Salt Tolerance and Effects of Salinity on some Agricultural Crops in the Sudan

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(Received: December 07, 2013; Accepted: February 17, 2014)

Abstract-The purpose of this study was to investigate the effects of different salinity levels on growth and chemical constituents of some agricultural crops in the Sudan. The tested plants include Abu Sabeen, Sorghum bicolor var. sudanense (Stapf.) Hitch., Pennisetum americanum (L.) Leeke, roselle, Hibiscus subdariffla L., okra, Abelmoschus esculentus (L.) Moench and purslane, Portulaca oleracea L. The plants were grown in five concentrations of NaCl and NaHCO3 Salts ranging between 0.0-1.0% (i.e. 0.0 - 177.0 mol m-3 NaCl; 0.0 - 190 mol m-3 NaHCO3). With increasing salinity levels, both salts negatively affect the growth behaviour and the chemical composition of the tested plants: NaHCO3 was noted to inflict more detrimental effects than NaCl. This is due to differences in the pH and ionic toxicities of the two salts. In general, the growth behaviour of the tested plants followed this sequence: P. oleracea showing the best response followed by S. bicolor, then P. americanum, H. subdariffla and A. esculentus. The vegetative performance was severely reduced by salt treatments, especially at high concentrations. Chloride and carbonate accumulations within the plants’ tissues were correlated to salinity levels. The effects of NaCl on crude protein formation, and ash content were different from NaHCO3; NaCl enhanced the production of more crude protein and ash, whereas NaHCO3 slightly reduced both parameters; crude fiber content was decreased by both NaCl and NaHCO3. Symptoms related to salt injury such as leaf chlorosis, necrosis, leaf folding, leaf–tips and margins burning, shrinking and leaf shedding became increasingly evident with increasing salt concentrations.

Index Terms- Brackish and saline soils, Salt stress, Monocotyledons, Succulence, Dicotyledons, Glycophytes

I. INTRODUCTION

Soil salinity is a problem of global concern Choudri [1]. Dudal and Purnal and Yensen [2, 3] estimated that terrestrial saline habitats constitute about 7% of the world’s land area i.e. ca. 7 million km². Plant growth in saline soils is suppressed by non-specific osmotic effects, toxic solutes and sodicity [4, 5]. Most agricultural crops are sensitive to salinity [6, 7]. Crop yield has usually been expressed as the yield decrease expected for a given level of soluble salts in the root medium as compared with the yield under non-saline conditions [8, 9]. Salt tolerance data may be used to select crops with the highest potential for agricultural production with highly saline waters [10, 11 and 12].

Land use the Sudan is geared towards achieving high and extensive agricultural production, pastures of natural grazing (ranching) and forest production for wood and charcoal [13]. Agricultural production is the most important system of land use, involving irrigated schemes as well as rain fed cropping [14]. In recent years, the demand for more food dictated considerable expansion of cultivable land [15]. The efforts to maximize agricultural production encountered many constrains of which soil salinity is a major element [16, 17]. Although the majority of agricultural crops are salt sensitive, there are differences in their ability to withstand salt stress among the various species [18]. This ability is determined by multiple biochemical pathways that facilitate retention and/or acquisition of water, protect chloroplast functions, and maintain ion homeostasis [19]. The present work was proposed to study the effects of salinity on five important agricultural crops (glycophytes) in Sudan: Sorghum bicolor var. sudanense (Stapf.) Hitchc. “Ar. Abu Sabeen, for it ripens in 70 days”, Pennisetum americanum (L.) Leeke, “pearl millet”, Hibiscus subdariffla, “Roselle”, Abelmoschus esculentus “okra”, and Portulaca oleracea L. “purslane”. The choice of the five glycophytes has been according to personal communications with the farmers, supported by field observations and confirmed by preliminary tests under greenhouse conditions.

S. bicolor is a common fodder in Central and Northern Sudan. The plant is widely known for its salt tolerance in brackish and saline soils of these areas. P. americanum, is an important crop for human use and as fodder in dry tropical and subtropical regions of Africa, Arabian Peninsula to India and Burma and America [20]. In Sudan, the plant is of second importance to Dura, Sorghum bicolor (L.) Moench for human consumption mainly in western and eastern regions of the country. The plant is grown in sandy soils in valleys (wadis) and seasonal streams (khors) that accumulate enough alluvial deposits [21]. H. subdariffla L. is an important commercial kenaf species grown for its calyx (herbal tea), pigments, fibres and oil [22]. Roselle fibres were reported to be superior to that of jute [23] and its seeds’ oil content is similar to kaok and cotton seeds. Okra Abelmoschus esculentus (L.) Moench is widely distributed in the tropics and subtropics [20]. In the Sudan, okra fruits are

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used as vegetable, sometimes dried and cooked. The species is identified as sensitive to salinity [24]. *P. oleracea* L. purslane

**II. MATERIALS AND METHODS**

Seeds of “Abu Sabeen, pearl millet, roselle, okra, and purslane were sown in clay pots (20 cm diameters) containing a mixture of sand and vermiculite (1.5 kg vermiculite mixed with 50 kg clean sand) in a growth chamber at the Institut fur Angewandte Botanik, University of Hamburg, Germany. The conditions within the chamber were as follows: temperature was set at 30-32°C, relative humidity 40% and light intensity 29000 lux at the pots surface. Light duration was 16 hrs per day and light was provided by SICOM-PACT-LICHTFUTER 5 N 717 Fa. SIEMENS POWER STARS HQT 400W/DH OSRAM. To insure successful germination, 3-5 seeds were sown in each pot and the pots were flooded from the bottom once every twelve hrs with a salt-free nutritive solution till germination was confirmed. The nutritive solution consisted of a stock solution [25], A-Z solution [26] and Fe III complex [27]. Flooding was carried out using the system described by Weihe and Dreyling [28]. Flooding continued for 30-60 minutes depending on the stage of growth of the tested plants. This system of irrigation was used till the termination of the experiments. After successful germination, the germinated seeds were thinned to leave only one seedling per pot. Each treatment was repeated three times i.e. for each treatment three plants were used. NaCl and NaHCO₃ salts were used separately to test the salt tolerance of the plants.

The choice of the two salts was based on their common occurrence in tropical soils [29, 30]. The salts were added gradually to the growing seedlings (2–7 days) to reach the required salt concentration. Concentrations used were 0.0, 0.1, 0.25, 0.5 and 1.0 % i.e. 0.0, 17.7, 44.2, 88.2 and 177.0 mol m⁻³ for NaCl and 0.0, 19.0, 47.5, 95.0 and 190.0 mol m⁻³ for NaHCO₃. The species is identified as sensitive to salinity [24]. *P. oleracea* L. purslane

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The solutions were changed every two weeks and the experiments were timed for eight weeks after the seedlings establishment. Daily visual observations on growth and development of plants were noted. The following parameters were measured: height, number of tillers per plant (for Abu Sabeen and pearl millet), fresh weight, dry weight, % dry weight, Cl uptake (only for plants tested with NaCl), CO₃ (only for NaHCO₃ treatments), ash content, crude protein and crude fibre. Cl uptake was determined by Schachtshabel [31] and CO₃ content was determined according to Schlichting [32]. Crude protein and crude fibre were determined using Kjeldahl method [33, 34]. The data obtained was statistically analyzed (ANOVA multivariate test) using SPSS Version 13.

**III. RESULTS AND DISCUSSION**

The five tested plants differ markedly in their response to different concentrations of NaCl and NaHCO₃. All vegetative parameters and chemical constituents of the two plant families (monocotyledons and dicotyledons) were adversely affected by increasing concentrations of the two salts. Heights of the five plants and the number of tillers of monocots; *Sorghum* and *Pennisetum* decline as the NaCl and NaHCO₃ concentration increased (Fig. 1a, b, 2a, and b) and the two species failed to form Tillers at high concentrations.

**Table (1)**

Concentrations, pH and EC of NaCl and NaHCO₃ solutions used to test the five plants

<table>
<thead>
<tr>
<th>Concentrations Of NaCl and NaHCO₃ (%)</th>
<th>Con. Mol m⁻³</th>
<th>pH</th>
<th>ECX10⁻³ Scm⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NaCl</td>
<td>NaHCO₃</td>
<td>NaCl</td>
</tr>
<tr>
<td>0.0</td>
<td>00.00</td>
<td>00.0</td>
<td>5.03</td>
</tr>
<tr>
<td>0.1</td>
<td>17.70</td>
<td>19.0</td>
<td>6.26</td>
</tr>
<tr>
<td>0.25</td>
<td>44.20</td>
<td>47.5</td>
<td>6.34</td>
</tr>
<tr>
<td>0.5</td>
<td>88.50</td>
<td>95.0</td>
<td>7.09</td>
</tr>
<tr>
<td>1.0</td>
<td>177.00</td>
<td>190.0</td>
<td>7.09</td>
</tr>
</tbody>
</table>

![Fig. 1a Effects of NaCl on height and no. of tillers of s.bicolor and P.americanum](image-url)
Dwarfness and stuntness of plants were clear symptoms of the tested plants under various salt concentrations [11]. In general, NaHCO₃ expressed more damaging effect than NaCl probably due to differences in pH of the two salts (NaCl pH ranges between 6.64 and 7.42; NaHCO₃ between 6.64 and 9.73) and higher ionic toxicity. Each plant exhibited optimum growth at a different salt concentration depending on its salt tolerance. These results are in conformity with many studies on the effects of salinity on agricultural plants like cotton and leguminous plants e.g. [35, 36, 37 and 38].
Fresh and dry weights of the tested plants with the two salts (Fig. 3a, b-4a, and b) gave a conclusive evidence for the undesirable effects of salinity especially at high concentrations. NaHCO₃ has more damaging effects than NaCl. Here also maximum vegetative performance was encountered at free to low salt concentrations. These results are in agreement with the findings of Minhas and Sharma [39] who emphasized the effects of salinity as related to the fact that salinity reduces water availability for plant use and presence of high salt levels in the soil hinders water absorption.
Similar findings were reached by Mickelsen, Swarj, Therios and Zekri [40, 41, 42 and 43]. NaCl directly influenced the chemical constituents of; chloride uptake and ash content (Fig. 5a) of monocots and dicots (Fig. 5b) which were increased by increasing salt concentration. According to Hatzmann [44], this increase could be attributed to the successive accumulation of salt within the shoot system.
NaHCO₃ treatment (Fig. 6a and b) revealed a significant increase in the shoot-(CO₃)²⁻ and ash content which indicate a direct relationship between (CO₃)²⁻ concentration, ash formation and salinity levels [45].
Crude proteins synthesis (Fig 7a, b) seems to be enhanced by increasing NaCl concentration in most of the studied agricultural plants, but NaHCO$_3$ depressed their production.

Similar results were reported by Helal, Ashraf and Rao [46, 47 and 45] who attributed such effects to the reduction of N supply for the synthesis of amino acids and proteins. Crude fibre production under NaCl and NaHCO$_3$ (Fig. 7, and 8) followed the plants growth explained earlier i.e. concentrations beyond 0.1% substantially decreased crude fibre within the plants. According to El-Saidi and Hawash [22], reductions on crude fibre production by H. sabdariffa e.g. can be by >50% compared with the control. The only exception was noted in purslane where crude fibre formation was unaffected by both salts probably because of its high salt tolerance in comparison with the other crops. The plant is the only succulent species among the five tested plants, a character of importance of keeping the osmotic pressure at a safe level due to dilution [48].
The statistical analysis of the data revealed the following: no significant differences were evident when the 5 tested plants were exposed to the different concentrations of NaCl (P>0.05). A clear significant difference was calculated (P<0.05) when analyzing NaHCO₃ data. Analysis of the response of the 5 plants to the two salts gave significant correlations with some parameters e.g. fresh weights and ash content (p<0.05). These findings may be explained as due to differences in the salt tolerance of the tested plant and toxicity of NaCl and NaHCO₃ salts; NaHCO₃ inflicted more harmful effects than NaCl.

Diagnostic symptoms of salt damage related to chloride or carbonate accumulation [49, 50] appeared during the 3rd – 4th week after the full application of both salts. The symptoms which develop with low Cl⁻ become more conspicuous at moderate concentration (up to 0.5%) and pronounced under salt stress of high concentration (1.0%). Symptoms caused by bicarbonates are much advanced compared to corresponding concentrations of Cl⁻. At (1.0%) bicarbonates are decidedly lethal for all the species except the succulent Portulaca and the salt sensitive A. esculentus perished at even lower concentration (0.5%). These symptoms manifested in chlorosis and drying up of the leaves that normally start from the margins and tips and proceed into the leaf lamina. Other symptoms include leaf shedding, necrosis, rusting, leaf brittleness, stems and leaves yellowing and blackening, leaf tips burning, leaf folding and shrinking. The plants subject to salt injury become weak and more susceptible to disease e.g. fungal infections (Asperigillus sp. and Fusarium sp.) which happened while the leaves are still attached to the plants. These symptoms were related to accumulation of salts within the leaf tissues, a phenomenon used by the plants to modify salinity effects. Leaf shedding is a mechanism carried out by salt stressed plants to get rid of the damaging accumulated salts within their leaves and thus balances their osmotic pressure. These findings are in agreement with, Grattan, Grattan, and Tester [51, 52 and 53] who showed that the magnitude of salt injury and its damaging symptoms increased with the increment in the salt concentration and negatively affect plant growth rates as the injury increased. Salt damage was more drastic under NaHCO₃ treatments than that of the corresponding NaCl [54].

Salinization of the soil in inland locations can be caused by natural processes such as mineral weathering or the gradual withdrawal of an ocean. It can also be caused by irrational artificial processes such as irrigation of cropland due to mal-agricultural practices [55]. Naturally saline soils have little or no effects on land use, normally colonized by native salt-tolerant species. Irrational land use results in total to partial loss of the soil for agricultural activity [56]. Such lands are presently found in the northern sector of the massive Gezira Scheme [57] and the Nile banks in central and northern states in Sudan [58]. The appropriate approach of land use of such salt affected areas would be a careful selection of salt-tolerant crops rather than abandoning them. According to experience, the farmers select candidate crops that are compatible with local salinity. In the Sudan, S. bicolor, P. americanum and P. oleracea are popular crops in salt-affected cultivated land. H. sabdariffa and A. esculentus are common for mildly saline soils. In all the three popular glycophytes, height may be attainable at 0.25% followed by H. sabdariffa and A. esculentus. The appropriate approach of land use of such salt affected areas would be a careful selection of salt-tolerant crops rather than abandoning them. According to experience, the farmers select candidate crops that are compatible with local salinity. In the Sudan, S. bicolor, P. americanum and P. oleracea are popular crops in salt-affected cultivated land. H. sabdariffa and A. esculentus are common for mildly saline soils. In all the three popular glycophytes, height may be attainable at 0.25% followed by H. sabdariffa and A. esculentus. The appropriate approach of land use of such salt affected areas would be a careful selection of salt-tolerant crops rather than abandoning them. According to experience, the farmers select candidate crops that are compatible with local salinity. In the Sudan, S. bicolor, P. americanum and P. oleracea are popular crops in salt-affected cultivated land. H. sabdariffa and A. esculentus are common for mildly saline soils. In all the three popular glycophytes, height may be attainable at 0.25% followed by H. sabdariffa and A. esculentus.
problems in semi-arid tropical Sudan. It is hoped that further endeavours be carried out to enhance efficient land use in salt affected areas.

IV. CONCLUSIONS
1. The experiments carried out on the effects of NaCl and NaHCO₃ in the present study on the different stages of the five glycyphytes have shown considerable differences between the species and salts.
2. The results showed that the tested agricultural crops in the present study expressed different growth performances due to their variable salt tolerance: best growth parameters were revealed by purslane and the least by okra. Other species occupied intermediate positions:
3. The salt tolerance of the five tested plants was as follows: Portulaca oleracea “purslane” was the most tolerant plant followed by Abu Sabeen, pearl millet, Roselle and okra “most sensitive”. Superiority of purslane was mainly related to its being a succulent plant that contains large amounts of water in its shoot system that contributes to moderating the effects of salinity.
4. Salinity reduces water availability for plant use. High salt levels hinder water absorption. The soil may contain adequate water, but plants roots are unable to absorb inducing physiological drought in the plant. This manifests in poor growth performance, low productivity and various salt damage symptoms on agricultural crops.
5. Soil salinity is caused by many factors e.g. land use and irrigation with water containing high levels of salts. Correcting a salt–affected soil involves identifying the kind and amount of salt, chemical treatment and leaching. When salinity problems are identified, corrective steps should be taken immediately. Prompt action will give a better chance of reclaiming the affected soils, be less expensive and pose less risk of plant damage.
6. Strategies worked out for successful crop production on saline soils and proper selection of salt tolerant crops/cultivars and irrigation methods and controlled frequency for enhancing water-table contribution must be adopted to ensure sound soil management that facilitates high production levels.

ACKNOWLEDGEMENT
This study was sponsored by the German Academic Exchange Service (DAAD), the German Agency for Technical Co-operation (GTZ) and Hamburg University/Khartoum University Partnership. We are grateful to Frau I. Onchen for technical assistance. The help offered by technicians in the different Departments at Institut fur Angewandte Botanik, University of Hamburg, Germany is also appreciated. Special thanks are due to Dr. Elshibli Elshibli Elshibli, Al Neelain University, for his help with the statistical analysis.

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