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Performance of Finger millet under salt affected soil

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Abstract
Salt affected soils are very unproductive. Growth and development of crop were hampered by the ill effects of salt affected soils. Due to the physiological stress imposed by the salts, crops fail to uptake essential mineral nutrients and moisture from the soil in the vicinity of its root zone. Finger millet is the widely grown crop in the arid and semi-arid tropics of our country. But most of the arid and semi-arid tropics of our country are dominated with salt affected soils. Hence after realising the importance of this crop, we tried to review the performance of finger millet under salt affected soils.

Keywords: Performance, Finger, salt, affected, soil

Introduction
The current state of competition for land use from housing, bio-energy and industrial sectors coupled with severe water shortages (Godfray *et al*., 2010) and the alarming rate of natural resource degradation and biodiversity loss (FAO, 2011) have necessitated a paradigm shift in the conventional ways and means of food production. While continued development and spread of salt-affected soils (SAS) is seen as a threat to agricultural sustainability, these degraded ecosystems offer immense opportunities to harness the productivity potential through appropriate technological interventions. Even marginal to modest gains in crop yields in such soils would mean dramatic improvements in the lives of thousands of poor farmers in salinity affected regions of the world. In this background, our purpose is to highlight the past achievements, current state of research, emerging challenges and future requirements to sustainably utilize the salt affected soil and water resources.
Soil salinization alone has rendered significant chunks of land unproductive or less productive. Soil salinization is a global and dynamic problem and is projected to increase in future under climate change scenarios, *viz*. rise in sea level and impact on coastal areas, rise in temperature and increase in evaporation etc. Precise statistics on the recent estimates of global extent of salt affected soils are not available and different data sources provide variable information (Shahid *et al.*, 2018).

Characteristics of salt affected soils
Soil reaction (pH) and electrical conductivity (EC) of soil saturation extract, exchangeable sodium percentage (ESP) and sodium adsorption ratio (SAR) are the criteria used to classify the salt-affected soils. Based on these parameters, SAS are classified into two main categories: saline and sodic (Abrol *et al*., 1980) [2]. All soils invariably contain soluble salts, but under certain soil and environmental conditions, excess salts accumulate in the root zone which often deteriorates the soil physical, chemical and biological properties to such an extent that crop production is adversely affected (Rengasamy, 2006) [28]. The excess soluble salts present in saline soils characterized by EC values above 4 dS m^{-1} at 25 °C render them unsuitable to grow majority of the food crops. Similarly, in sodic soils excess exchangeable sodium percentage (ESP >15) adversely affects the growth and development in most crop plants (Abrol *et al*., 1988) [1].

Table 1: Characteristics of salt affected soils

Soil type	pH	EC (dSm^{-1})	ESP
Saline	<8.5	>4.0	<15
Sodic	>8.5	<4.0	>15
Saline-Sodic	>8.5	>4.0	>15

Besides physical and chemical weathering of rocks and primary minerals as the main processes, other factors responsible for the formation and/or accumulation of soluble salts in soils include irrigation with saline groundwater, development of saline creeps due to excessive leaching, ingression of sea water in coastal regions, congestion of natural drainage and seepage from canals, waterlogging due to faulty irrigation practices and localized redistribution of salts. The chlorides and sulphates of Na^{+}, Ca^{2+} and Mg^{2+} are the dominated neutral soluble salts in saline soils. Saline soils have good physical properties and water permeability. White salt crusts on the surface and scattered growth of crops are the indicators of salinity problem (Singh, 2009) [34]. High salt concentrations due to ancient marine deposits, poor drainage and shallow water table conditions often tend to accentuate the salinity problem (Horney *et al*., 2005) [22].

Nearly 147 million ha of land is subjected to soil degradation, including 94 million ha from water erosion, 23 million ha from salinity/alkalinity/acidification, 14 million ha from water-logging/ flooding, 9 million ha from wind erosion and 7 million ha from a combination of factors (Bhattacharyya *et al*., 2015; Mythili and Goedecke, 2016) [26]. Around 6.727 million ha area in India, which is around 2.1% of geographical area of the country, is salt-affected, of which 2.956 million ha is saline and the rest 3.771 million ha is sodic (Arora *et al*., 2016; Arora and Sharma, 2017) [4, 3]. Around 2.347 million ha of the salt-affected soils occur in the Indo-Gangetic plains of the country, of which 0.56 million ha are saline and 1.787 million ha are sodic (Arora and Sharma, 2017) [3]. Nearly 75% of salt-affected soils in the country exist in the states of Gujarat (2.23million ha), Uttar Pradesh (1.37 million ha), Maharashtra (0.61 million ha), West Bengal (0.44 million ha), and Rajasthan (0.38 million ha) (Mandal *et al*., 2018) [24].

In India, the area under salt-affected soils is about 6.73 million ha with states of Gujarat (2.23 m ha), Uttar Pradesh (1.37 m ha), Maharashtra (0.61 m ha), West Bengal (0.44 m ha) and Rajasthan (0.38 m ha) together accounting for almost 75% of saline and sodic soils in the country. In most of the salt-affected environments, prevalence of poor quality (saline and sodic) waters is also noted. The states of Rajasthan, Haryana and Punjab, lying in the north-western arid part of the country, greatly suffer from the problem of marginal quality waters (Singh, 2009) [34]. According to estimates, the present area under salt-affected soils (6.73 million ha) in country would almost triples to 20 million ha by 2050 (Sharma *et al*., 2014a) [30, 33]. The problem of poor-quality waters would also significantly increase in the foreseeable future due to planned expansion in irrigated area and intensive use of natural resources to fulfill the food and other livelihood requirements of an increasing population (Sharma *et al*., 2011) [31, 32].

Finger millet (*Eleusine coracana* L.) is an annual herbaceous plant, widely grown as a cereal crop in arid and semiarid areas in Africa and Asia. Abiotic pressures like salt stress limit the crop growth and yield; also limit the land available for farming. It is thus needed to understand, how plants respond to adverse conditions. By studying the effects of environmental stresses, tolerance in plants may be understood (Joseph *et al*., 2010) [23]. High concentration of soluble salts in the soil moisture of root zone is referred to as salinity in agricultural soils. These concentrations of soluble salts through their high osmotic pressures reduce plant growth by restricting the uptake of water by the roots. As the absorption of nutritional ions is restricted, plant growth is affected (Tester and Davenport, 2003) [36].

Salinity creates two major threats to plant growth: osmotic and ionic stress (Flowers and Colmer, 2008) [28]. Salinity stress alters different physiological and metabolic processes of plants. The responses of these changes are often accompanied by a variety of symptoms such as the decrease in leaf area, increase in leaf thickness and succulence, abscission of leaves, necrosis of root and shoot and decrease of internode lengths (Parida and Das, 2005) [27]. More recently, climate change has shown a trend that leads to differences in rainfall patterns, temperature extremes and soil composition changes, including salinization (Versules *et al*., 2006) [37]. The main aim of this review is to find out performance of finger millet under problematic soil conditions.

Effect of Biochar on soil reaction and soluble salts in sodic soil

The soil reaction is considered to be the most important soil physico-chemical property since it plays a vital role in deciding the availability as well as the uptake of nutrients by the crop. In the present investigation, the soil pH was considerably reduced when compared to the initial soil pH (9.16) in all the treatments that received different rates of biochar either solely or in combination with gypsum. Significantly lower soil pH was observed due to the application of 50% GR plus biochar @ 20 t ha^{-1}. The decrease in soil pH with the application of 50% GR or combination with biochar might be due to the replacement of exchangeable Na^{+} by Ca^{2+} (Izhar *et al*., 2007). Similar decrease in pH of surface and sub soil horizons of salt affected soil due to biochar additions was reported by Luo *et al*. (2017). Wang *et al*. (2016) reported that the biochar additions decreased the soil pH, through the release of H^{+} ion from exchange complex by adding Ca^{2+} or Mg^{2+}. Another likely reason for the decreased pH is due to increased soil CEC by biochar application that helped to promote uptake of cations in plants (e.g. K^{+}, Ca^{2+} and Mg^{2+}), resulting in H^{+} release from roots to balance charges (Hinsinger *et al*., 2003). Besides, the proliferation of acid producing soil microorganisms (Kim *et al*., 2016) due to biochar application might have also decreased the soil pH.

A significant difference in EC was observed due to the application of biochar at different rates and gypsum either solely or in combination compared to control. The increased EC with increasing rates of biochar was observed when it was applied with 50% GR. The highest EC was recorded by 50% GR plus biochar @ 20 t ha^{-1} application. Increase of EC in all treatments over initial level could be attributed to the higher amount of salts contributed by the inorganic NPK fertilizers which was uniformly added through soil application and irrigation water (4.81 dS m^{-1}) applied for pot experiment. The increased EC in soil could also be attributed to the addition of biochar and gypsum, as these amendments had higher EC than soil. Lohan and Dev (1998) reported that the application of organic amendments along with fertilizers increased the EC of soil by the addition of salts through fertilizers and solublization of native minerals due to the reduction in the pH of the soil.

Effect of Biochar on grain and straw yield of finger millet in sodic soil

Grain yield of finger millet was significantly increased with increasing levels of biochar along with gypsum. The data on mean grain yield of finger millet ranged from 7.39 to 8.52 g plant^{-1}. The highest grain yield (8.52 g plant^{-1}) was registered in the treatment that received 50% GR plus biochar @ 20 t ha^{-1} and was on par with 50 % GR plus biochar @ 10 and 5 t ha^{-1}. Crop response to biochar application depends on the physical and chemical properties of the biochar, crop type, climate and soil conditions (Yamato *et al*., 2006; Van Zwieten *et al*., 2010; Gaskin *et al*., 2010; Haefele *et al*., 2011). The results obtained in the present study is agreed with the views of Asai *et al*. (2009) and Major *et al*. (2010) who reported that the applications of biochar resulted in increased crop productivity by improving the physical and chemical properties of cultivated soils. The results are also in line with the finding of Mahmoud *et al*. (2017) who reported that the application of biochar and phosphogypsum significantly increased the grain yield of maize plant.

The results of the present investigation clearly indicates that the biochar @ 20 t ha^{-1} plus 50% GR combination can be used as an amendment in sodic soil for decreasing the soil pH, ESP and SAR besides, increasing the yield of finger millet when compared to sole application of either biochar or gypsum 50% GR. The research findings clearly highlighted the potential benefits of biochar as an amendment to reclaim sodic soils. However, the high cost involved in the production, transport and high application rates of biochar remains a significant challenge to its widespread use. Besides, the pH of biochar feedstock will also have a profound influence in its use as an amendment to reclaim salt affected soils.

Effect of land configuration and nitrogen levels on yield parameters of finger millet in sodic soils

Growth parameters of finger millet were significantly influenced by different land configurations and N levels (Table 2). Among the land configurations, ridges and furrows registered significantly taller plants (98.2 cm), more number of tillers (210 m^{-2}), dry matter production (9932 kg ha^{-1}) at harvest stage and higher leaf area index (4.75) and SPAD reading (39.8) at flowering stage than flat bed. This could be attributed to the fact that higher moisture and nutrients availability under ridges and furrows improved the higher plant height and number of leaves per plant and higher LAI which resulted in more photosynthetic rate and finally higher dry matter production of finger millet. This was followed by broad bed furrows, which recorded higher plant height (95.7 cm), number of tillers (196 m^{-2}), dry matter production (9026 kg ha^{-1}).

Table 2: Effect of land configuration and nitrogen levels on yield parameters of finger millet in sodic soil

Treatments	Flowering stage		Harvest stage		
	Leaf area index	SPAD reading	Plant height (cm)	Number of tillers m^{-2}	Dry matter production (kg ha^{-1})
Land configuration					
M_1-Flat bed	4.09	36.4	91.2	193	8044
M_2-Ridges and furrows	4.75	39.8	98.2	210	9932
M_3-Broadbed furrows	4.29	39.0	95.7	196	9026
S.Ed	0.16	0.20	0.87	4	265
C.D (P=0.05)	0.45	0.54	2.41	11	735
Nitrogen levels					
S_1-100% RDN	3.99	35.0	89.9	190	7875
S_2-125% RDN	4.36	38.7	95.7	201	8956
S_3-150% RDN	4.78	41.4	100.5	211	10172
S.Ed	0.14	0.73	2.37	4	226
C.D (P=0.05)	0.30	1.59	4.65	8	494

*RDN-Recommended Dose of Nitrogen

Source: Nagarajan *et al*., 2018

Table 3: Effect of land configurations and nitrogen levels on grain and straw yields and nitrogen uptake of finger millet in sodic soil

Treatments	No. of productive tillers (m^2)	Finger length (cm)	No. of grains (earhead^{-1})	Earhead weight (g)	Test weight (g)
Land configuration					
M_1-Flat bed	172	5.7	1621	5.7	3.2
M_2-Ridges and furrows	196	6.1	1789	6.4	3.3
M_3-Broadbed furrows	184	5.9	1684	6.1	3.2
S.Ed	4.0	0.08	39.0	0.19	0.03
C.D (P=0.05)	9.1	0.21	84.9	0.40	NS
Nitrogen levels					
S_1-100% RDN	164	5.5	1640	5.6	3.1
S_2-125% RDN	177	5.8	1725	6.0	3.2
S_3-150% RDN	194	6.4	1806	6.6	3.7
S.Ed	3.6	0.20	34.1	0.15	0.9
C.D (P=0.05)	7.9	0.44	77.6	0.29	0.19

*RDN-Recommended Dose of Nitrogen

Source: Nagarajan *et al*., 2018

General management options to mitigate effect of salinity and sodicity:

Sub-surface drainage

The adoption of sub-surface drainage technology in saline soils resulted in 3-fold increase in farmers' income. The yields of paddy, wheat and cotton increased by about 45, 111, and 215%, respectively (Sharma *et al*., 2014a) [30, 33]. Besides, it significantly increased cropping intensity and socio-economic benefits in terms of on-farm employment generation (Singh, 2009) [34]. The subsurface drainage technology was able to generate around 128 man-days additional employment per ha per annum (Sharma *et al*., 2011) [31, 32].

Addition of organic matter

The addition of organic materials in conjunction with gypsum hastens the reclamation process and also reduces the gypsum requirement (Chorum and Rengasamy, 1997; Vance *et al*., 1998; Arora and Sharma, 2017) [3]. Addition of organic material increases soil microbial biomass while gypsum lowers soil pH (Wong *et al*., 2009) [38]. Industrial byproducts such as phosphogypsum, pressmud, molasses, acid wash, and effluents from milk plants help in the reclamation of sodic soils by providing Ca directly or indirectly by dissolving soil lime (Arora and Sharma, 2017) [3].

Integrated agro-forestry systems

Multi-storeyed integrated agro-forestry systems involving fish or shrimp culture, poultry, plantation crops, cattle, and diversified arable crops etc. seem to have potential in these areas. Khan *et al*. (2014) reported an average yield advantage of 20–30% over the existing rice yield of 2.9–3.3 t ha^{-1} by using biocompost @ 2–6 t ha^{-1} in sodic soils of Uttar Pradesh. Promising agro-forestry models, fruit-based agro-forestry models, silvi-pastoral models etc. along with appropriate planting and management techniques have been developed specifically for saline/sodic/saline-sodic etc. conditions (Singh *et al*., 1994; Dagar *et al*., 2008, 2015; Sharma *et al*., 2014b) [18]. Under saline irrigation conditions medicinal and aromatic plants such as isabgol (Plantago ovata), aloe (Aloe barbadensis), kalmeg (Andrographis paniculata), Matricaria chamomilla, Vetiveria zizanioides, Cymbopogon martini, and Cymbopogon flexuosus have been found to produce high biomass (Tomar *et al*., 2003a,b; Dagar *et al*., 2004, 2006; Tomar and Minhas, 2004) [16, 15].

Microbial population

Halophilic bacteria have the potential to remove sodium ions from soil and increase metabolic and enzymatic activities in plants. Arora *et al*. (2016) [4] used halophilic bacteria for the remediation of saline and sodic soils. A low-cost microbial bio-formulation "CSR-BIO," a consortium of Bacillus pumilus, Bacillus thuringenesis, and Trichoderma harzianum, is rapidly becoming popular with the farmers in many states (Damodaran *et al*., 2013) [19]. This bio-formulation acts as a soil conditioner and nutrient mobilize and has been found to increase the productivity of the high value crops such as banana, vegetables.

Varieties/ Cultivars

Use of salt tolerant varieties of field crops is another practical option to manage salt-affected soils with the poor farmers, especially small and marginal, for whom chemical amendment technologies are not feasible without Government subsidies (Arora and Sharma, 2017) [3]. Several varieties of important field crops like rice, wheat and mustard, having potential to yield reasonable economic returns in saline and sodic soils, have been developed (Singh and Sharma, 2006) [35].

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