GEOGRAFICKÝ ČASOPIS

54 2002 4

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EFFECTS OF LONG-TERM IRRIGATION ON SOLUBLE SALTS AND EXCHANGEABLE BASE CATIONS IN VERTISOLS FROM SUDAN GEZIRA

E. A. Elias, F. Alaily: Effects of long-term irrigation on soluble salts and exchangeable base cations in vertisols from Sudan Gezira. Geografický časopis, 54, 2002, 4, 5 figs., 3 tabs., 16 refs.

Salt concentrations as affected by long term irrigation and continuous cropping for more than 80 years in Gezira soil were assessed. The study included two profiles in the Gezira Research Station (GRS) farm at Wad Medani. One profile was in a plot that was left permanently fallow while the other one was in a plot under continuous cropping according to the rotation of the Gezira Scheme. Evidence was not found for any increase in salinization accompanying irrigation in these soils despite the arid climate and the primary saline phase associated with these soils. Investigations carried out in the study included total chemical composition, CEC, EC, exchangeable cations, soil pH and soluble cations and anions. Difference in base saturation found in these soils is explained in terms of changes in quantities of exchangeable bases as affected by leaching, dissolution and possibly redistribution of bases.

Key words: Vertisol, irrigation, salt affected soil, Gezira, Sudan

INTRODUCTION

Vertisols cover an area of approximately 257 M ha of worldwide, mostly in the tropics (4 % of the total land area), with 79 M ha in India and 50 M ha in

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Sudan (Dudal 1965, Dudal and Eswaran 1988). The Vertisols of Sudan, composed of the central clay plain in addition to the southern clay plain and Nuba Mountain clays, are of special importance to the economy of the country as they host most of the important agricultural schemes. This study was undertaken in Gezira, the part of the central clay plains of Sudan that falls between latitudes 13° 30' and 15° 30' North and longitudes 32° 30' and 33° 30' East. The Gezira scheme constitutes no less than half the total irrigated area, of 1.8 M ha, in Sudan and produces the main cash crops of the country by means of irrigated agriculture. Irrigation has been applied for the last 80 years on these soils.

The soils of the Gezira are aggradational plains deposited as a uniform blanket of clay by the receding Blue Nile system 12 000 to 5000 years ago (Blokhuis 1993). The deposited clay reaches a depth of 20 m or more. The Gezira clay plain has the characteristics of an alluvial fan. According to the USDA classification system (Soil Survey Staff, 1975) the soils are classified as Entic or Typic Chromusterts with small areas of Pellusterts (Nachergale 1976).

The Gezira scheme started for production of long staple cotton from as early as 1925. In the seventies food crops were introduced and the rotational fallow was decreased as a result of the intensification and diversification policy. When the scheme started anticipations for the salinization of the soil were high due to the primary salinity of the soil and the high content of clay. Irrigation induced salinization was known to have affected millions of acres of once non saline lands in India, Egypt, Pakistan, Argentina, Australia and many other parts of the world (Ghassemi et al. 1995). Early warning against water logging salinity in Gezira were raised by Greene (1928) who calculated an amount of 1000 kg of salts to be added per feddan in each cotton season. Ball (1934), as quoted by Farbrother (1996), was of the opinion that over-watering may lead to a rise in Ground Water-Table (GWT) leading to accumulation of salts in the root zone and has recommended the use of a drainage system. On the other hand Tothill (1948) claimed a gradual, but steady improvement in the soil properties. Ayed (1968) has reported high cotton yields even in soils with ESP as high as 35 %. However, studies performed so far did not provide any evidence of increased salinity in the Gezira soils. Fadl and Farbrother (1973) have shown that production was checked by salinity or alkalinity only on sites with inadequate irrigation water. However, there are other opinions attributing reduction of cotton yields to increased salinization (Plusquellec 1990).

In the farm of the Agricultural Research Station at Wad Medani a plot was left permanently fallow so that changes in soil properties resulting from soil use could be quantified using this plot as a yardstick. This is particularly important as irrigation water is expected to have modifying effects on soil chemical properties especially with regard to salinity. In this study the soil physical and chemical properties of the cropped and non-cropped plots were analyzed. The study aimed at providing more information on the effects of long term irrigation on soil salinity under the conditions of the Gezira Vertisols.

MATERIALS AND METHODS

Soils from two adjacent sites in the Gezira were used for this study. One profile was dug in the Permanent Fallow (PF) plot and the other was in an irrigated and cropped plot at the farm of the Gezira Research Station (GRS) of the Agricultural Research Corporation in Wad Medani. The location of sites in the Gezira region is shown in Fig. 1. The cropped plot has been under normal Gezira Scheme rotation for more than 80 years. The sites studied are on flat areas, with a slope of 1 % or less. Each profile was divided into horizons according to the structure of the dry soil or according to other visible features.

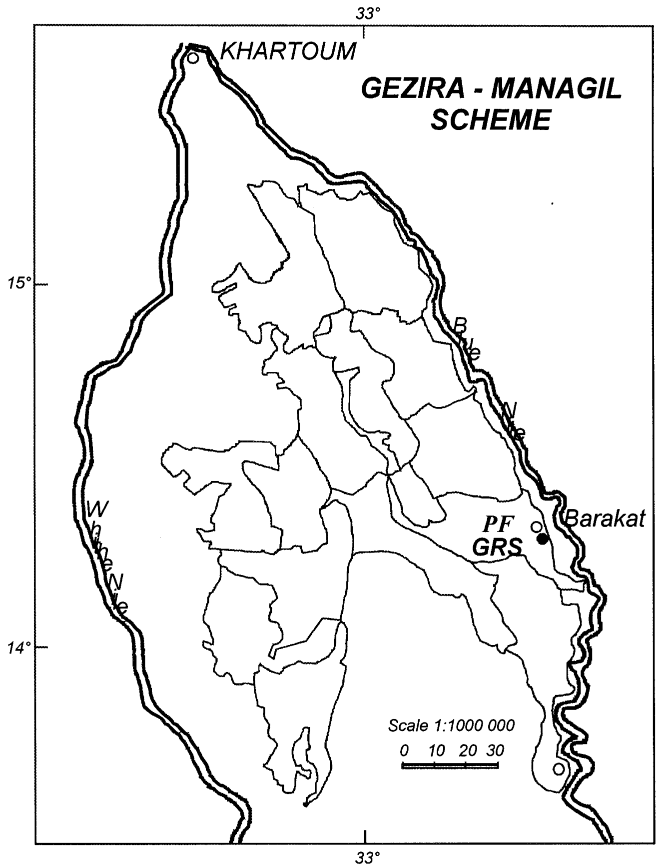

Fig. 1. Location of study sites in the central clay plains of Sudan

Soil samples were collected from each horizon and were dried, ground and sieved to pass a 2 mm mesh. The exchangeable cations were determined by leaching the soils with 1 M ammonium acetate at pH 7 in leaching tubes. The excess of ammonium was washed by 95 % ethanol. The exchangeable ammonium was used as leached out by 1 M NaCl at pH 7 and was read as a measure of CEC. Soluble cations and anions were determined after shaking 5 g of soil in 50 ml of deionized water for 30 minutes. The suspension was then filtered and the solutions were used for determinations of soluble cations and anions. The electrical conductivity (EC) of soils was measured in a soil suspension of a soil to water ratio of 1:10. Soil pH was measured in a 1:5 soil to water suspension using a glass electrode. Total carbon and nitrogen were determined using gas chromatography. Organic carbon was determined by difference after determining carbon content before and after loss on ignition.

RESULTS AND DISCUSSION

History

Irrigation is the main source of agricultural development of Sudan. Most of the country's exports (cotton, sugarcane, etc.) are produced in the central clay plains and under irrigated agriculture. Irrigation in this region started first in the year 1908 at a Pilot farm in Taiybah with water pumped from the Blue Nile. In 1925, after construction of Sennar dam, gravity irrigation started using the water raised at the dam. The soil of the Gezira being used mainly for cotton production were found to have a readily available water capacity of 100 mm (420 m^3 fed^{-1}). The water requirement of cotton was found to be 30 m^3 fed^{-1}. Following this fact the soils were irrigated every 14 days with an amount of 420 m^3 fed^{-1}. The main crops produced in the region include wheat, groundnuts, other legumes, fodder, vegetables in addition to cotton. It was anticipated at the first days of the scheme that secondary salinization could develop as a result of mobilization of salts dissolved by irrigation water. When primary salinity is present it is reported by Greene (1928) to be Na_2CO_3 when the salt content is low, while at high salt content and gypsum accumulation Na_2SO_4 salinization is present. This was also confirmed by Purnell et al. (1976) on vertisols from Gezira.

Climate and vegetative cover

The Gezira region has an arid, semi-arid type of climate characterized by a short season of rain. Precipitation is widely variable and erratic. The rainfall reaches about 400 mm at Wad Medani increasing southwards to 750 mm and decreasing northwards to less than 200 mm. Maximum temperature during the summer reaches 40 °C and falls to 30 °C in the rainy season. The coldest temperature ranges from 13 to 17 °C. Evaporation rates differ only during the rainy season from north to south decreasing to the south. There is no month in which the average rainfall exceeds the potential evapotranspiration. Gezira has an abundant sunshine and a solar radiation of 548 cal cm^{-2} day^{-1}.

Gezira is now mainly used as irrigated land. The remaining natural vegetation cover is a scatter of *Acacia spp.* with grasses and annual herbs.

QUALITY OF IRRIGATION WATER

According to the USDA classification of irrigation water the Blue Nile water is classified as C1-S1 when the river is high and C1-S2 when the river is low. The maximum SAR is 1.44 in the Month of December. The electrical conductivity of the river water ranges from 120 to 220 µS cm^{-1} (Mustafa 1973). However, Farbrother (1996) reported the maximum electrical conductivity at the recession season to reach 430 µS cm^{-1}. The maximum concentration of sodium is reported by Mustafa (1973) as 1.3 mM_c l^{-1}. The Blue Nile water was found to contain a safe level of residual carbonate.

The suspended sediment in the Blue Nile water varies between 100 mg l^{-1} to 10 000 mg l^{-1} depending on the flood stage (Farbrother 1996).

EXPERIMENTAL RESULTS FROM THIS STUDY

The physical and chemical characteristics of the Gezira soils as reflected by the two selected profiles are shown in Tab. 1. Both profiles have EC values ranging from about 300 to about 4000 μS/cm. Soil pH differed only slightly in the surface horizons as it was greater in the permanent fallow plot. This observation also applies to total nitrogen and organic carbon both of which were slightly greater in the surface horizons of the continuously cropped plots.

Tab. 1. Basic properties of the soils under investigation, PF denotes permanent fallow and GRS denotes the continuously cropped plot

Depth (cm)	EC μS/cm	pH	CEC mM_c/kg	Organic-C g/kg	Total C g/kg	Total N g/kg	Clay %
	PF						
0-7	301.0	8.3	621	4.00	9.99	0.25	51.9
7-35	344.5	8.5	610	4.61	10.39	0.22	57.3
35-65	433.0	8.8	557	4.67	10.77	0.19	57.2
65-90	675.5	8.7	539	5.77	10.46	0.21	59.9
90-120	2475.0	8.1	623	6.34	10.84	0.29	63.0
120-150	3970.0	7.9	615	6.06	11.30	0.18	60.6
	GRS						
0-10	325	7.4	594	6.35	11.64	0.34	52
10-35	275	8.4	626	5.44	10.59	0.23	55
35-65	490	8.9	618	4.79	9.84	0.19	56
65-85	731	8.7	621	5.96	10.47	0.18	55
85-115	1371	8.3	682	6.30	10.74	0.22	58
115-150	3605	7.6	679	6.43	11.77	0.22	58

TOTAL BASE CATIONS

Redistribution of different elements concentration within the soil profile has taken place more clearly in the irrigated plot (data not presented). Total Ca and Mg were greater in the lower depths of both profiles, but greater amounts were found in the permanent fallow plot. In the fallow plot total Na increased with increasing depth in the profile, while in the irrigated plot total Na was less at the bottom of profile and the lowest Na quantities were found in the surface horizon clearly reflecting the effect of irrigation water in dissolution of Na and changing its zone of accumulation. Potassium was higher in the surface horizon of the irrigated plot indicating the effects of silt deposits with irrigation water which are always high in K content.

EXCHANGEABLE BASE CATIONS

The exchangeable base cations differed between the two plots as Ca was found to range between 295 to 419 mM_c/kg in horizons of the permanent fallow while it was 160 to 322 mM_c/kg in the irrigated plot horizons. Mg, Na and K were 97 to 170, 65 to 281 and 9.1 to 12.9 in the permanent fallow plot as compared to 78 to 95, 10 to 83 and 8.1 to mM_c/kg in the irrigated plot for the three elements, respectively (Fig. 2). The cation exchange capacity of the soils was not affected by the continuous irrigation and it ranged from 585 to 678 and 594 to 682 mM_c/kg in horizons of the permanent fallow and irrigated plots, respectively. The exchangeable sodium percentage was found to be greater in all horizons of the permanent fallow plot (Fig. 3). The base saturation percentage was significantly greater in the permanent fallow plot reaching values of 68 to 130 % compared to 51 to 75 % in the irrigated plot (Tab. 2) indicating leaching of soluble anions and cations with irrigation water down the soil profile. This latter statement was confirmed when soluble anions and EC were determined. Differences in base saturation found in these soils is explained in terms of changes in the quantities of exchangeable bases as affected by leaching, dissolution and perhaps redistribution of bases.

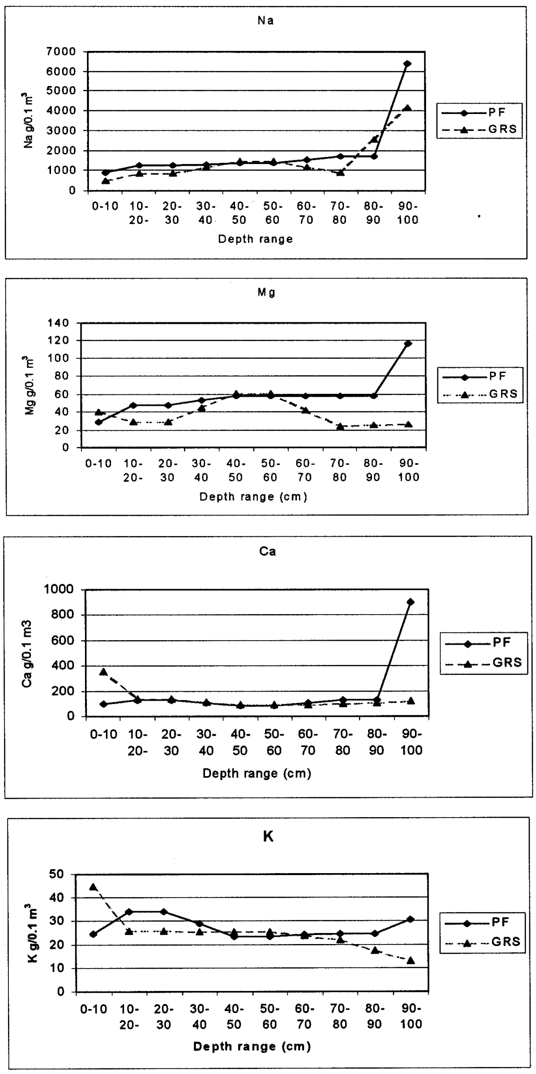

Fig. 2. Exchangeable base cations in the two sites of the study. PF denotes permanent fallow and GRS denotes the continuously cropped site

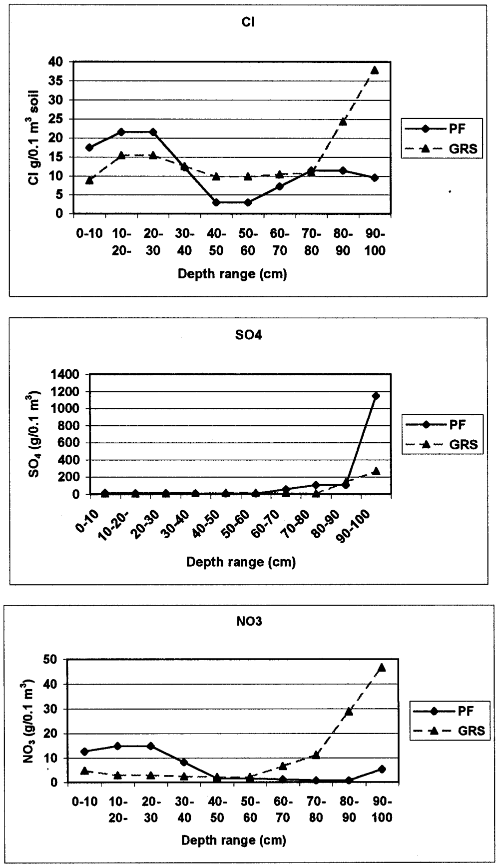

Fig. 3. Exchangeable sodium percentage in two sites of study, identifying legends are as in Fig. 2

Tab. 2. Percentage base saturation in soils of the study sites, depths of soil horizons were as in Tab. 1 for both soils

Base saturation (%)		
Horizon	PF	GRS
1	83.3	56.2
2	78.3	51.4
3	97.6	53.8
4	96.3	50.9
5	111.0	55.1
6	131.3	75.1

SOLUBLE SALTS

The amounts of soluble cations in both sites are presented in Tab. 3. The data is quoted in kg per cubic metre volume of soil volume. Greater amounts of the four base cations determined in this study were found in the permanent fallow plot.

Tab. 3. Amounts of soluble cations (kg/m³) at the study sites

	Cations			
Site	Na	K	Ca	Mg
PF	20.3	0.27	2.14	0.61
GRS	15.0	0.24	1.34	0.38

The main anions in these soils are chlorine and sulphate. Sulphate was found to be greater at depths in the permanent fallow plot, while chlorine was higher at the top of the profile, but was significantly lower when the values were compared for the bottom of the profiles (Fig. 4). At the surface of the profiles, both Cl^{-1} and NO^{-3} were lower in the cropped plot increasing downwards to values significantly greater than those in the permanent fallow plot. It is possible that amounts of these anions at or close to the soil surface are being reduced by both uptake of growing crops and by volatilization. Accumulation of these anions deep in the soil profile as a result of leaching with irrigation water is conceivable. It is also possible that chlorine and nitrate values were affected by the sampling and storage procedure maintained in this study.

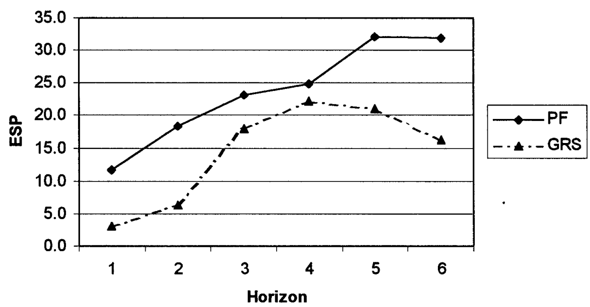

Fig. 4. Soluble anions in the two sites of the study, identifying legends are as in Fig. 2

The soil electrical conductivity was higher in the deeper soil horizons in the permanent fallow plot as shown in Fig. 5. The EC of these soils reflects the overall status of the soluble salts.

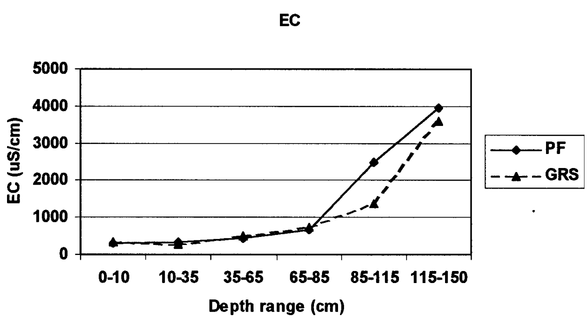

Fig. 5. Electrical conductivity in the two sites of the study identifying legends are as in Fig. 2

The long-term effects of irrigation on Gezira soils have reflected worries, in the past, on the likely possibilities of waterlogging and salinisation under continuous irrigation. This was based on the impermeable nature of the Gezira clay and on the high concentrations of sodium found within the rooting depth. It was assumed that irrigation would add to the accumulation of salts. A perched water-table was also anticipated as a result of possible over-watering. In a period of 20 years of irrigation in Kareema and Sidon, calcium carbonate has increased form 2 to 2.2 % and from 1 to 4 % at the two sites, respectively. The electrical conductivity of Kareema soils increased form 0.63 to 1.1 mS/cm (Bureymah 1977). This was not the case in Gezira as evident from this study and supported by the findings of Fadl and Farbrother (1973). Flood irrigation have been used in Dakhlah, Kharga and Baris oasis in Egypt for centuries under a mixed cropping system of palm trees, small fruit trees and vegetables, and grain crops with no evidence of any increase in salinity (Alaily 1993). If Farbrother (1996) commenting on data collected in the seventies and before has argued that no deterioration was found in the Gezira Vertisols as a result of continued irrigation the data provided in this study confirm this finding and, furthermore, it may prove the ameliorative effect of irrigation water on sodium hazards in the Gezira. So far as it is known, no increase in GWT was observed throughout the Gezira and hence the risks of salinity or alkalinity and water logging normally associated with high water-table do not apply under the conditions of the soils under study. As was mentioned earlier in this text there is no salinity hazard associated with the quality of the Blue Nile water. This is evident from the chemical analysis of the river water and from the fact that more than 0.9 million ha of cultivated land in the Gezira has been under irrigation for over 80 years with no signs of salinization. It is thought that the main factors to affect this matter are:

1. Physical condition of the soil,
2. Ground Water-Table,
3. Quality of irrigation water,
4. Primary salinity.

The first and the fourth factors have negative effects but were counterbalanced in the case of Gezira by the deep water-table and the high quality of Blue Nile water.

CONCLUSIONS

The Gezira Scheme of Sudan represents a rare example of irrigated agriculture in arid climates where no salinity has been developed despite 70 years of continuous irrigation. On the contrary salt accumulation under permanent fallow was found to be higher than under continuously cropped conditions. The high quality of water of the Blue Nile river, EC of 150 µS/cm and SAR of 1.2, is thought to be the main factor controlling this matter in addition to other favourable conditions including a deep water-table.

This work is sponsored by the Alexander von Humboldt Foundation as a Post-doc Fellowship to the first author. The authors are indebted to the Foundation.

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ÚČINKY DLHODOBÉHO ZAVLAŽOVANIA NA ROZPUSTNÉ SOLI A VYMENITEĽNÉ BÁZICKÉ KATIÓNY VO VERTISOLOCH SUDÁNSKEJ GEZIRY

Sudánske vertisoly, ktoré sa nachádzajú na centrálnej ílovej plošine, južnej ílovej plošine a v pohorí Nuba, majú pre hospodárstvo krajiny veľký význam, pretože sa v nich sústreďujú významné poľnohospodárske aktivity. Táto štúdia bola uskutočnená v Gezire, časti centrálnych plošín Sudánu, ležiacich medzi 13°30’ a 15°30’ severnej šírky a 32°30’ a 33°30’ východnej dĺžky. Gezirský plán predstavuje polovicu celkovo zavlažovanej plochy 1,8 mil. ha v Sudáne a produkuje hlavné plodiny krajiny pomocou závlahových systémov. Záplavové zavlažovanie sa na sudánskych vertisoloch praktizuje vyše 80 rokov.

Na farme poľnohospodárskej výskumnej stanice vo Wad Medani sa ponechal permanentne úhorový pozemok ako kontrola, aby bolo možné merať zmeny vlastností pôdy. Má to svoj zvláštny význam, lebo závlahová voda má modifikačný účinok na chemické vlastnosti pôdy najmä v súvislosti so zasolením. V tejto štúdii sa analyzovali fyzikálne a chemické vlastnosti pôd osiateho a neosiateho pozemku. Pomocou dvoch profilov, vykopaných na oboch pozemkoch, sa skúmali aj morfologické vlastnosti.

Cieľom štúdie bolo stanoviť účinky zavlažovania na celkový obsah rozpustných solí a vymeniteľných báz. Pomocou štandardných laboratórnych techník sa na pedologickom oddelení univerzity v Berlíne určila škála veľkosti častíc, celkové chemické zloženie, obsah vymeniteľných katiónov, rozpustných katiónov a aniónov, celkového a organického uhlíka, celkového dusíka, pôdne pH a elektrická vodivosť (EC).

Najnápadnejším zistením štúdie bolo, že v zavlažovanej pôde došlo k jasnejšiemu rozloženiu rôznych prvkov v pôdnom profile. Celkový obsah vápnika (Ca) a horčíka (Mg) bol vyšší vo väčších hĺbkach oboch profilov, ale vyššie množstvá boli zistené na kontrolnom pozemku. Tu sa celkový obsah Na zvyšoval so zvyšujúcou sa hĺbkou v rámci profilu, kým na zavlažovanom pozemku bol celkový obsah Na nižší na dne profilu a najmenšie množstvá Na sa zistili v povrchovej vrstve, čím sa jasne potvrdil účinok závlahovej vody na rozpustnosť Na a zmenu oblasti jeho akumulácie. Obsah draslíka bol vyšší v povrchovej vrstve zavlažovaného pozemku, čo je dôsledkom ukladania sedimentov s vysokým obsahom K závlahovou vodou.

Výsledky dosiahnuté v tejto štúdii ukázali, že hoci pôdy majú svoju primárnu fázu slanosti, nepretržité zavlažovanie nemalo za následok tvorbu sekundárnej slanosti. Prekvapením bolo, že obsah rozpustných solí bol vyšší na kontrolnom pozemku. Percentá vymeniteľného sodíka (Na) a celkových vymeniteľných katiónov boli vyššie na úhorovom pozemku. V podmienkach Geziry, kde sa ročné zrážky rovnajú alebo sú nižšie ako evapotranspirácia, sa predpokladalo, že čoskoro po zavedení záplavového zavlažovania vznikne sekundárna salinita. Pri tomto predpoklade sa bral do úvahy aj vysoký obsah ílu v pôde a s tým súvisiace riziko zmáčania pôdy pri nadmernom zalievaní. Podľa US Salinity Laboratory je kvalita vody Modrého Nílu používaného na zavlažovanie týchto pôd C1-S1. Tento fakt spolu s veľkou hĺbkou hladiny podzemných vôd spôsobil zlepšenie salinity.

Preložila H. Contrerasová