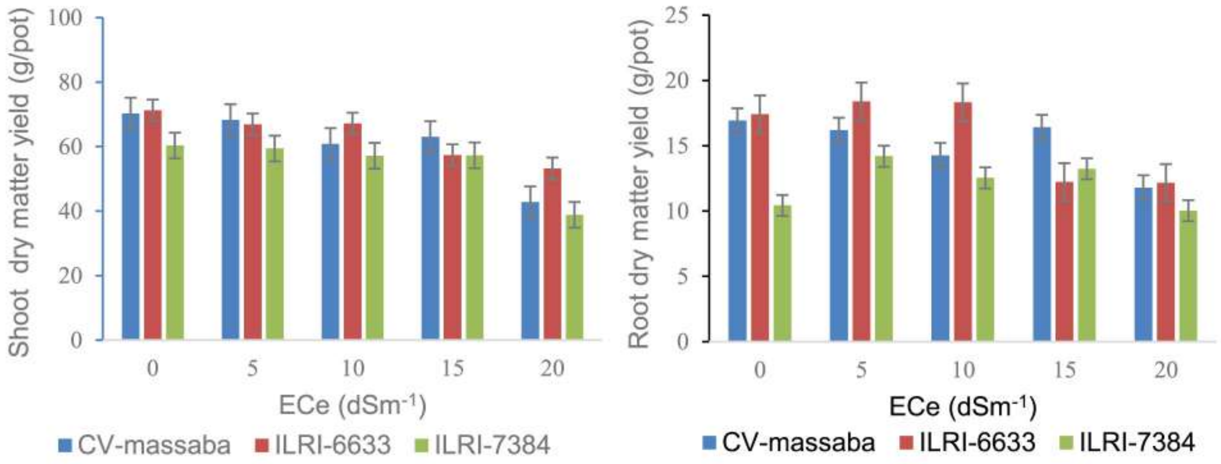


Figure 17. Shoot dry matter and root dry matter of three selected Chloris gayana genotypes.

The highest root dry matter was achieved for ILRI-6633, followed by CV-massaba at all salinity levels. The maximum root dry weight for ILRI-6633 and CV-massaba was obtained at 5-10 dSm-1. The average reduction in dry root matter ranged from 11.3-16.3 g/pot with an increase in salinity from 5-20 dSm-1. These declining trends could be because plants spend more energy to get water and nutrients from the soil under saline conditions. This situation negatively affects the yield and quality of the plant.

Nutrient Composition

Forage grasses are the most remunerative form of animal feed in semi-arid regions. The nutritional value of forages mainly depends on their nutritional composition, such as crude protein (CP) and fiber and ash contents (Ventura and Sagi, 2013). Crude protein is an essential element of the animal diet that enhances their milk-producing capacity and maintains meat quality (Al-Dakheel et al., 2015). Both CP and ash contents of three Chloris gayana genotypes exhibited a decreasing trend with increasing soil salinity. The highest CP (6.1%) and ash (15.5%) contents were obtained in ILRI-6633 and ILRI-7384 genotypes at low salinity levels (5 dSm-1). In contrast, CV-massaba reported the lowest crude protein (3.8%) and ash content (12.4) at the same salinity level (Figure 18).

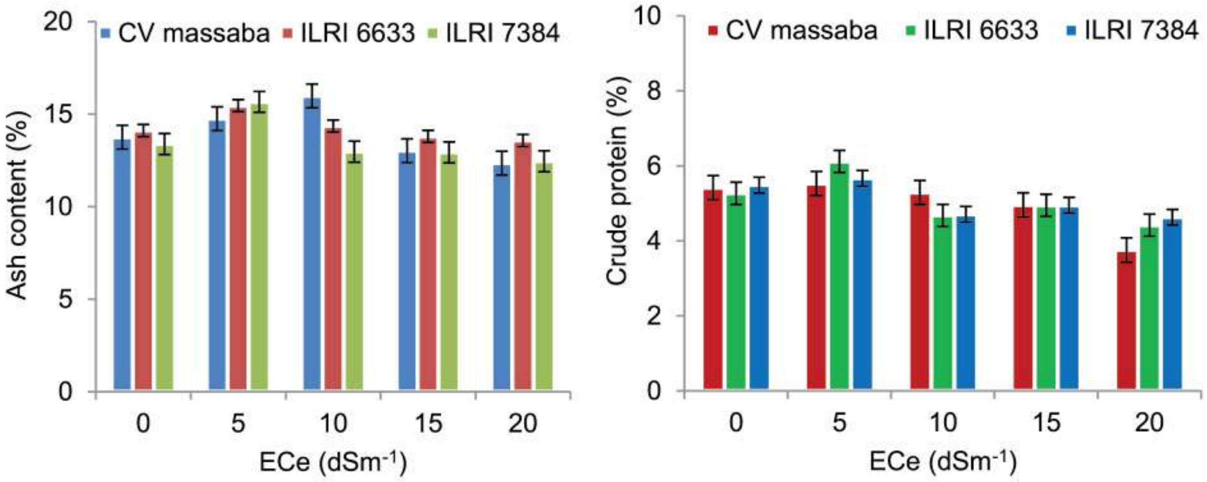


Figure 18. Effect of salinity on Ash content and Crude protein on three Chloris gayana genotypes

The CV-massaba genotype produced a higher CP content at salinity levels of 10–15 dSm-1. Generally, low dry matter-producing genotypes have higher CP content, whereas high dry matter-producing accessions are low in nutrition at low salinity levels (Al-Dakheel and Hussain, 2016; Suyama et al., 2007). All three genotypes produced high CP and ash content at low to medium salinity (0–10 dSm-1) levels, while a falling trend was observed at higher salinity levels (15–20 dSm-1). This shows that these varieties are more suitable for low to moderate salinity conditions.

Neutral Detergent Fiber (NDF) consists of hemicellulose, cellulose, and lignin. From the feeding point of view, lower NDF values are desirable for fodder and grains. The NDF values for all three genotypes showed an increasing trend with the growing salt stress. Differences in NDF among the Chloris gayana genotypes show a similar trend for CP. ILRI-6633 reported the highest NDF (70.9–73.9%) value, whereas the lowest values (67.5–72.9%) were observed in CV-massaba for all salinity levels (Figure 19). The average Invitro Dry Matter Digestibility Content (IvDMDC) was 42.9% for control, 41% at 5 dSm-1, 41.6% at 10 dSm-1, 40.2% at 15 dSm-1, and 36.1% at 20 dSm-1 (Figure 19). The highest IvDMDC was obtained in ILRI-6633 at control, while the lowest was observed in CV-massaba at 20 dSm-1.

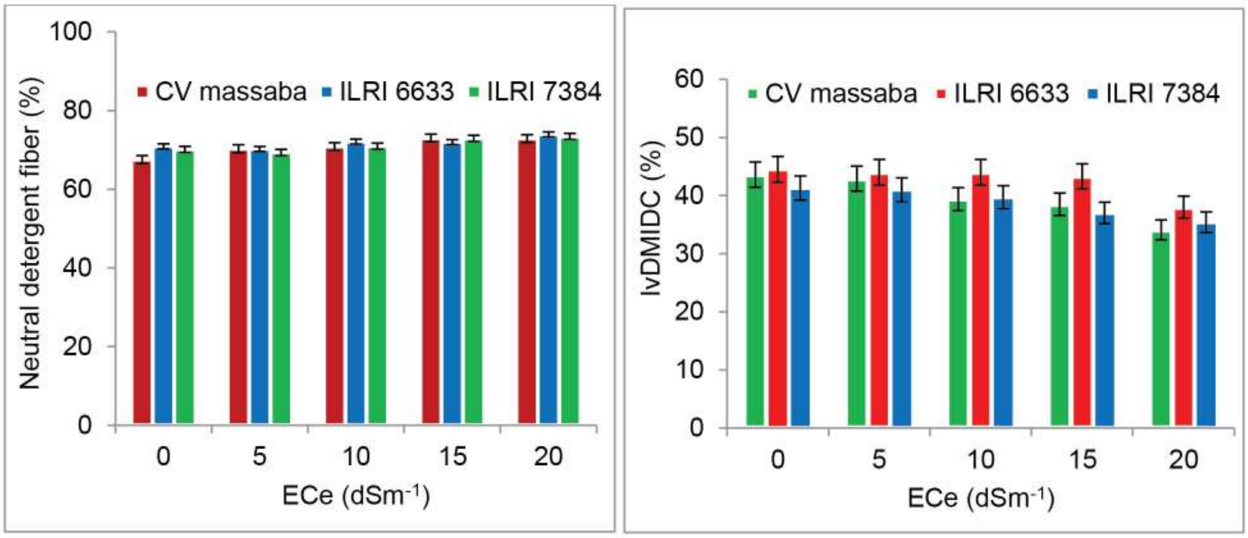


Figure 19. Effect of salinity on NDF and IvDMDC on three Chloris gayana genotypes.

3.14 Lablab purpure genotype screening under control conditions

Ten seeds of each genotype were planted in each pot. The data regarding germination time, number of tillers, and plant height was collected from all pots. Lablab purpureus legumes were sustained up to 60 days after planting, and both shoot, and fresh root weight was recorded at the time of harvesting. The first germination count was done on the 5th and the second on the 15th after plantation.

The increasing salinity negatively influenced the GP and MGT of three Lablab purpureus genotypes. GP values exhibited a declining trend with the growing soil salinity. The GP ranged between 96.7-100 percent at control, 96-98.7 percent at 5 dSm−1, 90-93.3 percent at 10 dSm−1, 70.7–86.7 percent at 15 dSm−1, and 43.3-63.3 percent at 20 dSm−1 (Figure 20). ILRI genotypes showed higher GP (100%) at control than the local cultivar (96.7%). However, this was not the case at 15-20 dSm−1 salinity, where a declining trend was observed. At higher salinity, i.e., 15-20 dSm−1, the maximum GP was marked in ILRI-6529T. ILRI-6529T proved most salt-tolerant than the other two cultivars as far as GP was concerned.

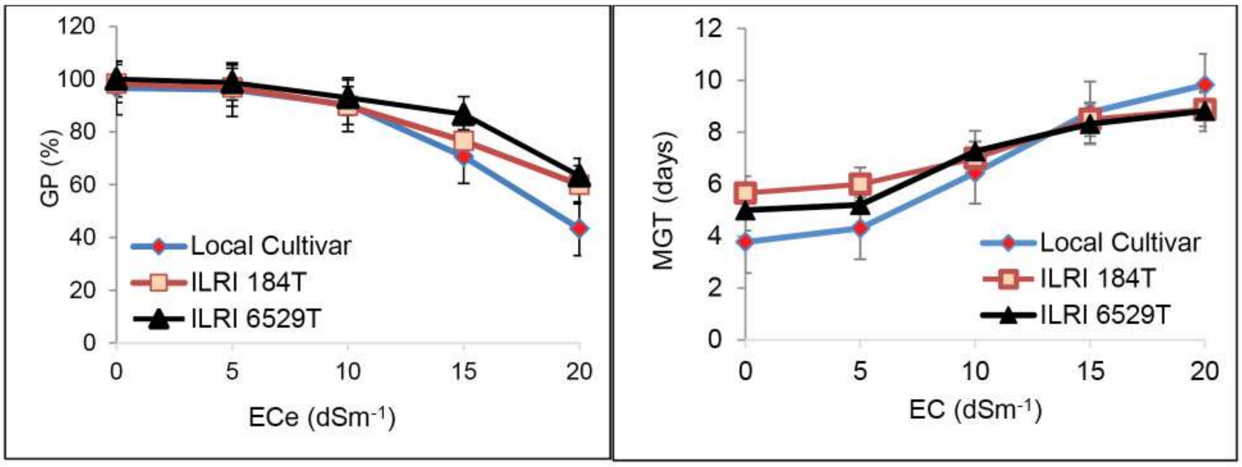


Figure 19. GP and MGT of three Lablab purpureus genotypes as affected by different levels.

The increasing salinity levels delayed the seed emergence, and the effect was more noticeable at higher salinity levels. The MGT values ranged between 3.8–5.7, 4.3-6.0, 6.3-7.3, 8.3-8.8, and 8.8-9.8 days at 0, 5, 10, 15, and 20 dSm−1, respectively (Figure 20). The average increase in the MGT was 6.45, 29.95, 43.36, and 47.27% at 5, 10, 15, and 20 dSm−1, respectively. The mean MGT value at control was 4.83 days for all tested Lablab genotypes, highest for ILRI-184T (5.7 days). Similarly, the average MGT was 9.71 days for all tested Lablab genotypes at 20 dSm-1, with local cultivar taking the lead (9.8 days). This shows that at higher salinity levels, MGT for all three genotypes was comparable.

Plant population at maturity and Chlorophyll (SPAD value) content

The effects of soil salinity on plant population at maturity and chlorophyll content (SPAD value) of three Lablab genotypes are shown in Figure 21. The plant population at maturity was negatively affected by the increasing soil salinity. The average plant population for all genotypes decreased from 8.0-8.7 at control to 4.3–5.7 at 20 dSm−1. The percentage reduction in plant population was 4.17, 8.70, 19.05, and 59.24 at 5, 10, 15, and 20 dSm−1, respectively. The highest average plant population at control was observed for ILRI¬6529T genotype (8.7), whereas the lowest (5.23) was found at 20 dSm-1. However, ILRI-6529T and ILRI¬184T genotypes performed better at 20 dSm-1 compared to local cultivar.

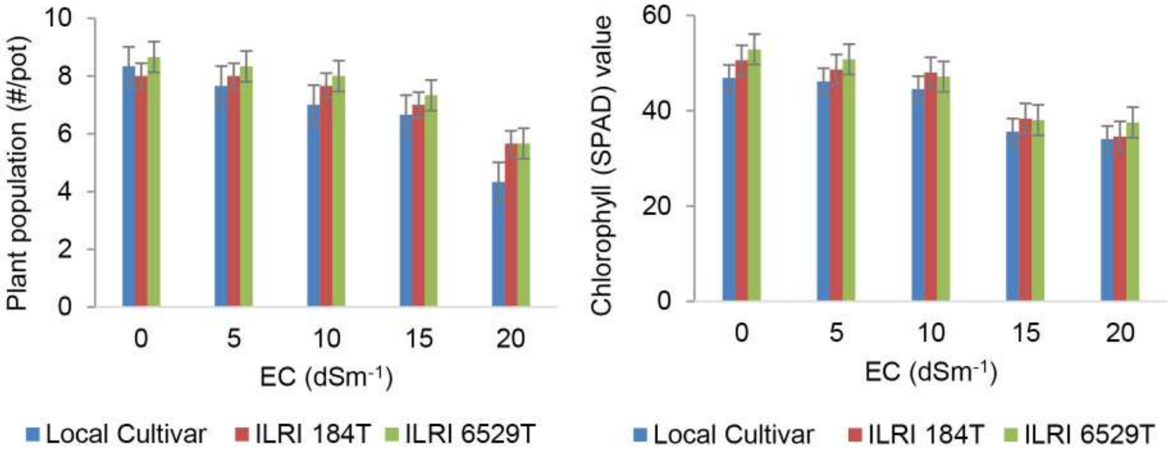


Figure 19. Plant population and SPAD value of three Lablab genotypes at different salinity levels.

The average chlorophyll (SPAD value) content of three Lablab genotypes was recorded as 50.1, 48.6, 46.6, 37.3 and 35.4 at 0, 5, 10, 15 and 20 dSm-1, respectively (Figure 21). ILRI-6529T and ILRI-184T produced higher chlorophyll (SPAD value) content than the local cultivar. The maximum SPAD value was observed at all salinity levels for ILRI-6529T, followed by ILRI-184T and the local cultivar. The chlorophyll (SPAD value) content was negatively affected at higher salinity levels. At 20 dSm−1, the highest chlorophyll (SPAD value) content was observed in ILRI-6529T (37.6) and the lowest in local cultivar (34.1).

Shoot and root dry matter

The shoot and root dry matter yield was negatively affected by inflated salinity values (Figure 23). At control, ILRI-6529T showed maximum shoot biomass (44 g/plant) followed by ILRI-184T and local cultivar. The shoot biomass for ILRI-6529T was reduced to 39 and 35 g/plant at salinity of 15 to 20 dSm-1, respectively. The local cultivar was the lowest shoot biomass (35 g/plant at 15 dSm-1 and 30 g/plant at 20 dSm-1). ILRI¬6529T genotype proved best for salt tolerance for above-ground shoot biomass.

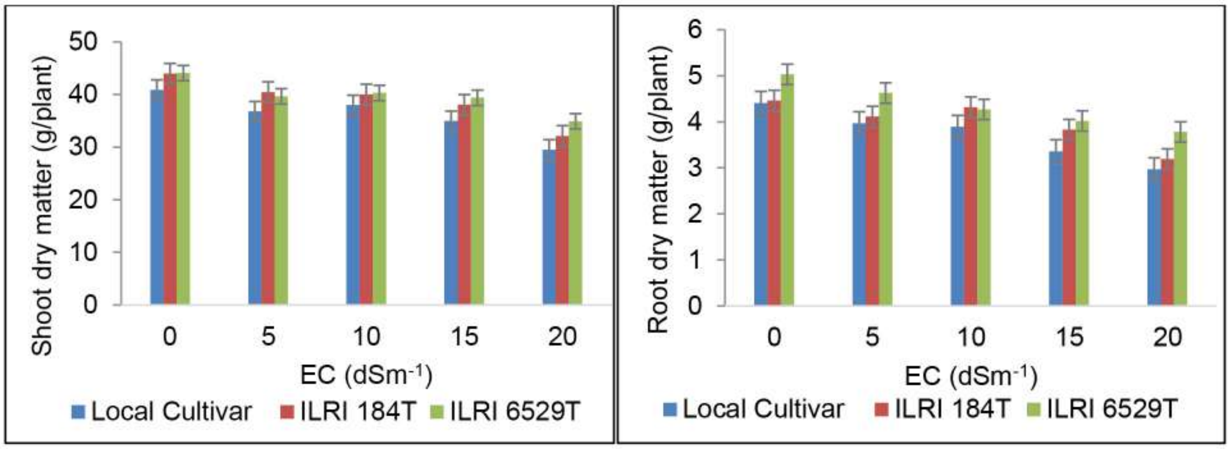


Figure 22. Shoot and root dry matter yield of three Lablab genotypes at different salinity levels.

The root dry matter yield trends were like that of shoot dry matter yield (Figure 23). ILRI-6529T showed the highest root dry matter for all salinity levels, followed by ILRI-184T and local cultivar. The maximum root dry weight for ILRI-6529T and ILRI-184T genotypes was obtained at 5-10 dSm-1. The performance of the local cultivar was the poorest of the other two genotypes. The reduction in dry root matter ranged from 1.2 to 3.9 g/plant with salinity increase from 5 to 20 dSm-1.

Nutrient composition of selected Lablab purpureus genotype

The forages legumes are the cheapest form of animal feed available in terms of quantity and quality. The feeding value of forages is mainly dependent on the crude protein and ash contents. Crude Protein (CP) and Ash content of Lablab purpureus genotype were highly affected at high salt stress. The highest crude protein content (20.91%) and Ash content (20.76%) was obtained in the ILRI-6529T genotype at 0 dSm−1. At the same time, the lowest crude protein (15.93%) and ash content (16.45) were analyzed in the local cultivar of Lablab purpureus (Table 23). However, the local cultivar of Lablab purpureus produced lower CP content at salinity levels of 10-15 dSm-1. Generally, low dry matter producing genotypes have higher nutritional value, and higher dry matter producing accessions have lower nutritive value in terms of CP at lower salinity (Al-Dakheel et al., 2015). The effect of salinity on CP content of ILRI-184T was less pronounced than ILRI-6529T and local cultivar.

Table 23. Effect of salinity on Ash content, CP, and NDF on three Lablab genotypes.

Parameters	Genotypes	NaCl salt level (dSm^{-1})					LSD (p < 0.05)	CV (%)
		0	5	10	15	20		
Ash (%)	Local Cultivar	19.16	18.98	18.20	17.16	16.45	2.45	13.51
	ILRI 184T	20.08	19.98	19.44	18.32	17.43		
	ILRI 6529T	20.76	20.08	19.4	18.29	16.55		
CP (%)	Local Cultivar	18.49	18.31	17.34	16.52	15.93	2.31	16.37
	ILRI 184T	19.67	18.98	18.35	18.21	17.18		
	ILRI 6529T	20.91	19.20	18.15	17.84	16.77		
NDF (%)	Local Cultivar	69.05	68.79	64.42	62.13	59.76	3.87	19.21
	ILRI 184T	74.97	73.23	69.96	66.72	62.16		
	ILRI 6529T	75.93	74.01	70.49	66.11	64.41		

Neutral Detergent Fiber (NDF) mainly consists of hemicellulose, cellulose, and lignin. From the feeding point of view, low NDF is a desirable parameter of fodder and grains. Neutral detergent fiber (NDF) showed an increasing trend with the growing salt stress. Differences in NDF among the Lablab purpureus genotypes were like that of crude protein. The genotypes with lower CP tend to have higher NDF values. ILRI-6529T has the highest NDF (64.41–75.93%), whereas the lowest NDF (59.76–69.05%) was found in CV-massaba for all salinity levels (Table 23).

In general, forage quality increases as CP content increases and NDF decreases. The average In vitro dry matter digestibility content (IvDMDC) was 67.73% for control (0 dSm-1), 67.70% at 5 dSm−1, 64.08% at 10 dSm−1, 60.13% at 15 dSm−1 and 55.99% at 20 dSm−1 (Table 24). The highest IvDMDC was obtained in ILRI-184T at control, while the lowest was observed in the local cultivar of Lablab purpureus at 20 dSm-1. The ME content (MJ kg-1 DM) ranged from around 8.10 for local cultivar at 20 dSm-1 to 10 for ILRI-184T of Lablab purpureus genotype at 0 dSm-1 , with the overall mean of 9.47 MJ kg-1 DM. Generally, forage legumes like Lablab purpureus are of comparable quality with high CP, IvDMDC, and ME levels and low detergent fiber fractions.

Table 24. Effect of salinity on IvDMDC and ME on three Lablab genotypes.

Parameters	Cultivar	NaCl salt level (dSm^{-1})					LSD (p<0.05)	CV (%)
		0	5	10	15	20		
IvDMDC (%)	Local Cultivar	66.68	66.09	63.04	58.9	54.02	3.78	14.69
	ILRI 184T	69.19	68.86	65.14	60.16	57.44		
	ILRI 6529T	67.33	68.15	64.07	61.33	56.53		
ME (MJ kg $^{-1}$)	Local Cultivar	10.00	9.91	9.46	8.84	8.10	1.53	13.97
	ILRI 184T	10.38	10.33	9.77	9.02	8.62		
	ILRI 6529T	10.10	10.22	9.61	9.20	8.48		

(IvDMDC = in vitro dry matter digestibility content; ME = metabolizable energy; LSD = Least Significant Difference; CV = Coefficient of Variation)

04

FIELD EVALUATIONS IN SOUTH SUDAN

4.1 Trial sites in South Sudan

Field trials in South Sudan were conducted in five regional states. These sites were selected in collaboration with the representatives of the Ministry of Agriculture and Food Security, local research organizations, and research scientists. The chosen locations include Juba, Bor, Aweil, Kapoeta, and Renk regions (Figure 23). For each selected state, the number of sites was chosen as listed below:

1. **Jubeik State (Juba)** -Juba, Luri, and Rajaf
2. **Jongule state (Bor)** -Bor town, Panliet and Cuei Nyok)
3. **Aweil State (Aweil)** -Nyalith, Awulic, Rice Scheme Nogwe, and Kuom
4. **Namurnang state (Kapoeta)** -Kapoeta, Katico, Lomilmil and Kotomo
5. **East Nile state (Renk)** -Renk, Rumeila, Mangara, Khor Ajais, Abu Khadra and Feyuer

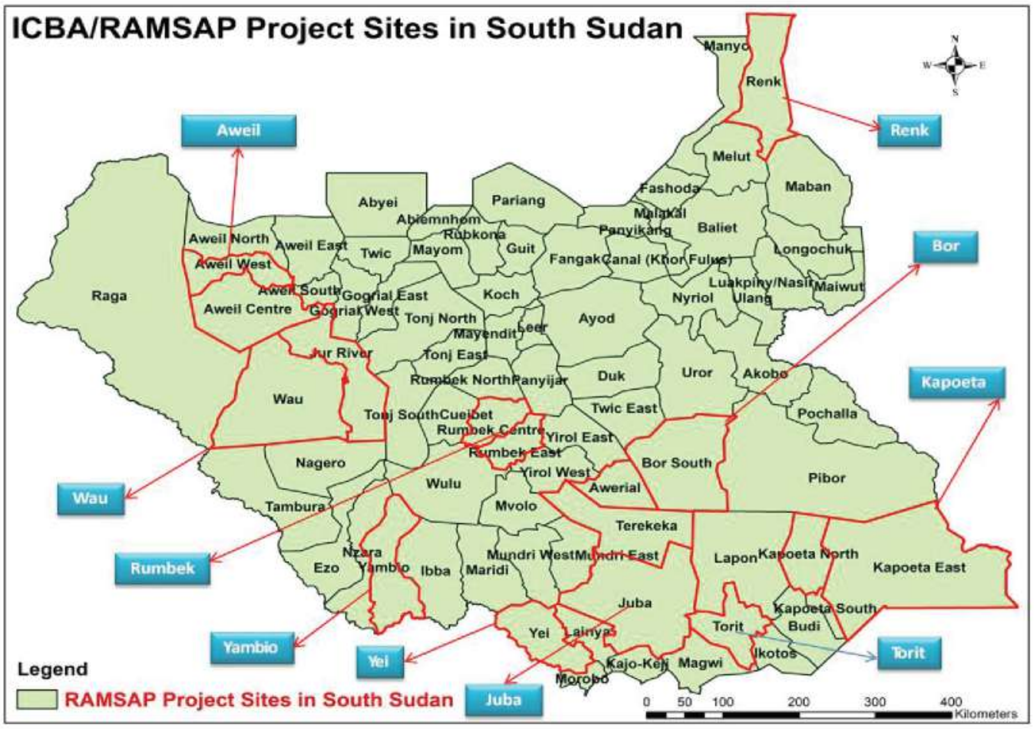


Figure 23. Location of the selected sites in South-Sudan.

Table 25. General characterization of selected sites in South Sudan.

No.	Site	Zone	Type of Crops
1	Aweil	Western Flood Plains	(Agro pastoralism): livestock and agriculture predominant. Main crops are sorghum, pearl millet, vegetables, cow peas.
2	Bentiu	Nile-Sobat Rivers	(Agro-pastoralism and fishing): prone to seasonal flooding. Major crops sorghum, beans, and vegetables.
3	Bor	Nile-Sobat Rivers	(Agro-pastoralism and fishing): prone to seasonal flooding. Major crops include sorghum, beans, and vegetables.
4	Torit	Hills & Mountains	Agriculture and livestock husbandry. Crops include cassava, sweet potatoes, sorghum, maize, finger, pearl millet.
5	Juba	Hills & Mountains	Agriculture and livestock husbandry. Crops include cassava, sweet potatoes, sorghum, maize, finger, pearl millet.

During the field trials, different genotypes of Barley, Sorghum, Cowpea, Sesbania, and Peal Millet were tested on farmer fields. These genotypes were provided by ICBA as listed in Table 26. These trials aim to test the growth and yield parameters of selected crop varieties under local soil and climatic conditions before they can be

Table 26. List of food and fodder crop seeds imported from ICBA gene bank.

Common name	Scientific name	ID	Origin
Barley	*Hordium vulgare*	CM72	Egypt, Ethiopia, Tibet
Barley	*Hordium vulgare*	58/1A	Egypt, Ethiopia, Tibet
Cowpea	*Vigna unguiculata*	TVU9716	Africa, Latin America, South Asia
Cowpea	*Vigna unguiculata*	9333A	Africa, Latin America, South Asia
Cowpea	*Vigna unguiculata*	11114A	Africa, Latin America, South Asia
Sesbania	*Sesbabia sesban*	ILRI 9643	Tropical Africa and Asia
Sesbania	*Sesbabia sesban*	ILRI 1178	Tropical Africa and Asia
Sesbania	*Sesbabia sesban*	ILRI 1198	Tropical Africa and Asia
Sorghum	*Sorghum bicolar*	ICSV700	Northeastern Africa
Sorghum	*Sorghum bicolar*	ICSR93034	Northeastern Africa
Pearl Millet	*Pennisetum glauccum*	IP13150	Sahel zone of West Africa
Pearl Millet	*Pennisetum glauccum*	IP19586	Sahel zone of West Africa

Different crops grown on farmer fields in South Sudan

4.2 Results of field trials

Testing of improved varieties was considered among the best strategies to improve production and faster and obtaining information about different crop varieties for specific areas. Therefore, ICBA varieties of cowpea, pearl millet, sorghum and the various grasses could be grown in all the States in South Sudan where the demonstrations were established to maximize the yield potential for the small holder farmers. They recorded high clean seed weight low severities for major common diseases and were relatively more stable throughout the vegetative and maturity stages compared to the local varieties used as checks. It is worth mentioning that South Sudan have trends of preferences both for the cereals and legumes therefore, the varieties that resemble the farmers' preference may be highly important in promoting adoption.

The performance of the ICBA varieties is highly dependent on the farmer management and cropping system. This was noted on the differences in the performance of the varieties under on-farm demonstrations within different seasons. The wide range of growth habits among ICBA varieties has enabled the crops to be cultivated successfully under different agro-ecological environments of South Sudan. Most of the varieties were favoured by farmers because of their early maturing uniqueness that enables households to get cash returns essential to pay for food and other household needs when other crops have not yet matured. Thus, it is essential to educate and create awareness to farmers to cultivate ICBA seeds or grains as business rather than just for subsistence use.

Field preparation for demonstration and field trials

These crop genotypes were planted on farmer fields in all selected regions under the supervision of local agriculture and extension departments. The field size of the trial site was 3x3 feddans, with 48 blocks sized 5x5m. The trial was designed in a Randomized Complete Block Design (RCBD) with three replications. These trials were also used as demonstration fields to neighboring farmers. The data on different parameters of crop growth is being collected from all trial sites. The promising genotypes from these field trials will be used for seed multiplication for scaling up.

During the field trials, ICBA genotypes recorded higher seed weight, low severities for common diseases, and more stability throughout the vegetative and maturity stages than the local varieties used as checks. It is worth mentioning that South Sudan has preferences for cereals and legumes; therefore, the crops that resemble the farmers' choice may be significant in promoting adoption (Table 27). The performance of the ICBA varieties is highly dependent on the farmer management and cropping system. The wide range of growth habits among ICBA varieties has enabled the crops to be cultivated successfully under different agro-ecological environments of South Sudan. Farmers favoured these varieties because of their early maturing uniqueness that allows them agro-ecological environments of South Sudan. Farmers favoured these varieties because of their early maturing uniqueness that allows them to get cash returns essential to pay other household needs. Thus, farmers should cultivate ICBA seeds or grains as a business rather than subsistence use.

At the same time, seed multiplication of the selected genotypes was done for scaling up in the designated areas. These activities were carried out along the River Nile and where the water source was available. Two locations such as Rajaf-East and Kapuri, were selected around Juba. In the Rajaf-East area, field activities were conducted on farmer fields by selecting individual active farmers. In Kapur, field demonstrations were carried out in Farmers' Training Center. Farmers were provided all inputs, i.e., the entire operation cost (Land preparation, sowing, weeding, irrigation, pesticides in case of any infection, technical supervision, and harvest). Farmers were responsible for field operations.

Table 27. Selected results of field trials on different crops.

Site	Crops	Variety	Germination rate (%)	Flowering (Days)	Height at flowering (cm)	Grain wt/plant	Plant dry weight
Juba	Sorghum	ICSV-700	80	120	137.2	16.5	12.5
	Sorghum	ICSR-93034	75	120	147	18.2	15.5
	Peal Millet	IP-13150	70	63	110	5.3	3.2
	Barley	CM-72	86	64	123	4.5	2.3
	Cowpea	11114A	75	60	35	8.5	6.3
Kapoeta	Barley	58/1A	86	64	123	4.5	2.8
	Sesbania	ILRI-1198	85	60	66	5.1	3.2
	Sesbania	ILRI-9643	83	62	52	5.5	3.2
Aweil	Cowpea	TVU-9716	80	70	108	6.5	4.3
	Sesbania	ILRI-9643	85	60	66	5.1	3.2
	Sesbania	ILRI-1198	83	62	52	5.5	3.2
Bor	Cowpea	TVU-9716	65	63	52	6.5	4.5
	Sesbania	ILRI-9643	85	60	60	10.5	8.3
	Sesbania	ILRI-1198	80	60	51	8.7	5.3
Renk	Sorghum	ICSR-93034	80	120	163	22.5	18.5
	Peal Millet	IP-13586	85	60	110	5.5	3.2
	Peal Millet	IP-13150	88	62	105	3.5	3.3

Different crops grown on farmer fields in South Sudan

4.3 Managing irrigation at trial sites

Two water sources (i.e., river Nile and groundwater) were used for field demonstrations and trials. Water from the Nile is pumped to irrigate the demonstration and seed multiplication plots at the riverbank in Rajaf East whereas electric motor was used to extract groundwater to a storage tank located at the center of the field in Kapuri farmers training center. Realizing the fact that without continued supply of irrigation water, field trials and field demonstration of successful varieties will not be possible, RAMSAP project supplied water pump to the farmer in the Rajaf-East site to extract water from the Nile River for irrigation. In Kapuri, the farmers training center have a well-established water pump system, but it was out of service due to some technical breakdown. Therefore, RAMSAP project did the maintenance and now it is used to irrigate the cropped fields. In both locations, farmers were extremely happy for this assistance because now they can irrigate project fields as well as their fields where they have grown other local forages and cereals.

As mentioned earlier, access to irrigation water and its distribution within the field to increase water use efficiency and crop productivity is one of the biggest challenges for the smallholder farmers in South Sudan. Farmers usually do not have enough cash and technical skills to install irrigation systems in their fields. Therefore, under this project, a low-cost drip system was designed and installed at Juba field site. This system can be operated by using both groundwater and surface water from the river. Instead of traditional costly rubber pipes, this drip system has been designed using locally made PVC pipes of different sizes. These pipes are cheap and durable and cannot be damaged by rodents (Figure 24). The system can effectively work for 10 years if properly maintained.

This system can be re-adjusted to different crops to be grown in each season. The system has got great acceptance by farmers due to its low-cost and ease of operation and maintenance. To ensure sustained irrigation water supply to crops, a groundwater well (6m deep) was also installed at this site. At other four sites, irrigation water was pumped from the nearby rivers therefore no groundwater wells were planned.

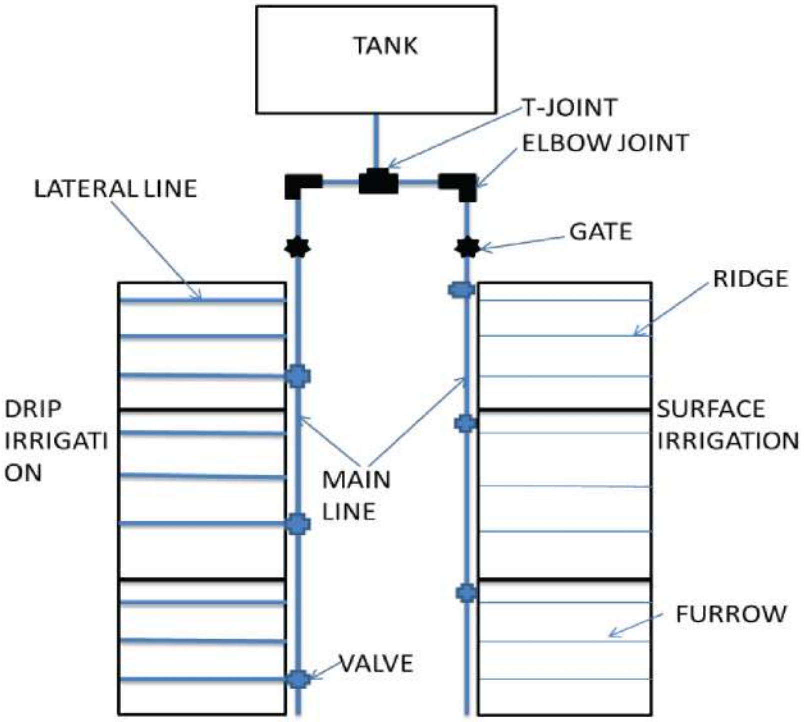


Figure 24. Layout of the installed irrigation system at Juba

Before the commencement of field activities, farmers were trained on the use and maintenance of the water pump for irrigation purposes. Supply of irrigation water is very crucial in South Sudan especially in the dry season because majority of farmers rely on small plots along the river Nile to produce vegetables for domestic and commercial purposes. Farmers highly appreciated the introduction of ICBA salt-affected crop varieties. These farmers consider them very good for increasing their production and farm incomes. The farmers from nearby villages also came to see the crops grown by ICBA seed and they asked for seed as well. Therefore, it was agreed that after the harvest of crop, seed will be distributed to these farmers as part of our scaling up activities. It was proposed and agreed that each farmer who will get seed from ICBA will further distribute it to at least 5 farmers to multiply the benefits for the rural community. This model will enhance cooperation among farming communities. Through this initiative, farmers will also learn from each other's experience about the management of soil and water resources for increasing their productivity.

Field activities in Rajaf-East and Kauri field sites.

This project has enabled Linkages' development between local seed companies and MoA through meetings, farm/field visits, and telephone calls. Consequently, seed companies are also multiplying cowpea seed. The Gumbo Glow seed companies visited the field sites and promised to start setting up demos on their fields by the first season of 2020, and after that, they can take over the multiplication of seeds. The seed companies also showed interest in ICBA materials which were still under evaluation.

Based on the field trial results, 11 genotypes were selected for field demonstration and seed multiplication purposes (Table 28). The demonstration fields were established according to the ICBA recommended protocol whereby each crop variety was planted in 10*10m plots. For seed multiplication, farmers were provided with all inputs such as fertilizer, seed, pesticides, and other necessary information about the crop's sowing and care. Farmers were also trained about the harvesting of the crops and separating the seed and keeping it healthy for scaling up. During the crop growth period, the field staff of the DRT continues visiting field sites to monitor the progress and guide farmers.

Table 28. Genotypes multiplied in South Sudan for scaling up

S/N	Crop	Variety	Origin
1	Cowpea	ILRI 12713	ICBA
2	Cowpea	ILRI 9331	ICBA
3	Cowpea	AGRAC01	South Sudan
4	Sorghum	ICSV700	ICBA
5	Sorghum	ICSR93034	ICBA
6	Sorghum	Gadam	South Sudan
7	Grass	Sesbania 1198	ICBA
8	Grass	Chloris gayana	ICBA
9	Peal Millet	IP 13586	ICBA
10	Peal Millet	IP 13150	ICBA
11	Peal Millet	Local	South Sudan

4.4 Field challenges and opportunities

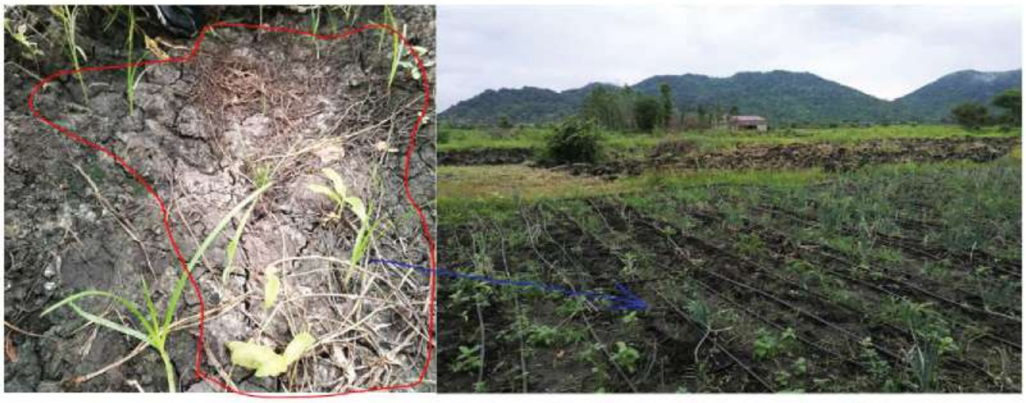
(a) Effect of saline groundwater use on drip irrigation system and soil

Some progressive farmers in South Sudan used saline groundwater to irrigate their crops with the newly developed drip irrigation system (Figure 24). They are getting good crop yields; however long-term use of this practice may increase salinity of their soils. Therefore, appropriate irrigation management practices need to be adopted to avoid soil fertility losses. Factors affecting root zone salinity under drip irrigation include the amount and salinity of the applied water, soil hydraulic properties, design of drip irrigation system and the quality of groundwater.

To reduce the negative impact of saline groundwater, use by farmers, ICBA-RAMSAP project designed a comprehensive training to educate farmers on the following:

a) Effects of saline water in irrigation
b) Required amount of saline water for a given crop.
c) Soil hydraulic characteristics in response to salt water
d) Placement of drip lines relative to plant rows subsurface vs. surface drip lines, and under saline, shallow ground water conditions, the ground water depth and salinity

Drip irrigation system for saline groundwater at Juba



Effect of saline groundwater on soils

(b) Challenges and opportunity of flood in the Bor area

Most of the farming systems in South Sudan are rainfed. Public irrigation projects in the area have resulted in rather modest outcomes, because of the high upfront financial investment and the burden of operation and maintenance costs. Full control irrigation systems (canals, gravity systems, etc.) require high initial capital investment. Their maintenance also requires both significant skills and strong institutional arrangements. In the current situation of flood in some areas in South Sudan, innovative agricultural water management solutions can help to mitigate floods. It is, therefore, essential to investigate alternative and complementary options to rainfed agriculture and public irrigation schemes to increase food production.

In the areas dominated by flood-prone lands (Northern parts of South Sudan), exercising flood recession agriculture can potentially be an effective solution to meet the food requirements of rural populations and increase their incomes. In many parts of the world, flood recession farming is used to harness flood water for productive agricultural use. While the frequency of flood events seems to be increasing, it is possible to take advantage of floods and increase overall annual agricultural production by growing adapted crops once the flood waters recede. Floods bring fertile nutrients and increase residual soil moisture, making flood-prone lowlands favorable to productive farming activities for several staple crops such as rice, maize, sorghum, soybean, potatoes, and melons. Poor and vulnerable communities living around rivers, lakes, and wetlands use flood recession farming as a strategy to sustain their livelihoods (Motsumi et al., 2012). Therefore, flood recession farming could be a practical solution for food security and water management.

Effects of floods on farmers' fields in the Bor area

(c) Challenges of agricultural land clearance

Agricultural land availability is not a problem in South Sudan, but clearance of a virgin land for large-scale agriculture is the main challenge faced by group and individual farmers. Establishment of new farm or expansion of farm size requires clearance of tress due to nature of land in South Sudan which is mostly covered by dense forest. The most dominate factors affecting land preparation/clearance are as follows:

- High cost of hiring heavy duty tractors
- High cost of employing hand labors
- Lack of proper road for the machine and people to access the required areas.

The obstacles on farmland that need to be cleared before a viable agriculture can practice on these lands is shown in below picture. As farmers lack resources to clear their land for cultivation, farmland is mostly kept with obstacles (small trees or tree roots) that restricts faming activities such as difficulties in working with the agricultural machinery such tractors and plowing equipment. The presence of some parts of a tress on the farmland makes it easier for the spread birds, rats or other harmful animals such as snake. These predators are thread for both crop and farmers.

Land preparation challenges in the Torit area

05

CONCLUSIONS AND RECOMMENDATIONS

The rising global demand for food has challenged scientists to look for alternate crops, especially for the marginal areas where agricultural production is inefficient due to unfavorable climatic conditions, low soil fertility, and lack of good quality irrigation water. In many Middle East and African countries, scientists experiment with different crops tolerant to salinity and use much less water than other crops. Against this backdrop, this study was designed to assess the feasibility of genotypes of different crops for the dry and saline soil under controlled and field conditions. The seed germination and crop yields were adversely affected by the rising salinity. The salinity impedes seed germination either without loss of viability at higher salinities and/or by inducing stress to seeds. The effects of five soil salinity levels on the agronomic and nutritional quality parameters were evaluated on different food and fodder crops under other agro-climatic conditions in Ethiopia and South Sudan. The main findings for each crop are briefly discussed below:

The tested barley genotypes showed significant differences in grain yield, dry biomass yield, and spike length. However, differences in days to 50% emergency, days to 50% maturity, number of tillers per plant, and plant height were non-significant. The CM-72 genotype performed superior in terms of grain yield compared to CM-58/1A. However, the highest dry biomass yield was recorded in CM-58/1A. Both genotypes performed better in relatively less saline and wet regions. This shows that these genotypes are suitable for the less salty and wet part than dry, hot, and saline areas.
Sorghum genotypes also showed significant differences in all parameters except panicle length at high salt stress. Among the sorghum genotypes, Melkam was superior in terms of grain yield than ICSR-93034 and ICSV-700 genotypes. However, ICSR-93034 and ICSV-700 genotypes produced higher dry matter yields than the local Melkam genotype. This made these genotypes highly attractive for animal feeds. Farmers prefer these two varieties because they have reasonable grain yields and significantly higher biomass.

Under field conditions, the IP-13150 genotype produced higher grain and dry biomass yield compared to the IP-19586 genotype. The highest dry biomass yield was recorded in IP-13150, which is very important for animal feeds. The field data shows that pearl millet varieties produce more than 1.0 tha-1 grain yield and around 10 tha-1 dry biomass yields under highly saline field conditions. These are very encouraging results for the highly saline areas of Ethiopia. This shows that these two ICBA introduced varieties (IP-13150 and IP-19586) can successfully be grown to improve the productivity of saline lands. The soils of the Werer research station are also high in ESP, which means that these pearl millet genotypes can also survive in alkaline soils. Therefore, these varieties should be introduced to farmers in saline areas.

The cowpea genotypes also showed significant differences in all growth parameters under field conditions. The ILRI-9643 genotype performs superior grain and biomass yield than the other two tested genotypes (ILRI-9334; ILRI-12713). The grain and dry biomass yield of ILRI-9643 was higher than the two different genotypes. This shows that this cowpea genotype is more suitable for high lands with relatively lower temperatures and higher rainfall. Therefore, it would be wise to recommend these varieties for this area.

The three Rhoades grass (Chloris gayana) genotypes (ILRI-6633; ILRI-7384 and CV-massaba) for dry and hot conditions of Ethiopia were evaluated. The highest germination rate, lowest germination time, maximum plant height, and the number of tillers per plant were observed in ILRI-6633 compared to ILRI-7384 and CV-massaba. For all genotypes, root length was more affected than the shoot length at all salinity levels. Increasing soil salinity negatively affected the shoot and dry root matter of three Chloris gayana genotypes. The reduction in dry shoot matter was more noticeable at the higher salinity levels (15-20 dSm-1).

The Chlorophyll content was consistent up to 10 dSm-1. However, a significant reduction was observed at higher salinity levels (15-20 dSm-1). The most elevated crude protein (CP) and Ash content (AC) values were obtained for ILRI-6633 and ILRI-7384 at 5 dSm−1. From the feeding point of view, lower values of Neutral detergent fiber (NDF) are desirable. NDF values showed an increasing trend with the growing salt stress. The genotypes with lower CP values tend to have higher NDF values. On average, maximum NDF values were found in ILRI-6633 and the weakest in CV-massaba. The average In vitro dry matter digestibility content (IvDMDC) also showed decreasing trend with the increasing salinity levels. This means Chloris gayana forage grass has higher digestibility. In conclusion, ILRI-6633 was the most salt-tolerant, high-yielding, and better nutritional forage grass than the other two genotypes. CV-massaba is superior to the two different genotypes in terms of germination under saline conditions.

There are considerable differences in various plant growth parameters with the increasing salinity on five quinoa genotypes. The most limiting factor for decreased plant growth was the reduction in photosynthesis expressed in the production of chlorophyll. We suggest that plant breeding should focus on developing new genotypes that can withstand salinity and have high antioxidant activity in the future. In this study, the performance of ICBA-Q3 was superior, followed by ICBA-Q4 and ICBA-Q5. However, further optimization of these genotypes is recommended to enhance their productivity.

The agronomic and nutritional composition of three L. purpureus genotypes (ILRI-6529T, ILRI-184T, local cultivar) showed a declining trend with the growing salt stress. The results of this study indicate that the ILRI-6529T and ILRI-184T genotypes performed superior compared to the local cultivar in terms of all agronomic and nutritional parameters at all salinity levels. Therefore, these two genotypes can be grown in salt-affected areas to increase the productivity of the livestock sector.

The agronomic and nutritional composition of two Sesbania sesban genotypes (ILRI-1198, ILRI-1178) and local cultivar) showed a declining trend with the growing salt stress. Both genotypes gave the highest maximum shoot and root length compared to local genotypes. For all genotypes and salinity levels, shoot length was less affected than root length. The shoot and dry root matter were affected more under high soil salinity conditions. The chlorophyll content (SPAD value) showed a falling trend at 15-20 dSm-1. The CP and IvDMD contents were higher for ILRI-1198 and ILRI-1178 genotypes compared to local genotypes. IvDMD content and metabolizable energy content were also negatively affected by increasing salinity.

In South Sudan, ICBA genotypes also recorded higher seed weight, low severities for common diseases, and more stability throughout the vegetative and maturity stages than the local varieties used as checks. It is worth mentioning that South Sudan has preferences for cereals and legumes; therefore, the crops that resemble the farmers' choice may be significant in promoting adoption. The wide range of growth habits among ICBA varieties has enabled the crops to grow under different agro-ecological environments of South Sudan. Farmers favoured these varieties because of their early maturing uniqueness allows them to get good cash returns. Thus, farmers should cultivate ICBA seeds as a business rather than subsistence use.

At the same time, seed multiplication of the selected genotypes was done for scaling up in the designated areas. These activities were carried out along the River Nile and where the water source was available. Two locations such as Rajaf-East and Kapuri, were selected around Juba. In the Rajaf-East area, field activities were conducted on farmer fields by selecting individual active farmers. In Kapur, field demonstrations were carried out in Farmers' Training Center. Farmers were provided all inputs, i.e., the entire operation cost (Land preparation, sowing, weeding, irrigation, pesticides in case of any infection, technical supervision, and harvest). Farmers were responsible for field operations.

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BRIEF ABOUT THE RAMSAP PROJECT

Background

Increasing salinity remains a challenge to the sustainability of irrigated agriculture in Ethiopia and South Sudan as it reduces natural biodiversity and farm and livestock productivity. The agricultural sector in Ethiopia supports 85% of the workforce. About 85% of the population living in rural areas is directly dependent on agriculture for their livelihood. Seven million smallholder farmers produce more than 95% of the total agricultural outputs, including food crops, cereals, oilseeds, and pulses. Cotton and sugar are grown in state-owned large-scale enterprises. Ethiopia also has enormous livestock resources, including cattle, sheep, goats, and camels. Despite high biodiversity and distinctive ecosystems, food shortages are widespread, and since 1970 there have been severe famines almost once per decade.

Land degradation is considered one of the major causes of low and, in many places, declining agricultural productivity and continuing food insecurity, and rural poverty in Ethiopia. Today, Ethiopia stands first in Africa in salt-affected soils due to human-induced and natural causes. Currently, about 11 million ha (Mha) land in Ethiopia is exposed to salinity and sodicity, out of which 8 Mha have combined salinity and alkalinity problems. In contrast, the rest 3 Mha have alkalinity problems. About 9% of the population lives in salt-affected areas. The saline areas in Ethiopia are in the Awash River basin, and the situation is expected to exacerbate due to climate change-induced factors. There is an urgent need for salt-affected soils to be restored to their production potential to produce enough food for the rising population.

In South Sudan, agriculture accounts for 36% of the non-oil GDP, with 80% of the population living in rural areas largely dependent on subsistence farming and 75% of the households consuming cereals as a prominent part of their daily diet. Despite abundant water supplies, only 5% of the total 30 Mha arable land is cultivated. Crop yields are low, which negatively affects the incomes and livelihood of poor farmers. Significant barriers are lack of agricultural inputs such as seed and fertilizer, poor advisory services, and inefficient irrigation management. Although South Sudan has the highest livestock per capita globally, with 23 million cattle heads, sheep, and goats, there is little use of improved seed or breeds of livestock. For increased livestock productivity, there is a need to introduce improved forage varieties resistant to common diseases. The salt-affected lands in South Sudan are in the White Nile irrigation schemes. These areas have not been utilized for agricultural production despite availability of freshwater from the Nile. Therefore, bringing degraded lands to production is essential to ensure food security and social stability.

With a 3% average population growth in these countries, future food security and the livelihood source for a considerable portion of the population remains a challenge to the governments. 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 both countries can increase their agricultural productivity and farm incomes if their technical and financial capacity is enhanced. They need 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 these countries, access to inputs will be a dividing line between poverty and well-being.

The areas of low to moderate salinity levels can be restored by improving 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 of salt-tolerant fodders and halophytes integrated with livestock and appropriate management systems. These integrated crop-forage-livestock feeding systems can increase resilience of smallholder farmers who are largely dependent on the livestock sector.

This project will devise a strategy to improve the productivity of saline soils to an economically feasible level and minimize future salinity development in these areas. The project will draw on past work's successful experiences to identify the most productive alternative crop and forage production systems and devise a strategy for scaling up these production packages to improve livelihood of rural communities, especially women in the target areas of both countries. Through enhanced crop yields and reduced land degradation, the project will improve farmers' resilience, thereby reducing migration to cities and health problems due to stress on families suffering from the impact of salinity on their livelihoods.

Project Goals and Objectives

The project's overall goal is to attain higher agricultural productivity, food security and income for smallholder farmers, agropastoral/pastoral communities through rehabilitation and sustainable management of irrigated salt-affected farming areas of Ethiopia and South Sudan. The main objective of this project is to introduce and promote appropriate technologies and practices for rehabilitation and management of salt-affected lands in Ethiopia and South Sudan and draw lessons for scaling up.

The Target Group

The project will directly target 5,000 smallholder farmers in selected areas in Ethiopia and South Sudan who face high food insecurity due to their high dependency on marginal water and land resources. The indirect beneficiaries will be about 50,000 farmers (40,000 farmers in Ethiopia and 10,000 farmers in South Sudan) dependent on forage production in both countries with an estimated total area of about 200,000 ha (150,000 ha in Ethiopia and 50,000 in South Sudan). These targets will be achieved by producing and distributing tested crop and forage seeds, disseminating improved soil and water management practices, and training farmers and extension workers in the target areas.

The rehabilitation of degraded lands will improve the livelihood of 9% of the population of Ethiopia which lives in salt-affected areas. In South Sudan, where 7% of 30 Mha of land is being cultivated, rehabilitation and management strategies developed under this project will open a window of opportunity for thousands of rural farmers to improve the productivity of their degraded lands and increase their farm incomes. The outcomes of this project will significantly benefit women as they will have better access to food and health facilities. The transformation of degraded lands into productive lands will also create direct and indirect job opportunities for the large young population. This will help in reducing the migration trends of unemployed youth from rural areas to urban areas.

The project will target Ethiopian highlands (Tigray, Amhara, and Afar) and lowlands (Omara and Somali), which produce 87% of cattle and 5% of its sheep and goats; however, land degradation has reduced farm and livestock productivity of these areas resulting in rural poverty. The developed crop-livestock value chain system will benefit Ethiopia because this is the largest livestock producer in Africa.

The project will target the White Nile irrigation schemes (50,000 ha area) in South Sudan. These soils have an immense potential due to the availability of fresh water from the White Nile River and its tributaries which run through 7 out of 10 states, providing ready access to an abundant water supply and river transport access for agriculture producers. However, these soils are not being cultivated for decades due to low soil fertility and the non-availability of good quality seeds for crops and forages. Currently, 18% of the land is not cultivated because of seed shortage, and 9% is due to low soil fertility. Increasing the productivity of these lands will be crucial to ensure food security for the smallholder farmers of the area.

Strategy, Approach and Methodology

This project will adopt an integrated soil and water management approach to tackle the salinity problems in irrigated areas of both countries. The project strategy would be first to diagnose the issues and then develop long-term mitigation, management, and rehabilitation strategies at the farm and regional level relevant to the problem using proven and high-level international salinity science and management. Since the rehabilitation of saline soils through engineering or chemical amendments is an expensive and time-consuming process, this project will work on adaptive and mitigation methods to rehabilitate these soils.

This project will adopt a participatory approach to conduct field trials in different parts of both countries to test the suitability of local and imported crop and forage species to rehabilitate salt-affected soils. Adaptation trials will be conducted at the Farmers Training Centers (FTCs) and volunteer farmers' plots in collaboration with the national partners. These trials will also be used for demonstration purposes before scaling up. The project team will jointly implement the best management practices for salinity control at the farm level. Smallholder farmers (especially women and young farmers) will be trained to establish seed/gene banks at the community level. ICBA has successfully applied this approach in SSA.

The project will generate and disseminate sustainable integrated crop-livestock technology packages to diversify farmers' incomes through the sale of animal products and forages to local markets, thus making the production systems economically sustainable. However, salt-tolerant forage plants are variable in biomass production and nutritional value. The available salt-tolerant forages have not been selected or managed for improved livestock production. For this reason, they need to be tested locally for their (a) edible biomass production; (b) nutritional value (i.e., the response in animal production per unit of voluntary feeding intake), and (c) the use of micronutrients and nutraceutical properties.

The project will address gender equality and social issues as cross-cutting themes in each area. The project will include the most vulnerable groups of the society to ensure that the interventions benefit poor farmers and households. Since rural women play a crucial role in undertaking agricultural and livestock activities, enhancing their knowledge and capacity will be one of the main targets of this project.

Project Outcomes and Impacts

The immediate outcome will be the full implementation of new salt-affected management strategies within the pilot sites with related benefits to farming communities and land management organizations. The long-term effect will be new thinking and awareness about the new salinity management approaches and implementation of overall system reform. This, in turn, will lead to out-scaling of production packages beyond the project area through project partners, including key government organizations. The successful implementation of the above activities will increase the productivity of salt-affected lands, which will positively contribute to the country's economy and reduce rural poverty. The overall impact of the project will be revitalized agriculture in Ethiopia and South Sudan.

Scaling up Pathways

The critical element of this project is to pilot innovative strategies and approaches for the rehabilitation and management of salt-affected soils and then “scale up' recommended technologies to reach up to a more significant number of rural poor. All activities of this project will be carried out with the involvement of local rural communities. Once convinced, these communities will act as the champions of change and critical drivers in the process of scaling up. For successful scaling up, policy support and institutional infrastructure is very crucial. Opportunities and constraints that may affect the scaling up process will be critically evaluated during the pilot stage. For long-term sustainability, the overall impact of the alternative production systems on the lives of the rural poor, natural resources and environment will be reviewed.

Socio-Economic and Environmental Impacts

The project will develop modified approaches to improve water management for salinity control and demonstrate best soil management practices for different salt-tolerant crops and forages. Adopting alternative crop and forage production systems will reduce the area lost to salinity degradation, bring income to farmers, and improve the livelihood of poor rural communities, especially women. The transformation of salt-affected lands into productive lands will also contribute directly to poverty reduction by increasing fuelwood, construction materials, wild foods, and medicinal plants.

ABOUT THE INTERNATIONAL CENTER FOR BIOSALINE AGRICULTURE (ICBA)

ICBA is a not-for-profit, international center of excellence for research and development in marginal environments. It was established in 1999 through the visionary leadership of the Islamic Development Bank (IDB), the Organization of Petroleum Exporting Countries (OPEC) Fund, the Arab Fund for Economic and Social Development (AFESD), and the Government of United Arab Emirates. Through the Ministry of Climate Change and Environment and the Environment Agency – Abu Dhabi extended the agreement with IDB in 2010 and increased their financial support to the Center.

ICBA initially focused on the problems of salinity and using saline water for irrigated agriculture. Over the last 15 years, ICBA has evolved into a world-class modern research facility with a team of international scientists conducting applied research to improve the well-being of poor farmers in marginal environments. In 2013, the Center developed a new strategic direction addressing the closely linked income, water, nutrition, and food security challenges. The new Strategy takes innovation as a core principle and identifies five innovations that form the core research agenda: assessment of natural resources; climate change adaptation, crop productivity, and diversification; aquaculture and bioenergy, and policy analysis. ICBA is working on several technology developments, including conventional and non-conventional water (such as saline, treated wastewater, industrial water, and seawater); water and land management technologies, remote sensing, and modeling for climate change adaptation.

ICBA is a unique institute with a clear mandate and capacity to work on rehabilitating salt-affected lands. ICBA is the custodian of the world's largest collections of genetic resources of crops and forages suitable for salt-affected lands with a proven capacity of seed development and seed multiplication for a variety of environments. In addition, ICBA's long history of workingin Africa with localpartners makes it fully qualified and eligible to lead this project.

The International Center for Biosaline Agriculture (ICBA) is implementing a 4-year project on the "Rehabilitation and management of salt-affected soils to improve agricultural productivity (RAMSAP)" in Ethiopia and South Sudan. The project is funded by the International Fund for Agricultural Development (IFAD) and is being implemented with the technical support of the Ministry of Agriculture (MoA), Ehiopia and the Directorate of Research and Training (DRT), South Sudan. The project is of great importance for both countries as it directly targets resource-poor smallholder farmers, especially women and children, who face high food insecurity due to their dependence on marginal soils. The project is introducing innovative soil and water management practices and salt-tolerant genotypes of food and forage crops that have the potential to grow in marginal areas. In addition, scientists, extension workers and farmers are being trained to improve their capacity for the management of marginal resources. Through improved crop yields and reduction of loss of land to degradation, the project empowers farmers by increasing their resilience against the impact of salinity on their livelihoods.

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