REVIEW ON SALT-AFFECTED SOILS STUDIES IN SUDAN

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ABSTRACT

Salt-affected soils in the Sudan fall under three soil orders: Vertisols, Aridisols and Entisols; in a vast area between 14 and 22 latitudes' covering an area of about 4.874 million hectares; only 268636 hectares were mapped till 2007.Soil salinity occurs at soil depths of 30-60 cm, often associated with sodicity, the most commonly salts found are sodium chlorides and sodium sulphates. Comprehensive studies on physical and chemical properties of salt-affected soil the reclamation and management were undertaken by many research workers in Sudan.

The Relative hydraulic conductivity (RHC) of a salt-affected soil decreases with ESP increases as C decreases; and at a given ESP, RHC increases as C increases; DI increases with increasing ESP and decreasing C. The use of 5 and 10 tons gypsum/ha in ASSPC reduced the ESP from 18 to 5.5 and 7.3 and the EC_e from 4.2 to 1.2 and 2.2 dS/m and significantly increased wheat grain yield from 1141 to 1739 and 1926 kg/ha, respectively.

Application of organic and/or chemical fertilizers is very essential for crop production in high terrace soils especially wheat. In addition to 2N, the use of 5 tons FYM/ha plus 1P followed by 10 tons FYM/ha without P is recommended as a package for wheat promotion in the high terrace soils of Nile River. In another study, and in addition to a basal dose of 2N + 1P, the use of two tons CHM/ha was recommended for wheat production as another option package to 5 tons FYM/ha + 2N + 1P.

Phosphorus fertilization and P and K interaction significantly increased growth attributes and dry matter of forage sorghum. Application of 2N NPK to wheat in EHRF resulted the highest wheat grain yield (2979 kg/ha) compared with other DNS. In another study and in the same site, the use of 1N NPK topped by 1N ASN gave the highest wheat grain yield (2935 kg/ha). Dry matter yield of forage sorghum increased significantly with increase of nitrogen level, with decrease in irrigation interval and with gypsum application. Watering of lucerne every 7 days with addition of CHM was found superior treatment among others treatments (gypsum, Sulfur, dry sewage, CHM plus gypsum).

Wheat grain yield was significantly affected by irrigation interval and type of fertilizer but not by level and the impact of irrigation frequency is much greater than the impact of fertilizers and this was explained by alleviation of water and osmotic stresses. Light and more frequent irrigation increased the dry forage yield and WUE of lucerne. A significant increase in wheat grain yield at EHRF was found as a result of adding FYM and nitrogen irrespective of the land preparation method. Soil moisture distribution and salt leaching improved with short irrigation interval of 10 days compared to 15 days and the use of chisel and disc plowing was most effective in salt leaching.

INTRODUCTION

In general, the presence of salts is a widespread phenomenon in many arid and semi-arid regions of the world. In these areas, salinity may result as a consequence of geological weathering under low rainfall and high evaporation conditions, by upward capillary flow from shallow water tables or from artesian flow and Sudan is not an exception case.

A salt-affected soil is a general terminology given to saline, sodic or saline sodic soils.

Salinization and sodification are considered major desertification processes in irrigated lands of the world. Both salinity and sodicity are widely spread and have series adverse impacts on the productive capacity of agricultural lands, forestlands, and rangelands (Drenge *etal*1991; Mustafa 2007).

Secondary salinization process occurs due to the use of saline water for irrigation in heavy or medium textured soils, use of industrial waste saline water, and irrigation water transported over salt-affected areas to irrigate none saline soils.

The reclamation of salt-affected fine-textured soils in Sudan is very difficult. So, the suitable approach for these soils is to rely upon the use of salt-tolerant crops, addition of chemical and/or organic fertilizers, and efficient soil water management.

Most crops are sensitive to excessive concentration of soluble salts especially at germination stage. They have different ability to tolerate high levels of soil salinity. This largely depends on their stage of growth, variety/root stock, nutrition, irrigation and overall cultural practices management.

Soluble salts in soils are formed by a combination of cations mainly calcium, magnesium, sodium, potassium and anions namely bicarbonates, carbonates, chlorides and sulphates. The most commonly found in Sudan are sodium chlorides and sodium sulphates (Gabir1986; Buraymah, 1998; Lahmeyer, 2005). Top soil salinity is rarely occurred in Sudan and most of the salt accumulation occurred at a soil depths of 30-60 cm (Nachtergaele 1976). In a study including seven areas along the Blue Nile and the River Nile from Managil to Wadi El Khowi, Nachtergaele (1976) found that sodicity is often associated with salinity and sodium was the dominant cation.

The limited suitable agricultural land in the Northern regions of the Sudan necessitates a vital need for expansion in marginal lands of the high terraces of the River Nile, where soils are affected by different levels of salinity and/or sodicity. Most of these marginal lands belong to Aridisols order. They are characterized by low chemical fertility and various textural classes ranging from loamy sand to sandy clay loam. Also they have severe limitations that restrict their sustainability for agricultural production such as: unfavorable topography, gravels and stones, moisture deficiency, shallow soil depth and erosion hazard.

TYPES OF SALT-AFFECTED SOILS

Based on the electric conductivity of the soil extract (EC_e) at 25 C^o, exchangeable sodium percentage (ESP) and soil pH, and according to the American System, salt-affected soils can be divided into three groups viz:

- Saline soils: they have large amount of soluble salts exceeding 4 dS/m, ESP less than 15 and pH less than 8.5.
- Sodic soils: they have ESP more than 15, EC_e less than 4 dS/m and pH more than 8.5.
- Saline-sodic soils: they have ESP more than 15, EC_e more than 4 dS/m and pH less than 8.5.

The saline and saline-sodic soils are flocculated, well aerated and of excessive water infiltration rate while sodic soils are dispersed and compacted, badly aerated and have poor water percolation. Therefore, reclamation of saline or saline sodic soils is more possible than sodic soils especially when they have heavy clay texture.

SALINITY AND SODICITY

Soil salinity means an excess of soluble salts in the root zone of a soil profile. It affects plant growth through reducing osmotic pressure of the soil solution to the extent that it impedes plants ability to absorb water in addition to probable nutritional imbalance and specific iron toxicity.

Sodicity is defined as an excess of exchangeable sodium percentage (ESP) in the root zone of a soil profile. It raises soil pH to the extent that micronutrient cations are rendered unavailable to plants in addition to its effect on some physical properties of the soil like hindrance of water percolation, particularly in heavy textured soils. Also it causes soil crust which decreases plant seeds germination.

The levels of salinity (0-30 cm and 30-60 cm) and sodicity (0-30 cm and 30-120 cm) are rated in the Land and Water Research Centre of the Agricultural Research Corporation according to Kevie and Eltom (2004) classes (Table 1).

Table 1. Salinity and sodicity classes (Kevie and El Tom 2004)

Classes	Salinity (ECe dS/m)		Sodicity (ESP)		
	0-30cm	30-60 cm	Classes	0-30 cm	30-120 cm
None saline	< 4	< 6	None sodic	< 10	< 20
Slightly saline	4 – 8	6 - 12	Slightly sodic	10 – 20	20 – 35
Moderately saline	8 – 16	12 - 24	Moderately sodic	20 – 35	35 – 50
Strongly saline	> 16	> 24	Strongly sodic	> 35	> 50

LOCATION AND EXTENT

Salt-affected soils in Sudan fall under three soil orders: Vertisols, Aridisols and Entisols (USDA, 1999). They extend along vast areas at latitudes 14-22° N, including the White Nile, North Gezira, Khartoum state, crossing the River Nile and the northern states. In Sudan, it was estimated that 4.874 million hectares are salt-affected. Elmubark (2007) reported that about 268636 ha of the surveyed and mapped areas in Sudan –until 2007-were found to be affected by salinity and/or sodicity. Table (2) shows the extent and location of salt-affected soils in most affected and surveyed areas in Sudan.

Table 2. Location and extent of mapped Salt-affected soils in Sudan

Location	Extent (ha)	Soil survey report No.
White Nile	5862	92, 108
Gezira Scheme	141729	130, 132, 134, 146, 147, 148
South Khartoum	17323	47
North East Khartoum	16317	54
Shendi	2372	63, 64
Eddamer	19624	67
Dongola	14409	62, 96
Merowi-Dongola	51000	Lahmeyer, 2005
Total	268636	

Source: Land and Water Research Centre

PHYSICAL AND CHEMICAL PROPERTIES

Comprehensive studies on physical and chemical properties of salt-affected soils have been executed by many soil scientists. Most of these studies were carried out in Khartoum University, Farm at Shambat.

Hamid and Mustafa (1975) studied the impact of electrolyte concentration (C) and ESP on the relative hydraulic conductivity (RHC) and dispersion index (DI) of a Vetisols and an Aridisols. They found a general trend of decreasing in RHC with ESP increases as C decreases; and at a given ESP, RHC increases as C increases; DI increased with increase in ESP and decrease in C; the initial DI at a given C value increased rapidly with increase in ESP and then leveled off. These results are in agreement with those obtained later by MaliK*et al* in 1992.

Ishag and Mustafa (2005) investigated the impact of clay content, ESP and ECe on the coefficient of linear extensibility (COLE) for ninety-nine soil samples collected from fifteen Gezira Vertisols soil series. Regression analysis of the study revealed highly significant (P 0.001) increase in COLE with increase in clay content (r=0.471), and significant (P 0.05) increase with increase in ESP (r=0.282) and decrease in ECe (r=- 0.226).

SOIL RECLAMATION AND MANAGEMENT

Soil reclamation in salt-affected soils is made to remove the soluble salts below the plant root zone by leaching and/or replacing of the exchangeable sodium with calcium for development of soil aggregation process and better aeration status.

It was very limited until the 1970s, and was confined to some experiments in the Gezira, Soba and Hudeiba research stations. The decrease in good agricultural lands particularly in the Northern states due to desertification (soil degradation) led to expansion in new lands such as high terraces which are mostly considered as salt-affected soil. That necessitates the establishment of strong reclamation program which was started in 1970.

Many research activities were undertaken inthe Northern states of Sudan either to reclaim salt-affected soils using gypsum or to increase their chemical fertility through application of organic and/or synthetic fertilizers.

Two locations in Eddamer area were evaluated by Elaagib (1999) as indicated in Table (3). The Effect of farm yard manure (FYM) and commercial gypsum on salinity, sodicity and wheat grain yield at Arab Sudanese Seed Propagation Company (ASSPC) farm was investigated, and the result showed that the use of 5 and 10 tons' gypsum/ha reduced the ESP from 18 to 5.5 and 7.3 and the ECe from 4.2 to 1.2 and 2.2 dS/m (Table 3) and significantly increased wheat grain yield from 1141 to 1739 and 1926 kg/ha, respectively (Table 4) at location A.

Table 3. Soil analysis of ASSPC farm (location A and B)

Soil depth (cm)	Location A			Location B		
	pH (paste)	ECe (dS/m)	ESP	pH (paste)	EC (dS/m)	ESP
0 – 25	7.9	10.0	18	8.8	50	28
25 – 50	7.8	6.5	19	9.0	24	30

The differences in wheat grain yield between the two levels of gypsum and FYM were not significant. This indicated that application of 5 tons/ha of each of gypsum and cattle manure is suitable and enough in this location. Generally, the grain yield of wheat was low in location B because of the high levels of salinity and sodicity (Table 5). The trend of gypsum and FYM in location B was the same as in location A.

Table 4. Soil chemical analysis (composite samples) of different gypsum level after wheat harvest (location A)

Gypsum (ton/ha)	Soil depth (cm)	EC (dS/m)	SAR	ESP
0	0 – 25	4.3	16.4	18
5	0 – 25	1.2	5.0	5.5
10	0 – 25	2.2	5.8	7.3

Table 5. Wheat grain yield (kg/ha) as affected by gypsum and farm yard manure at the two locations, A and B

Gypsum (ton/ha)	Location A	Location B
0	1141	50
5	1739	276
10	1926	532
S.E±	96.7	79.6
FYM (ton/ha)		
0	1424	24
5	1590	172
10	1790	450
S.E±	96.7	79.6

Elaagib (2003) investigated the effect of four levels of FYM (0, 5, 7.5 and 10 ton/ha) in combination with four levels of phosphorus (0P, 1P, 1.5 P and 2P), 1P = 43 kg P_2O_5/ha, on wheat production on a high terrace soil in the Extension of Hudeiba Research Farm (EHRF) for three consecutive seasons (2000/03). The soil of the farm was classified as Sodic Haplocalcids, fine, mixed, hyperthermic (Soil Survey Staff, 1999) and correlated to Mukabrab soil series. Based on the combined analysis of wheat grain yield and economic assessment, and in addition to 2N (1N = 43 kg N/ha), he recommended the use of 5 tons FYM plus 1P followed by 10 tons FYM/ha without P for wheat production in the high terrace soils of the River Nile. The two packages out yielded the earliest recommendation (2N + 1P) and the yield increases were 21 and 27 %, respectively (Table 6).

Table 6.Wheat grain yield (kg/ha) as affected by farm yard manure and phosphorus fertilization

P_2O_5(kg/ha)	FYM (ton/ha)				Mean
	0	5	7.5	10	
0	1586	2751	2949	3251	2634
43	2557	3102	2705	3133	2874
64.5	2705	2940	2859	3223	2932
86	2752	2897	2862	3472	2996
Mean	2400	2923	2844	3270	2859

S. E± FYM = 52.8 P = 52.8 FYM× P = 105.6

Elaagib and Babiker (2004/05) evaluated the response of wheat to FYM (0, 5, 10 and 15 tons/ha) and nitrogen (0N, 1N, 2N and 3N) fertilization at the EHRF. The results of the study showed that FYM, N and their interaction significantly influenced the grain yield of wheat and the combination of 15 tons FYM/ha plus 1N out yielded the other treatments (2075 kg/ha) as shown in Table7. This indicated that the level of nitrogen fertilizer can be reduced with increasing FYM. Also, the high level of nitrogen (3N) may temporally suppress or decrease the microbial activity which is desired for decomposition of FYM.

Table 7. Response of wheat grain yield (kg/ha) to FYM and nitrogen at the EHRF, (season 2004/05).

FYM (ton/ha)	Nitrogen fertilizer				Mean
	0N	1N	2N	3N	
0	453	1153	1330	1413	1087
5	730	1123	1318	1223	1098
10	1540	1495	1683	1675	1885
15	1703	2075	1898	1863	1418
Mean	1107	1462	1557	1445	1372

S. E± FYM = 41.5 N = 41.5 FYM × N = 83.0

Elkhazin and Khalid (2013) studied the response of wheat to chicken manure (CHM) on a high terrace soils. The study included nine single treatments: six of three levels of CHM (2, 4 and 6 tons/ha) with or without a basal dose of nitrogen and phosphorus (2N + 1P) for each rate of CHM. The remaining three treatments consisted of the two earlier recommendations: 2N + 1P, 5 tons FYM/ha + 2N + 1P and the standard control. Differences in wheat grain yield between CHM and FYM treatments (7 treatments) were not significantly different (Table 8). Based on the results of the study, they recommended the use of two tons CHM/ha plus the basal dose of nitrogen and phosphorus (2N + 1P) for wheat promotion in the high terrace soils of the River Nile as another option package to five tons FYM/ha + 2N + 1P.

Table 8. Wheat grain yield as affected by the nine treatments

Treatment	Grain yield (kg/ha)	% Increase over 2N + 1P
Control	1105	- 48

2N + 1P	2147	0
5 tons FYM/ha + 2N + 1P	2554	19
2 tons CHM/ha	2050	- 5
4 tons CHM/ha	2294	7
6 tons CHM/ha	2567	20
2 tons CHM/ha + 2N + 1P	2666	24
4 tons CHM/ha + 2N + 1P	2760	29
6 tons CHM/ha + 2N + 1P	2816	31
S.E±	120	

El Mahi *et al* (2002) investigated the impact of P and K fertilizers on growth and yield of irrigated forage sorghum grown on a saline-sodic soil. The treatments included four levels of P and K fertilizers applied before sowing as triple super phosphate and potassium sulphate, respectively. The experiment was arranged in split-plot design with three replicates. Potassium was allotted main plots and P sub-plots. A basal dose of 132 kg N/ha was added to all plots. Phosphorus fertilization and P and K interaction significantly increased growth attributes and dry matter yield of forage sorghum. Phosphorus fertilizer significantly increased leaf P and N in the first season when salinity was high, whereas K fertilizer was not effective. Leaf P and N contents were greatly improved in the second season when salinity became low even without P fertilization. The dry matter yield increased from 5.45 to 6.92 ton/ha (27%) due to addition of 192 kg K_2SO_4/ha and 8.89 ton/ha (63%) due to addition of 357 kg P_2O_5/ha. The superior treatment was the addition of 357 kg P_2O_5/ha plus 96 kg K2SO4/ha which increased the dry matter to 10.86 ton/ha (99%).

Elaagib (2001/03) evaluated the response of wheat to Different Nitrogen Sources (DNS) at the EHRF. The tested DNS were: Urea (U) 46% N, Ammonium Sulphate (AS) 21% N, 24% Sulfur, Ammonium Sulphate Nitrate (ASN) 7% NO_3^-, 19% NH_4^+, 14% S and Nitrophoska (NPK) 18% N, 18% P_2O_5, 5% K_2O, 1.2% MgO, 3% S. In addition to 10 tons of FYM/ha, two rates of each fertilizer, 1N and 2N were tested. A dose of 1P was applied to all treatments, except for the Nitrophoska. As displayed in Table 9, application of 2N NPK resulted in the highest grain yield of wheat (2979 kg/ha) while the control recorded the lowest (1913 kg/ha). Differences in grain yield of wheat among fertilizer treatments were not significant and this is probably attributed to the high level of FYM that was added to all treatments, which acts as a continuous nitrogen supplying source. This reflects the need for adding organic matter to such soils for increasing the chemical soil fertility, and decreasing depletion of nutrients that takes place in light textured soils through leaching. From the economic point of view, the use of urea is more profitable because it contains high nitrogen content (46%) and has the lowest price compared to the prices of the other tested fertilizers.

Table 9. Effect of different nitrogen sources and rates on wheat grain yield (kg/ha) in high terrace soils

Treatment	Grain yield (kg/ha)	% Increase

Control	1913	-
U – 1N + 1P	2388	24
U – 2N + 1P	2579	34
AS – 1N + 1P	2548	33
AS – 2N + 1P	2870	50
ASN – 1N + 1P	2272	18
ASN – 2N + 1P	2476	29
NPK – 1N	2573	34
NPK – 2N	2979	55

S. E± = 211 U = Urea, AS = Ammonium Sulphate, ASN = Ammonium Sulphate Nitrate, NPK = Nitrophoska

Previous studies indicated that utilization of NPK fertilizer always results in the highest wheat grain yield (Elaagib 2001/03), and at the same time this fertilizer contains the lowest nitrogen content (18%) with the highest price among DNS.

Elaagib and Babiker (2004/05) investigated the effect of DNS on wheat production at the EHRF with respect to 1N NPK as a basal dose and to be topped by another 1N of each fertilizer (U, AS and ASN) compared to farmers cultural practice (2N – U + 1P). The results indicated that the highest wheat grain yield (2935 kg/ha) was obtained with the use of 1N NPK topped by 1N ASN. And, the yield increases of this treatment over the control and farmers cultural practice (earlier recommendation of 1N + 1P) were 58% and 21%, respectively (Table 10).

Table 10. Effect of DNS with basal dose of 1N NPK on wheat grain yield in the HT soils (2004/05)

Treatment	Wheat grain yield (kg/ha)	% Yield increase
Control	1873	-
2N – U + 1P	2425	29
1N NPK + 1N – U	2390	28
1N NPK + 1N – AS	2523	35
1N NPK + 1N – ASN	2935	58
S.E±	132.7	

IRRIGATION AND SOIL AMMENDMENTS

Salts leaching and using of soil amendments are very essential two components in reclamation of salt-affected soils.

Mustafa and Abdelmagid (1982) investigated the interrelationships of irrigation frequency (7, 10 and 15 days), nitrogen (0N, 1N, 2N and 3N), and gypsum (0 and 11.9 ton/ha) on forage sorghum growth and yield on a saline-sodic clay soil in the University of Khartoum Farm at Shambat. Data showed that the dry matter yield of the cuts of forage sorghum increased significantly with increase of nitrogen level, with decrease in irrigation interval and with gypsum application. ECe of 0 to 40 cm zone and ESP of 0 to 60 cm zone decreased with decrease in irrigation interval and nitrogen fertilization. Application of gypsum increased ECe but reduced ESP in the two zones, respectively.

Gabir (1984) conducted a trial at Soba Agricultural Research Station to investigate the effect of irrigation interval (7 and 14 days), and soil amendments (gypsum, sulfur, dry sewage, CHM and CHM plus gypsum) on Lucerne growth in a saline sodic clay soil. Watering every 7 days and adding CHM was found to be superior treatment.

El-Tilib etal. (1995) investigated the response of wheat to irrigation frequency and manuring on a saline-sodic clay soil in the University of Khartoum Farm at Shambat. The experiment consisted of three irrigation frequencies: 5, 10 and 15 days, three fertilizers: cattle manure (CAM), CHM and urea, each of these fertilizers applied at two rates which were 11.2 and 22.4 ton/ha for CAM or CHM applied in the top 15 cm; and 66 and 132 kg N/ha for urea. The experiment was arranged in a split-split plot design. The main plots were allotted to irrigation frequency, the sub-plots to the levels of fertilizers and the sub-plots to the levels of fertilizers and the sub-sub plots to the types of fertilizers. All plots received a basal dose of 150 kg P applied as triple phosphate. Results showed that wheat grain yield was significantly influenced by irrigation interval and type of fertilizer but not by level. Application of the first level of CAM, CHM or urea increased the grain yield from 0.81 to 1.00 (23%), 0.95 (17%) or 0.93 (15%), respectively. Application of these fertilizers in sequence and irrigating every 5 days instead of 15 days increased the grain yield by 113, 61or 98%. Thus, the impact of the irrigation frequency is much greater than the impact of fertilizers and this was explained by the alleviation of water and osmotic stresses.

Baraka *et al* (1999)conducted a field experiment in two consecutive seasons to investigate the impact of irrigation after the depletion of 18.8, 37.5 and 75% of the available water and application of 10 ton/ha FYM on yield, consumptive use and water use efficiency (WUE) of lucerne on a salt-affected clay soil in the University of Khartoum Farm at Shambat. The results showed that the light and more frequent irrigation increased the dry forage yield by about 49% and 31% in the first and second season, respectively. This treatment also increased the WUE of lucerne. The influence of FYM on the studied variables was slight and not consistent.

DIFFERENT TILLAGE SYSTEMS

Many research studies were undertaken to evaluate the influence of different tillage systems on wheat growth and productivity in the high terrace soils of the Nile River. Effects of two methods of land preparation (disking alone or coupled with chiseling), with or without 15 tons of FYM/ha, in combination with three rates of nitrogen (0, 43 and 86 kg N/ha)on wheat production were evaluated at the EHRF during three seasons (2000 to2003). Results of the study showed significant increase in wheat grain yield as a result of adding FYM and nitrogen fertilizers irrespective of the land preparation method. Also the results showed high significant interaction between FYM and nitrogen on grain yield of wheat. Based on the findings of this study, *Elaagib et al* (2012) reported that the treatment consisted of disking plus 15 tons FYM/ha plus 2N, which recorded the highest grain yield of wheat (2017 kg/ha) (Table 11) can be used for wheat production in the high terrace soils. Also, it was observed that FYM and nitrogen fertilization alleviated the adverse effect of soil crust on the establishment of wheat and promoted plant growth (Plates 1, 2, 3 and 4).

Table 11. Effect of land preparation method, FYM and nitrogen on wheat grain yield (kg/ha) at the EHRF

LPM±FYM	Nitrogen (kg/ha)			Mean
	0	43	86	
T1	420 e	589 e	781 d	596
T2	1219 c	1607 b	2017 a	1614
T3	1276 c	1701 b	2048 a	1617
Mean	971	1299	1615	1295

LPM±FYM = land preparation method with or without FYM, T1 = disc plowing (control), T2 = disc plowing + 15 tons FYM/ha, T3 = disc plowing + chiseling + 15 tons FYM/ha

Dahab and Mohamed (2005) executed a field experiment to assess the influence of four tillage systems: disc plowing, chisel plowing, disc harrowing and ridging under two irrigation intervals (10 and 15 days), on soil moisture distribution and salt redistribution in a saline sodic clay soil grown with the hybrid forage sorghum (Panar 888). Soil moisture distribution and salt leaching improved with short irrigation interval of 10 days compared to the 15 days. Chisel and disc plowing with 10-day interval were most effective in salt leaching.

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