UPWARD WATER AND SALT MOVEMENT IN LABORATORY COLUMNS AS AFFECTED BY DEPTH OF WATER TABLE

By

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DECLARATION

I, hereby declare, that the content of this thesis is a record of my research work. The subject matter herein has not been presented in any previous publications for a higher degree.

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CERTIFICATION

This thesis entitled UPWARD WATER AND SALT MOVEMENT IN LABORATORY COLUMNS AS AFFECTED BY DEPTH OF WATER-TABLE, by OGUNWOLE JOSHUA OLALEKAN, meets the regulations governing the award of the degree of Master of Science of the Ahmadu Bello University, Zaria and is approved for its contribution to scientific knowledge and literary presentation.

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J.O.O.

DEDICATION

This work is dedicated to:

(i) My father, Deacon David Olaniyi Ogunwole,

(ii) My Beloved Mother, Mrs. Abigael Ibidunni Ogunwole for her encouragement, prayers and support throughout these periods.

and

(iii) To all lovers of righteousness and those who believe in the course of the gospel.

ABSTRACT

Polyvinyl chloride pipes of 10cm I.D were used to study moisture and salt distribution in soil profiles overlying ground water at various depths (42, 60 and 9Ocm) *and* also, at various ground water electrolyte concentration (1500, 3000 and 4500 mgKcl per 1itre of water).

While daily evaporation was constant at 0.6cm and relative humidity at 50+ 35C, moisture loss and salt, accumulation increased with decrease in soil profile depth. The role of solute - induced flow was significant when the effect of ground water electrolyte concentration was used to determine moisture loss and ch1oride ion accumu1ation.

Depth of ground water tabic? had little effect on daily moisture distribution pattern along the soil profile.

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1.0 INTRODUCTION

1.1 IRRIGATION DEVELOPMENT IN NIGERIA

Irrigation has been defined as an agricultural practice that supplements a deficiency of the climate; the imbalance between water supply by precipitation and evaporation demand of the atmosphere. The need to produce sufficient food for the increasing population in Nigeria led to the reactivation of irrigated agriculture, most especially in the sudano-sahelian region. The dependence of this region on irrigated agriculture can be attributed to two important climatic features. One, is the seasonal distribution of rainfall, the harmattan months from October to May are cold and dry and rain falls almost exclusively during four months from June to September. Consequently, intensive agriculture during the harmattan months is impossible without irrigation. Secondly the high rate of evapotranspiration (almost all year round) in this region coupled with low relative humidity makes loss of water from the land surface to be considerably high.

Modern irrigation projects were initiated in Nigeria from 1970 to increase the production of food crops. In 1973, the responsibility of supervising and day to day administration of these projects were shouldered by the River Basin Development Authorities, whose primary mandate was to "develop irrigation scheme and to lease the irrigation land to farmers for a fee".

Three a large scale irrigation scheme with a present potential of 51900 hectares of land are presently under intensive agriculture in the sudano-sahelian region of Nigeria. These

irrigation schemes include Kano River, Bakolori and South Chad Irrigation Projects (Maurya and Kuzniar, 1988).

1.2 PROBLEMS

Reports all over the world have linked irrigated agriculture with Salt related problems. Under poor soil and water management practices, irrigation has been reported to significantly contribute to the accumulation of salts in soil profiles and to the pollution of ground water (Shalhevet and Reiniger, 1964; Bresler, 1967 and Bresler and Hanks (1969).

With the exception of the Bakolori Irrigation Project, the other two irrigation schemes have been reported to show cases of soluble salt accumulation due to either poor drainage facilities or rising levels of ground water table (Kuzniar, 1982; Bird, 1984; Adewumi et al., 1985; Maurya and Sachan, 1985; Maurya and Kuzniar, 1988).

The Kano River Project which is the area under study has been the subject of investigation due to the gradual buildup of salts in certain spots, particularly within the Kadawa, Waire and Agalawa sectors (Nwa, 1982; Maurya, 1982). In the Kadawa area, reports have indicated the presence of fluctuating water table caused by hardpans at about 80 to 150cm depth. It has been reported that the water table in this area is rising at about 1.5cm a year (Nwa, 1981). Salt encrustations have also been reported during the dry seasons in the area (Maurya and Sachan,

1985). The continuous rise in ground water under the high evaporation condition has resulted in the gradual salinization of the soils in this area.

1.3 JUSTIFICATION AND OBJECTIVES

As earlier mentioned, research reports and salinity surveys have established the occurrence of salinity due to high water table conditions in some spots of the Kadawa scheme. Although the rate of water table rise has been modelled, little or no work has been initiated on the rate of salt accumulation. It is evident that a search for solution will be impossible without a knowledge of important facts such as the rate of accumulation of soluble salt.

The evaluation and determination of the rate of accumulation of these salts will serve as guide in planning an appropriate cropping scheme, and optimal soil or water management practices which will consequently control the rate of salt build-up in these soils.

The reasons given above have led to this study which is designed to provide information on salt and water dynamics in soils of this region.

Specifically, the objectives include:

(i) To determine salt and moisture distribution in soil columns during evaporation.

(ii) To predict the rate of salt buildup as a function of water

table depth.

(iii) To evaluate the extent of the contribution of ground water electrolyte concentration to salt buildup in these soils.

2.0 LITERATURE REVIEW

2.1 PRINCIPLES OF EVAPORATION

Evaporation of water directly from the soil accounts for the loss of a large portion of the precipitation received in most parts of the world (Hanks et. al; 1967). Evaporation refers to the loss of liquid water from soil (or any other surface) by vaporization and vapour removal. Three requirements were suggested by Wild (1993) for evaporation to proceed continuously:

(i) A supply of energy which is needed to meet the latent heat of vaporization. The most common source of energy in this case is solar radiation.

(ii) A gradient of vapour pressure is also required such that the vapour pressure at the site of evaporation is greater than that of the overlying air.

(iii) A means of conveying vapour from the relatively dry overlying air.

From these conditions stated, it is evident that evaporation from a wet surface will depend on the energy inputs from solar radiation, the vapour pressure of the air, the saturated vapour pressure of the air above the surface (which depends on temperature) and the wind speed.

Under field conditions, evaporation of soil water will occur as a series of drying cycles interrupted by precipitation events. Evaporation in a wetted field soil can be characterized into three stages. The initial stage is that stage where the soil

surface is wet and flow is primarily in the liquid state called the constant rate stage. This process involves a rapid rate of water loss which is a function of external conditions. next, is the stage where evaporation rate decreases rapidly and the soil begins to assume regulatory role. The final stage is characterized by a very slow but relatively constant evaporation where water movement through the dry surface soil is primarily by vapour diffusion. These two latter stages are collectively called, the falling rate stage. This stage is operative for a much longer time in soils while the constant rate stage has short duration (Bond and Willis, 1969).

These characteristic stages enumerated above can best describe evaporation in a field condition where the water-table is deep, thus having little or no significant contribution to the upper layer wetness.

In areas where shallow water table exists and the soil profile is wet (e.g Kadawa), the loss of water due to evaporation may not follow this line of description since groundwater makes significant contribution to the moisture loss at the upper layer.

The controversy over the effect of heat flow on evaporation has continued to remain unsolved. While many investigators (Philip 1957; Gardner 1959; Gardner and Hillel, 1962) have claimed that heat flow has little influence on evaporation, other authors (Weigand and Taylor, 1962; Cary 1964; 1966) however, have continued to say that "thermal-induced flow is significant during

evaporation and should not be ignored".

2.2 THEORY OF WATER MOVEMENT IN SOIL

The basic theory of water movement in the soil shows that it is in response to various forces acting on it. These forces include pressure gradient, Osmotic and absorptive forces.

Darcy's law has been used to explain water movement in soils. It states that the discharge rate of water flowing through a column is directly proportional to the cross-sectional area and to the hydraulic head drop and inversely proportional to the length of the column.

This can be described by the equation.

$$Q \propto \frac{A \,\Delta H}{L} \qquad \text{---------- (1)}$$

where

Q = Discharge rate in $cm^3.s^{-1}$

A = Cross sectional area in cm^2

ΔH = Hydraulic head drop in cm

L = Length of the column in cm.

The discharge rate can be defined as the volume of water flowing through a column per unit time.

Hence,

$$Q = {}^{V}/_{t} \propto \frac{A \,\Delta H}{L} \qquad \text{------ (2)}$$

where

V = volume of water in cm^3

t = Time in seconds.

Dividing the discharge rate by the area yields the soil moisture flux.

$$q = {}^{Q}/_{A} = {}^{V}/_{At} \; a \; \frac{/\backslash H}{L} \quad \text{------ (3)}$$

where

q = Soil moisture flux in $cm.s^{-1}$

Therefore

$$q = -K \; \frac{/\backslash H}{L} \quad \text{-------- (4)}$$

Where

K = proportionality constant known as hydraulic conductivity in cm sec^{-1}.

This equation is popularly referred to as Darcy's equation. Hydraulic conductivity is a function of either matric suction or volume wetness in unsaturated soils, while in saturated soils, it is said to be constant.

The knowledge of water movement in this study becomes important since water movement influences the degree of salinization of soils and also explains salt behaviour in soil profile. Bresler (1981) argued that "the imbalance between transported incoming and outgoing salt causes salinization of soils and subsoils which results in increasing salinity of agricultural lands."

2.3 CAPILLARITY

Capillarity is the ability of the capillary interstices of the soil to raise water from the water-table to the ground surface. It is a well known fact that the depth of water table can affect the ability of a particular soil to raise water to the ground surface under a given condition.

Remson and Fox (1955) noted that the actual capillary water loss from a ground water body in a given situation will depend upon the ability of the soil. The ability of the atmosphere in this case can be attributed to its evaporation potential and the relative humidity. A high evaporation and low relative humidity will encourage capillary water loss from ground water until the drying soil eventually reaches a condition in which the capillary conductivity is reduced to a low value in the surface layer that little water will reach the surface. This is because a drying soil will eventually reach such a condition where capillary conductivity is reduced i.e when the moisture content of a soil is reduced to the permanent wilting point, both the actual and the potential capillary losses from the water table will be negligible (Moore, 1939).

Darcy's law has been used to adequately describe flow processes at steady state in which flux density is constant and equal over the conducting system.

In transient flow processes in which the magnitude and possibly even the direction of flux and potential gradient vary

with time, the law of conservation of matter expressed in equation of continuity is introduced.

This states that if the rate of inflow into a volume element is grater than the rate of outflow, then the volume element must be storing the excess and increasing its water content.

2.4 COLUMN EXPERIMENTS

Many laboratory experiments have been undertaken to measure water movement in soil columns.

Hadas and Hillel (1968) studied experimentally evaporation from soil columns in the presence of a water table using columns of 5cm diameter, and 70 and 120cm length. The soil columns were wetted to saturation with distilled water, containing 5ppm mercurochrome disinfectant.

The columns were later allowed to equilibrate with the water table. External evaporativity was measured with the aid of a water filled tube of the same diameter and elevation with the soil column while electric blowers were used to obtain evaporativity rates exceeding 5mm day^{-1}.

Bond and Willis (1969) worked on the effect of surface residue rate and placement effects on the soil water evaporation. They conducted their experiments in columns mounted on turntables operated at a speed of 1 r.p.m. Radient energy for evaporation was obtained through the use of thirty-two (32) infrared industrial reflector lamps (125watt) which were operated

continuously for 16 hours each day. A column was kept filled with distilled water to a constant depth with a mariotte measuring apparatus. Relative humidity was also partially controlled by a dehumidifier.

Abramova (1969) observed the movement of moisture as a liquid and vapour in soils of semi desert. He carried out this experiment using metal columns 1 meter long and 8cm diameter which after filling with soil were wetted with a dilute solution of calcium chloride up to 9.5% moisture content. He attained a uniform distribution of moisture (i.e equilibration) when the columns were closed for some days. The columns were later exposed under a lamp and the columns were heated for 20 days, 8 hours daily to study the migration of moisture at a lower moisture content.

Sutor (1969) determine soil moisture distribution function in non-isothermic condition. He used columns with a diameter of 30mm and a length of 110mm which he placed between two discharge tanks in which various temperatures were maintained by means of ultra-thermostat.

In all these instances, it is evident that for a similar experiment to be undertaken, columns must be employed with a source of evaporative energy (greater than 5mm day^{-1}) and the use of a dehumidifier becomes necessary for continuous water vapour movement into the atmosphere. To obtain an unbroken capillary stream, the column must be air-free, hence, the need to initially

wet the soil column to saturation and equilibration with the water table.

2.5 PREVIOUS WORK IN THE PROJECT AREA

Most work in this area were undertaken to determine the characteristics of the fluctuating ground water table. Nwa (1981) first reported a water table rising at about 1.5cm per year. Most of his work was restricted to installing observation wells and consequently monitoring the water table depth. This line of investigation was continued by Muazu et. al. (1991) who described their findings in the form of a ground water table contour map. Muazu and Nwadukwe (1991) in a technical paper on hydraulic properties of soils of Kano river project reported saturated hydraulic conductivity decreasing with depth from the soil surface which they attributed to the changes in texture, structure and the effect of tillage. Their work revealed that insitu hydraulic conductivity for these soils ranges from 0.44m day^{-1} to 3.14m day^{-1}.

Adeoye and Maurya (1982) modelled the upward movement of water from the water table to the soil surface to study the extent of ground water contribution to water used by wheat. They showed that yield of 5167Kg ha^{-1} wheat can be obtained even when water table depth is only 60cm below the surface and irrigation interval is 15 days. Yield of 5,000Kg ha^{-1} wheat was obtained when water table depth was 90cm to the soil surface and

irrigation interval was 7 days. Maximum water fluxes from water table were 7.9mm day^{-1} and 3.8mm day^{-1} respectively. Their results showed increased crop yield as water table rose up to a certain limit (60cm) after which yields decrease drastically. They concluded both from theoretical calculations and lysimeter studies that water movement into the root zone from a water table depth of 50-60cm would provide sufficient water to raise good crop of wheat on these soils without irrigation.

3.0 MATERIALS AND METHODS

3.1 SOIL SAMPLING AND HANDLING

Soil samples used in this study were collected from Irrigation Research Station, Kadawa which is in the sudano-sahelian region of Nigeria.

3.1.1 SOIL SAMPLING

A soil profile was dug up to a depth of 60cm. Further digging became difficult due to rise in ground water. Disturbed and undisturbed samples were collected at 10cm depth interval using spades and core sampler respectively.

3.1.2 SOIL PREPARATION

The core samples were weighed and immediately oven-dried at 105°C for 24 hours. After the oven dried soil has been weighed, the soil bulk density was determined. The duplicated core samples were saturated and used for the determination of saturated hydraulic conductivity. The disturbed soil samples were air-dried for about seven days, ground with a porcelain pestle and mortar to pass through a 2mm sieve. The sieved samples were later stored in air tight polythene bags for various laboratory determinations.

3.2 ROUTINE CHEMICAL ANALYSIS

3.2.1 SOIL PH (GLASS ELECTRODE-CALOMEL ELECTRODE PH METER METHOD)

Two solvents were used namely, distilled water and 0.01M calcium chloride solution. The soil-water and soil solution ratio was 1:2.5 in each case. The pH was measured using a Pye Unican Model 290 MK2 pH meter (McLean, 1982).

3.2.2 PARTICLE SIZE ANALYSIS

From each of the soil sample representing the various profile depths, 50g of the sieved soil was transferred into a plastic cup, 100mls of calgon solution was added to the soil and the entire mass diluted with 400mls of distilled water. After 10 minutes, the mixtures were shaken in an end to end (HS-500) Mechanical shaker for twenty minutes before they were transferred into 1000ml measuring cylinders. Hydrometer and thermometer were used to measure the behaviour of each solution and record their temperatures respectively at 40 seconds and 8 hours intervals. A blank of the reagents were also run (Day, 1965).

3.2.3 ORGANIC CARBON (WALKLEY-BLACK METHOD)

In 600mls Erlenmeyer Flasks, 2g of each soil sample was mixed with 10mls of 1N potassium dichromate and swirled to ensure dispersal of soil before 20mls of concentrated sulphuric acid was added to each of the flasks and swirled again for about a minute.

100mls of distilled water was added after 30 minutes and the whole solution was allowed to cool. The solutions were titrated with 0.5N Ferrous ammonium sulphate solution after the suspensions were filtered and 5mls of phosphoric acid plus five drops of O-phenanthroline ferrous complex were added to the solution. Colour changes from blue to dark green and finally red. A blank was also run to observed the behaviour of the reagents alone (Nelson and Sommers, 1982).

3.2.4 CATION EXCHANGE CAPACITY (AMMONIUM SATURATION METHOD)

40mls of 1N Ammonium acetate was added to 10g soil in 500mls Erlenmeyer flask. The mixtures were shaken and allowed to stand overnight before filtering with tight suction using a 55mm Buchner funnel. Leaching of the soil with neutral ammonium acetate continued until test for calcium became negative, further leaching was done with 1N ammonium chloride for at least four times and once with 0.25N ammonium chloride, the electrolyte was washed out with 200mls of 99% ethyl alcohol until test for chlorine in the leachate became negligible. After allowing the soil to drain thoroughly, the whole thing (except the leachate) was transferred into a 500mls Kjeldahl flask. About 200mls of distilled water, five drops of liquid paraffin, pumice bead (for bumping and fuming prevention) were added. 10mls of 1N sodium hydroxide and 10 drops of bromocresol green-methyl red mixed indicator were all added and titrated with standard 0.02N

sulphuric acid. Colour change is from bluish green to pink as the end point. The blank was also run on the reagents (Chapman, 1965).

3.2.5 EXCHANGEABLE BASES

The leachates from the determination of cation exchange capacity were utilized for the determination of calcium and Magnesium through the use of the Atomic Absorption Spectrometer (AAS) while flame photometer was used for potassium and sodium determination (Thomas, 1982).

3.2.6 CHLORIDE ANALYSIS (SILVER NITRATE TITRATION)

In centrifuge tubes containing 20g of each of the soil samples, 40mls of distilled water and 10mls of gelatine solution were added (to check absorption of Ag+ at the Agcl particles). The mixtures were shaken with the aid of the end to end (HS-500) mechanical shaker for 10 minutes, after which the mixtures were centrifuged under a high powered centrifuge, for five minutes before the clear solution was decanted into a conical flask, three drops of potassium chromate indicator were added before they were titrated with 0.01N silver nitrate solution. A blank was run on the reagent and colour changes from yellow to reddish brown (Adriano and Doner, 1982).

3.3 ROUTINE SOIL PHYSICAL ANALYSIS

3.3.1 SATURATED HYDRAULIC CONDUCTIVITY (CONSTANT HEAD METHOD)

The undisturbed core samples representing each layered profile were covered at one end with a piece of muslin cloth held in place with the aid of rubber bands and allowed to stand overnight in water to ensure complete saturation. These saturated samples were then arranged into a permeameter, velocity of flow and change in hydraulic heads were determined. Saturated hydraulic conductivity was calculated by substitution using Darcy's equation i.e:-

$$q = -K \frac{/\backslash H}{L}$$

Since, the minus sign indicates direction only, it can be deleted hence,

$$q = \frac{K/\backslash H}{L}$$

$$qL = K/\backslash H$$

$$K = \frac{qL}{/\backslash H}$$

Since $q = Q/A = V/tA$

$$K = \frac{V.L}{At/\backslash H} \quad \ldots\ldots\ldots\ldots (5)$$

Where

K = Saturated hydraulic conductivity in $cm.s^{-1}$

q = Soil water flux in $cm.s^{-1}$

Q = Discharge rate in cm^3sec^{-1}

V = Volume in cm^3

t = Time in sec.

A = Area in cm^2

L = Length of soil sample in cm

ΔH = change in hydraulic head in cm.

3.3.2 SOIL BULK DENSITY

A double cylinder, hammer driven core sampler was used to sample the profile at an interval of 10cm. The samples were then oven dried at 105°C for 24 hours after which they were weighed.

The diameter of the core samplers were determined and the volume of the core sampler was assumed equal to the volume of the soil in it.

Volume of sampler = $\pi r^2 h$

radius (r) = Diameter/2

Bulk density was then calculated as:

$$\frac{\text{Mass of oven dried soil}}{\text{Volume of the core sampler}}$$

3.3.3 MOISTURE CONTENT DETERMINATION

Soil samples were weighed immediately they were removed from the pressure membrane or from any other source as the case may be, and placed in an electric oven to dry at 105°C for 24 hours. After which the samples were removed, allowed to cool and weighed again.

The tare weight of the sample containers were also determined. Soil moisture content θ, was calculated using this formular.

$$\theta = \frac{\text{(Weight of wet soil + tare) - (weight of oven dry soil + tare)}}{\text{(Weight of oven dry soil + tare) - (tare)}}$$

i.e $\frac{\text{Weight of water}}{\text{Weight of oven dry soil}}$

$$\%\theta = \frac{\text{Weight of water}}{\text{Weight f oven dry soil}} \times \frac{100}{1}$$

3.4 SALT AND WATER DISTRIBUTION

3.4.1 COLUMN STUDIES

Polyvinyl chloride (PVC) pipes, 10cm diameter were used in these experiments in which treatments were varied pipe length (42, 60 and 90cm) and ground water electrolyte concentration (1500, 3000 and 4500mg Kcl per litre of water). For every set of treatment investigated, five PVC pipes with drilled holes and One sectioned pipe (to represent each layered profile) were employed. One end of each pipe was covered with muslin cloth and held in place by rubber bands. These pipes were later filled with soil, to simulate field bulk density of each layer, using the method described in section 3.3.2 for bulk density determination.

The mass of soil used to fill each column layer was determined using this formular:

Volume of each sectioned column = $\pi r^2 h$

Diameter = 10cm; radius = 10/2 = 5cm

Depth of a sectioned layer (for 60cm pipes) = 10cm

Volume of sectioned column = 3.143 x 25 x 10

= 785.75cm^3

From section 3.3.2,

Soil bulk density = Mass/volume

Therefore,

Mass = Volume x bulk density.

With the volume and bulk density determined, the mass of soil for every layer is calculated by re-arranging the formular for the bulk density. Every column was packed with their corresponding soil mass to occupy the exact volume of the column and they were wetted from the top to the bottom (i.e to saturation).

These columns were then lowered into a trough containing one of the above specified salt concentration and the columns were covered at the top to ensure equilibration. After three days, a hot pressure plate was introduced into the set up (after the cover has been removed and the sectioned columns weighed) to act as source of evaporative energy. This was aided by a ceiling fan regulated to the barest minimum to continuously dehumidify the surroundings of the soil columns and encourage continuous evaporation. This set up was run continuously for six to seven hours daily for five days until daily evaporation rate, a column similar to the soil columns but with one sealed end was filled

with water (i.e water column) to exactly the same level as the soil in other columns. The water column was kept at a constant level with the aid of a graduated mariotte bottle to ensure equal height at all times during the experiment.

The sectioned column which was bound together, was weighed daily to determine the moisture content profile using the method in section 3.3.4. The other soil columns were sampled for chloride analysis through the holes drilled along the length of the columns. This was the same procedure employed for all the treatments.

To measure the behaviour of salt and water due to varied depth of water table, the pipe lengths were varied while the concentration of ground water was constant. Also, in the case of ground water electrolyte concentration, only the ground water electrolyte concentration was changing but the depth of water-table was constant.

The change in the graduated mariotte bottle was calculated and assumed to be the amount of evaporation for the day. While, wet and dry bulb thermometer readings gave an idea of the relative humidity condition of the surrounding of the experimental area.

4.0 RESULTS AND DISCUSSION

4.1 RESULTS

Table 1 shows the results of routine chemical and physical analysis undertaken at the onset of the experiment. Tables 2, 3 and 4 show the daily soil water content and chloride - ion distribution for a period of five days as a result of varied water table depth (i.e 42, to 60 and 90cm respectively).

Tables 5, 6 and 7 also show daily soil water content and chloride ion distribution for a 5-day evaporation cycle, when water table depth was constant at 60cm and only ground water electrolyte concentration was varied (i.e 1500mgl^{-1}, 3000mgl^{-1} and 4500mgl^{-1} potassium chloride).

Table 1: Chemical and physical analysis of the soil samples

Soil Layer Depth (cm)	Mechanical Analysis Clay	Silt	Sand	Textural Class (USDA)	Bulk Density (gcm^{-3})	Electrical Conductivity 1:2.5 $mhoscm^{-1}$	pH Water	pH $CaCl_2$	Organic Carbon %	Cation Exch. Cap. meq/100g	Exchangeable Bases Meq/100 Soil Ca	Mg	K	Na
	%													
0-10	6	18.72	75.28	LS	1.68	$2.8x10^{-2}$	7.5	6.7	0.24	7.40	3.25	0.71	0.06	0.63
10-20	12	22.72	65.28	SL	1.68	$2.1x10^{-2}$	7.4	6.8	0.17	8.30	3.82	0.74	0.07	0.39
20-30	12	24.72	63.28	SL	1.69	$1.3x10^{-2}$	7.4	6.8	0.10	9.20	4.45	0.77	0.08	0.20
30-40	12	26.72	61.28	SL	1.64	$1.2x10^{-2}$	7.4	6.8	0.08	11.0	4.53	0.75	0.08	0.22
40-50	16	22.72	61.28	SL	1.65	$1.2x10^{-2}$	7.3	6.7	0.06	13.10	4.64	0.75	0.08	0.22
50-60	18	18.72	63.28	SL	1.65	$1.2x10^{-2}$	7.4	6.7	0.04	13.10	4.75	0.75	0.08	0.22

Table 2: Salt and water distribution in soil profile at 42cm above water table and ground water concentration of 3000mgL^{-1} KCl

Soil Layer Depth (cm)	After equilibration Volume Wetness %	Chloride Ion Conc. Mgl^{-1}	Day One Volume Wetness %	Chloride Ion Conc. Mgl^{-1}	Day Two Volume Wetness %	Chloride Ion Con. Mgl^{-1}	Day Three Volume Wetness %	Chloride Ion Con. Mgl^{-1}	Day Four Volume Wetness %	Chloride Ion Con. Mgl^{-1}	Day Five Volume Wetness %	Chloride Ion Con. Mgl^{-1}
0-7	46.7	0.6	33.3	1.0	23.3	1.8	16.9	1.2	12.0	1.0	8.3	1.2
7-14	39.8	0.8	35.8	1.0	34.1	1.8	33.4	1.8	31.5	1.0	29.2	0.8
14-21	43.8	1.0	40.9	0.8	39.8	0.8	38.5	1.4	38.5	1.4	37.6	1.0
21-28	46.1	0.8	43.6	0.8	42.9	1.0	41.9	1.6	41.9	2.2	41.4	1.8
28-35	50.2	1.6	47.9	1.6	47.7	1.6	47.2	4.2	47.2	6.6	46.6	9.8
35-42	52.8	2.0	50.2	3.2	50.4	3.8	50.0	6.2	49.6	9.9	49.1	11.0
Total Cl-Conc.		6.8		8.4		10.8		16.4		22.1		25.6
Average Profile Volume Wetness	46.57	42.28		39.70		37.98		36.78		35.36		

Average Moisture loss = Initial Ave. vol. wetness - Final Ave. vol. wetness

= 46.57% - 35.36% = 11.21%

Amount of chloride ion accumulation = total cl- conc. (final) - Total cl- conc (initial)

= 25.6mL^{-1} - 6.8mgL^{-1} = 18.8 mgl^{-1}

Table 3: Salt and water distribution in soil profile at 60cm above water table and ground water concentration of 3000mgl^{-1} KCl

Soil Layer Depth (cm)	After equilibration Volume Wetness %	Chloride Ion Conc. Mgl^{-1}	Day One Volume Wetness %	Chloride Ion Conc. Mgl^{-1}	Day Two Volume Wetness %	Chloride Ion Con. Mgl^{-1}	Day Three Volume Wetness %	Chloride Ion Con. Mgl^{-1}	Day Four Volume Wetness %	Chloride Ion Con. Mgl^{-1}	Day Five Volume Wetness %	Chloride Ion Con. Mgl^{-1}
0-10	45.4	0.6	39.2	1.2	34.6	1.4	28.6	1.0	23.9	1.4	19.2	1.6
10-20	40.8	1.0	36.7	1.0	35.1	1.0	32.9	0.8	31.2	1.0	29.6	1.2
20-30	46.3	1.0	43.5	0.6	42.1	0.8	39.9	1.0	38.7	1.4	37.6	2.0
30-40	44.1	2.2	43.3	1.2	40.8	2.0	39.3	2.4	37.7	4.4	36.2	2.6
40-50	53.4	3.8	51.5	4.0	49.9	3.0	48.1	4.6	47.4	5.8	47.0	7.4
50-60	48.0	5.2	47.7	6.4	46.7	6.9	46.2	6.4	45.5	7.0	45.2	7.6
Total Cl-Conc.		13.8		14.4		15.1		16.2		21.0		22.4
Average Profile Volume Wetness	46.33		43.65		41.53		39.17		37.4		35.8	

Average Moisture loss = 46.33% - 35.8% = 10.53%

Amount of cl- accumulation = 22.4mL^{-1} - 13.8mgL^{-1} = 8.6 mgL^{-1}

Table 4: Salt and water distribution in soil profile at 90cm above water table and ground water concentration of 3000mgl^{-1} KCl

Soil Layer Depth (cm)	After equilibration Volume Wetness %	Chloride Ion Conc. Mgl^{-1}	Day One Volume Wetness %	Chloride Ion Conc. Mgl^{-1}	Day Two Volume Wetness %	Chloride Ion Con. Mgl^{-1}	Day Three Volume Wetness %	Chloride Ion Con. Mgl^{-1}	Day Four Volume Wetness %	Chloride Ion Con. Mgl^{-1}	Day Five Volume Wetness %	Chloride Ion Con. Mgl^{-1}
0-15	43.3	1.0	39.7	1.0	33.9	1.2	28.9	1.2	25.0	1.4	22.9	1.6
15-30	33.5	1.2	32.6	1.2	31.2	1.5	29.9	1.8	28.5	2.0	27.7	2.2
30-45	34.5	1.6	34.0	1.8	33.1	2.4	32.4	3.0	31.7	3.6	31.1	4.0
45-60	33.4	1.2	33.2	1.2	32.6	1.0	32.3	0.8	31.9	0.8	31.5	0.8
60-75	44.0	1.6	43.7	1.6	43.3	1.4	43.8	1.8	43.2	0.8	42.7	0.8
75-90	41.9	1.8	41.3	2.1	41.1	2.4	41.0	2.8	40.9	3.2	41.4	3.4
Total Cl-Conc.		8.4		8.9		9.9		10.6		11.8		12.8
Average Profile Volume Wetness	38.43		37.42		35.87		34.72		33.53		32.98	

Average Moisture loss = 38.43% - 32.98% = 5.55%

Amount of cl- accumulation = 12.8mL^{-1} - 8.4mgL^{-1} = 4.4 mgL^{-1}

Table 5: Salt and water distribution in soil profile at 1500mgL^{-1} potassium chloride and 60cm water table depth

Soil Layer Depth (cm)	After equilibration Volume Wetness %	Chloride Ion Conc. Mgl^{-1}	Day One Volume Wetness %	Chloride Ion Conc. Mgl^{-1}	Day Two Volume Wetness %	Chloride Ion Con. Mgl^{-1}	Day Three Volume Wetness %	Chloride Ion Con. Mgl^{-1}	Day Four Volume Wetness %	Chloride Ion Con. Mgl^{-1}	Day Five Volume Wetness %	Chloride Ion Con. Mgl^{-1}
0-10	37.5	0.6	33.3	0.6	29.5	0.6	27.6	0.6	23.3	0.8	18.7	1.2
10-20	35.9	0.6	33.5	0.6	31.6	0.6	30.4	1.0	29.8	1.2	28.7	1.2
20-30	43.2	0.8	41.0	1.0	39.3	1.0	38.5	1.0	37.6	1.2	36.9	1.2
30-40	44.4	0.4	43.1	1.0	41.8	1.0	40.4	1.2	40.3	1.2	39.7	1.4
40-50	52.5	0.6	51.4	0.6	49.7	0.8	49.5	1.0	48.8	1.2	47.9	1.2
50-60	45.0	0.8	43.1	2.0	41.4	2.0	41.1	2.0	40.3	2.6	39.7	3.0
Total Cl-Conc.		3.8		5.8		6.0		6.8		8.2		9.2
Average Profile Volume Wetness	43.08		40.9		38.88		37.92		36.68		35.27	

Average
Moisture loss = 43.08% - 35.27% = 7.81%

Amount of cl- accumulation = 9.2mL^{-1} - 3.8mgL^{-1} = 5.4 mgL^{-1}

Table 6: Salt and water distribution in soil profile at 3000mgL^{-1} potassium chloride and 60cm water table depth

Soil Layer Depth (cm)	After equilibration Volume Wetness %	Chloride Ion Conc. mgL^{-1}	Day One Volume Wetness %	Chloride Ion Conc. mgL^{-1}	Day Two Volume Wetness %	Chloride Ion Con. mgL^{-1}	Day Three Volume Wetness %	Chloride Ion Con. mgL^{-1}	Day Four Volume Wetness %	Chloride Ion Con. mgL^{-1}	Day Five Volume Wetness %	Chloride Ion Con. mgL^{-1}
0-10	45.4	0.6	39.2	1.2	34.6	1.4	28.6	1.0	23.9	1.4	19.2	1.6
10-20	40.8	1.0	36.7	1.0	35.1	1.0	32.9	0.8	31.2	1.0	29.6	1.2
20-30	46.3	1.0	43.5	0.6	42.1	0.8	39.9	1.0	38.7	1.4	37.6	2.0
30-40	44.1	2.2	43.3	1.2	40.8	2.0	39.3	2.4	37.7	4.4	36.2	2.6
40-50	53.4	3.8	51.5	4.0	49.9	3.0	48.1	4.6	47.4	5.8	47.0	7.4
50-60	48.0	5.2	47.7	6.4	46.7	6.9	46.2	6.4	45.5	7.0	45.2	7.6
Total Cl-Conc.		13.8		14.4		15.1		16.2		21.0		22.4
Average Profile Volume Wetness	46.33		43.65		41.53		39.17		37.4		35.97	

Average
Moisture loss = 46.33% - 35.8% = 10.53%

Amount of cl- accumulation = 22.4mL^{-1} - 13.8mgL^{-1} = 8.6 mgL^{-1}

Table 7: Salt and water distribution in soil profile at 45000mgL^{-1} potassium chloride and 60cm water table depth

Soil Layer Depth (cm)	After equilibration Volume Wetness %	Chloride Ion Conc. mgL^{-1}	Day One Volume Wetness %	Chloride Ion Conc. mgL^{-1}	Day Two Volume Wetness %	Chloride Ion Con. mgL^{-1}	Day Three Volume Wetness %	Chloride Ion Con. mgL^{-1}	Day Four Volume Wetness %	Chloride Ion Con. mgL^{-1}	Day Five Volume Wetness %	Chloride Ion Con. mgL^{-1}
0-10	48.9	0.5	41.1	1.0	31.6	1.4	21.9	1.4	17.9	1.0	13.7	3.6
10-20	42.8	1.2	36.3	1.2	32.0	1.4	27.2	1.4	24.6	1.8	20.8	1.2
20-30	43.9	1.4	40.1	1.6	39.1	1.4	36.5	1.8	34.9	1.8	32.1	1.2
30-40	45.7	1.0	44.8	1.0	44.3	2.2	43.2	3.1	43.2	3.8	44.8	1.4
40-50	53.4	1.4	52.1	1.8	50.8	5.4	50.3	6.8	49.9	4.8	50.6	2.0
50-60	50.1	3.8	49.8	5.0	49.2	7.8	48.4	10.9	48.1	13.2	47.7	20.0
Total Cl-Conc.		9.3		11.6		19.6		25.4		26.4		29.4
Average Profile Volume Wetness	47.47		44.03		41.17		37.92		36.43		34.95	

Average Moisture loss = 47.47% - 34.95% = 12.52%

Amount of cl- accumulation = 29.4mL^{-1} - 9.3mgL^{-1} = 20.1mgL^{-1}

4.2 DISCUSSION

4.2.1 ROUTINE ANALYSES

Routine chemical and physical analyses showed a very slightly acidic to neutral soil reaction. The electrical conductivity which is a measure of total dissolved salts in soil decreases down the profile inferring an accumulation of soluble salts at the top layer. Also, bulk density decreases down the profile to the third layer which shows an abrupt increase and this could be as a result of heavy implements used in cultivation which tend to compact this area. Textural characterization of the soil showed the top layer to be loamy sand, while the rest layers were sandy loam.

Cation exchange capacity ranges from medium in the top layers to high in the lower layers. This suggests a possibility of the occurrence of leaching of cations in these soils. While exchangeable calcium and magnesium rates were medium, exchangeable potassium was very low but they all increased with increase in depth. Exchangeable sodium was high at the top most layer (0.63 meq/100g soil) causing an increase in the Exchangeable sodium percentage (ESP) to 8.5, which is about twice the ESP for other layers. ESP exceeding 15, is an indication of alkalinity condition in the soil.

Organic Carbon which is the measure of the Organic matter content of the soil, is very low and it declines with increasing

depth.

4.2.2 WATER TABLE DEPTHS AND SOIL WATER MOVEMENT

Soil profile with water table depth at 42cm, 60cm and 90cm are hereafter, referred to as soil profiles A-1, A-2 and A-3 respectively. These profiles were considered to evaluate the effect of constant evaporation (0.6cm day^{-1}), relative humidity of 50±3%, constant ground water electrolyte concentration at 3000mgL^{-1} potassium chloride and the influence of water table - depths on the soil profile moisture and chloride-ion distribution.

Figure 1 shows the soil profile moisture distribution on daily basis throughout the 5-day evaporation cycle. Soil profile A-1 evidently lost more water than any of the three soil profiles under investigation, which was followed by profiles A-2 and A-3 in that order. This shows that shallow soil profiles overlying a water table will tend to lose more water due to evaporation than deeper ones.

During the experiment, it was observed that as profile depth increases beyond 60cm, changes in moisture contents became negligible. The highest loss of water was recorded on the first day of evaporation in soil profiles A-1 and A-2 while in soil profile A-3, this was recorded on the second day. This can be due to the inability of the evaporative energy to reach deeper

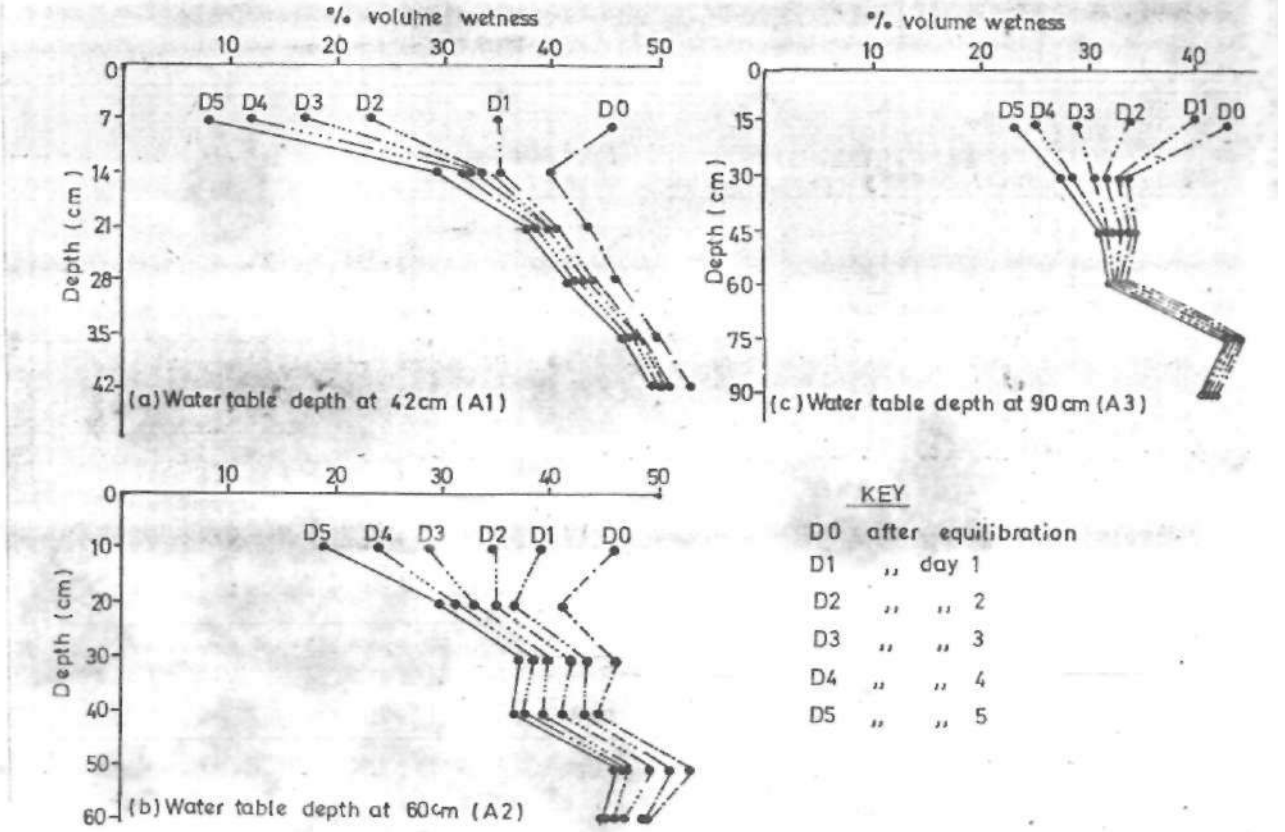


Fig. 1. Daily Moisture distribution as a result of evaporation in soil profiles at three varied water table depths and a constant ground water electrolyte concentration of 3000mgL^{-1} Kcl.

layers to induce water loss on the first day.

Figure 1 also shows a similar patterns of moisture distribution for all the profiles for each evaporative day. In profile A-3, only very slight changes occurred in moisture distribution beyond 60cm depth. This implies that there is limiting depth (>60cm) below which significant changes in volume wetness are no longer observed as the soil dries out.

4.2.3 GROUNDWATER ELECTROLYTE CONCENTRATION AND SOIL MOISTURE MOVEMENT

Here, water table depth was constant at 60cm daily evaporative rate and relative humidity at 0.6cm day^{-1} and 50±3% respectively. The only variable was the electrolyte concentration of the ground water at 1500mgL^{-1}, 3000mgL^{-1} and 4500mgL^{-1} potassium chloride which will be designated as C-1, C-2 and C-3 respectively.

Figure 2 shows soil profile C-3 favours more water loss to evaporation than any of the others, this was followed by C-2 and C-1 soil profiles. This implies that the more concentrated a ground water electrolyte is, the more the water loss to evaporation. This can be explained to be due to a solute concentration gradient which induce water flow by affecting the driving forces for flow, since the presence of a solute concentration gradient result also, in the presence of a gradient

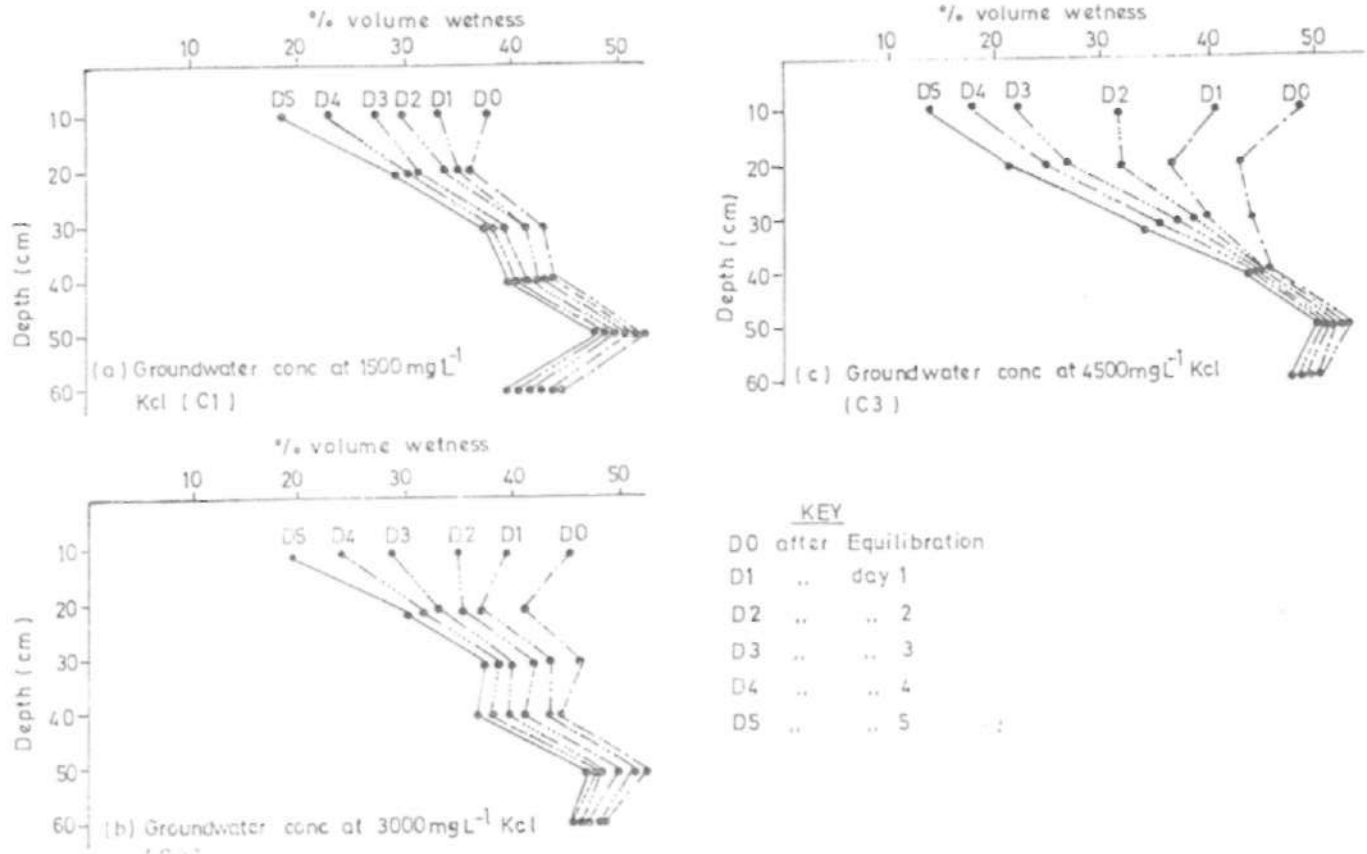


Fig 2. Daily moisture distribution as a result of evaporation in soil profiles of varied ground water electrolyte concentration and a constant water table depth of 60 cm.

of the chemical potential of the water in the soil solution.

This suggests that the significance of a solute-induced flow should not be over looked when similar or related studies are being considered for investigation. Also, in figure 2 a similar trend in the daily soil profile moisture distribution are noticed in all the profiles under investigation suggesting that ground water electrolyte concentration has no effect or does not control the pattern of soil water distribution along the profile.

4.2.4 WATER TABLE AND CHLORIDE-ION ACCUMULATION

Chloride-ion is soluble in water and moves with the solution in the soil, hence, one expects that where there is an appreciable movement of water in a soil profile, an appreciable movement of the dissolved chloride is also expected.

Figure 3 shows the distribution of chloride-ion in the soil profile both before and at the end of the 5-day evaporation cycle. In soil profile A-1 (42cm), appreciable accumulation was observed which was followed by soil profiles A-2 (60cm) and A-3 (90cm) in that order. If A-1 can lose more water due to its shallow nature, it goes without saying, that it will also experience high chloride-ion accumulation than any other one under study.

All other things being equal, it can be said that a shallow soil overlying a water table will lose more water and accumulate more chloride salt than deeper soils of the same

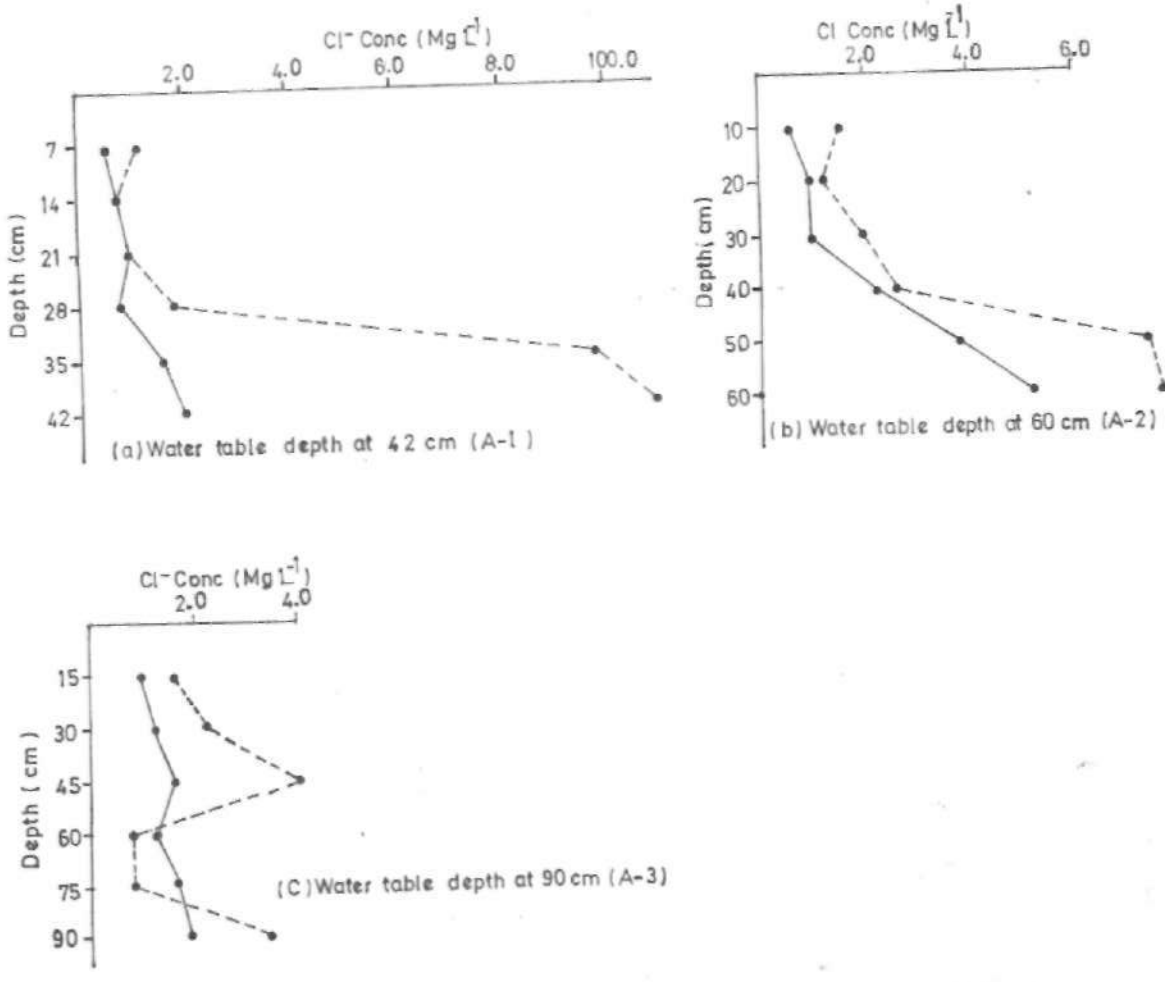


Fig. 3. Distribution of chloride-ion concentration along soil profiles at three varied water table depths and a constant ground water electrolyte concentration of 3000 Mg L^{-1} KCl

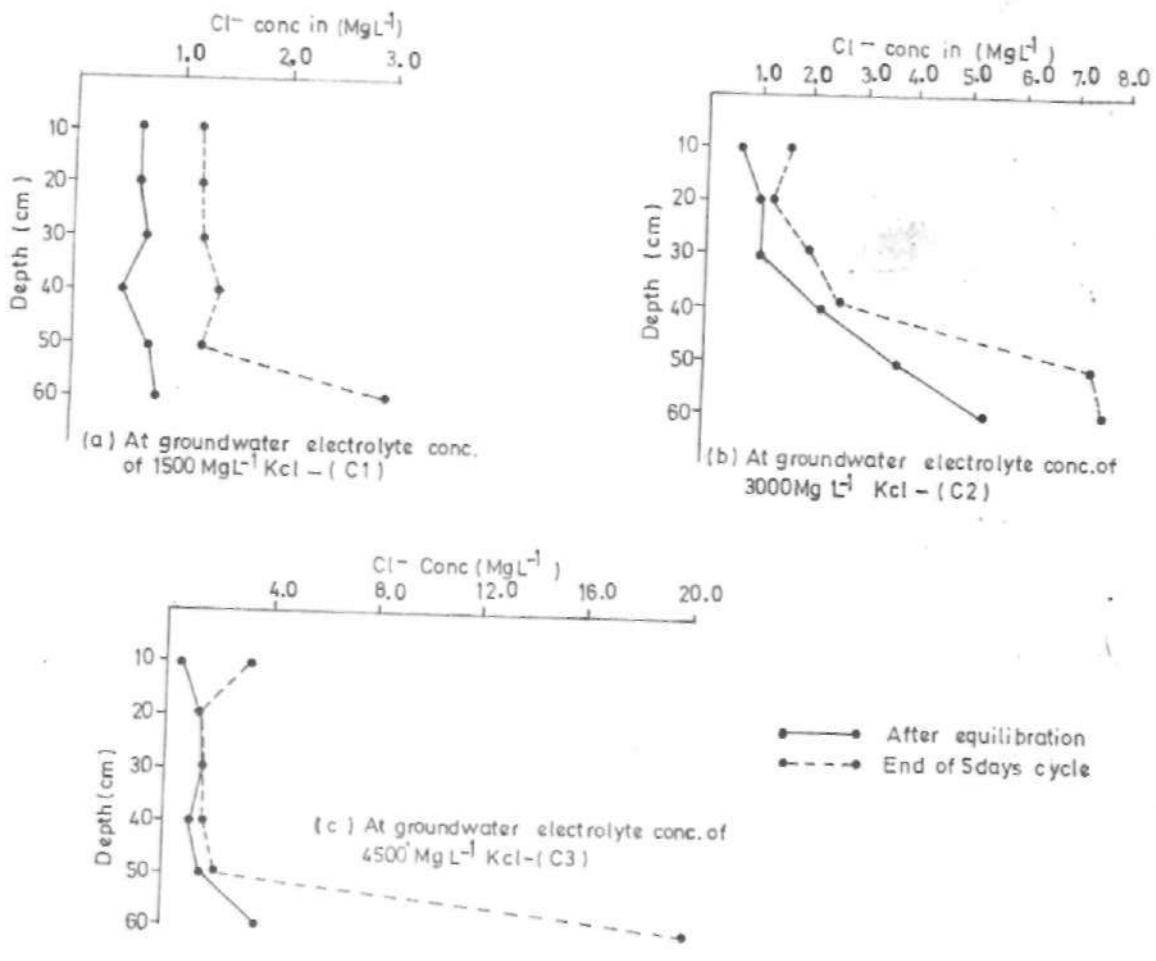


Fig. 4. Distribution of chloride-ion concentration along soil profiles at three varied ground water electrolyte concentration and a constant watertable depth of 60cm.

ground water. As the ground water electrolyte concentration increases as in C-2 and C-3, less amount of Cl-ion accumulated in the middle layers. This indicate that the concentration of ground water electrolyte affect the salt distribution pattern along the profile.

5.0 CONCLUSION

Evaporation-induced water loss and salt accumulation increases with increasing shallowness of soil profile depth. In this experiment, soil profile depth of 42cm had an average profile lost of about 11.2% in five days. Profile depth of 60cm experienced profile moisture loss of about 10.5% and an average profile moisture loss of 5.6% was recorded for profile depth of 90cm.

Due to the role of solute induced flow, higher concentration of ground water electrolyte concentration of 4500mgL^{-1} KCl recorded an average profile moisture loss of 12.52%, while 10.67% average profile moisture loss was recorded when ground water electrolyte concentration was reduced to 3000mgL^{-1} KCl. At 1500mgL^{-1}KCl, average profile moisture loss fell to about 7.82%. This is an indication that efforts should be made to reduce the rate of solute that gets down to the ground water.

All things being equal, maximum chloride ion accumulation of about 2744.8Kg, 1255.6kg and 642.4kg per hectare per year were recorded when soil profile length was varied at 42, 60 and 90cm respectively. This implies that salt accumulation is favoured by shallow depths. Also, soil profiles overlying ground water with high electrolyte concentration will tend to accumulate much salts. In the experiments reported here, 2934.6kg, 1255.6kg and 788.4kg per hectare per year chloride salts, were recorded at ground water electrolyte concentration of 4500mgL^{-1} KCl, 3000mgL^{-1} KCl and 1500mgL^{-1} KCl respectively.

6.0 REFERENCES

Abramova, M.M. (1969). Movement of moisture as a liquid and vapour in soils of semi desert: In water in unsaturated zone Vol. II, proc. of the Wageningen Symposium. pp. 781-789. IASH/AIHS-UNESCO.

Adeoye, K.B. and P.R. Maurya (1982). Upward water movement from shallow water-table and its influence on water requirement of wheat; proc. fourth Afro-Asian Regional Conference, ICID, Lagos.

Adewumi, J.K.; J.O. Duru and R.C. Yadav (1985). Irrigation efficiency at Kadawa Sector of Kano River Project. Paper presented at 9th conference of Nigerian Society of Agricultural Engineers, Owerri, 4-6th Sept.

Adriano, D.C. and H.E. Doner (1982). Bromine, Chlorine and flourine. In A.L. Page et. al. (ed.) Methods of Soil Analysis Part II: Chemical and Microbiological properties (2ed.). Agronomy 9 (Part 2): 159-165. Am. Soc. of Agron. Inc. Madison. Wisc.

Bird, A.C. (1984). The land issue in large-scale irrigation projects: Some problems from Northern Nigeria. Published Adams and Grove (ed.) Irrigation in Tropical African; African study centre Cambridge. p. 75-85.

Bond, J.J. and W.O. Willis (1969). Soil water evaporation surface residue rate and placement effects. Soil Sci. Soc. Amer. Proc. 33: 445-448.

Bresler, E. (1967). A model for tracing salt distribution in the soil profile and estimating the efficient combination of water quality and quantity under field conditions; Soil Sci. 104:227-233.

Bresler, E. (1981). Transport of salts in soils and subsoils. Agricultural water management 4:35-62.

Bresler, E. and P.J. Hanks (1969). Numerical method for estimating simultaneous flow of water and salt in unsaturated soils. Soil Sci. Soc. Am. Proc. 33:827-832.

Cary, J.W. (1964). Water flux in moist soil. Thermal versus suction gradient Soil Sci. 100:168.

Cary, J.W. (1966). Soil Moisture transport due to thermal gradients. Practical aspects. Soil Sci. Soc. Amer. Proc. 30:428-433.

Chapman, H.D. (1965). Cation exchange capacity. In C.A. Black et. al. (ed.). Methods of soil analysis. Agronomy 9:891-901. Am. Soc of Agron. Inc; Madison, Wisc.

Day, P.R. (1965). Particle fractionation and particle-size analysis. In C.A. Black (ed.). Methods of Soil Analysis. Part 1. Agron. No. 9. ASA, Madison, Wisconsin, USA. pp. 545-567.

Doering, E.J., R.C. Reeve and K.R. Stockinger (1964). Salt accumulation and salt distribution as an indicator of evaporation from fallow Soil Sci. 94:312-319.

Gardner, W.R. (1959). Solution of the flow equation for the drying of soils and other porous media. Soil Sci. Soc. Amer. Proc. 23:183-187.

Gardner, W.R. and D.I. Hillel (1962)> The relation of external evaporation conditions to the drying of soils. J. Geophys. Res. 67, 4319-4325.

Hadas, A. and D. Hillel (1968). An experimental study of evaporation from uniform soil columns in the presence of a water table. Trans. 9th Intern. Congress of Soil Sci. Adelaide-Australia. Vol. I, pp. 67-70.

Hanks, R.J., H.R. Gardner and M.L. Fairbourn (1967). Evaporation of water from soil as influenced by drying with wind or radiation. Soil Sci. Soc. Amer. 31:593-598.

Kuzniar, A. (1982). The Water utilization efficiencies for various irrigation practices. Presented at 9th National Irrigation Seminar, Sokoto.

Maurya, P.R. (1982). Development of salinity and alkalinity in irrigated soils of Nigeria. Proc. Fourth Afro-Asian Regional Conference of ICID, Lagos, Vol. II, 1-17.

Maurya, P.R. and R.S. Sachan (1985). Irrigated scheduling in relation to salt build-up under varying ground water table conditions, Proc. fifth Afro-Asian Regional Conference, ICID, Vol. I, 105-119.

Maurya, P.R. and A. Kuznair (1988). Needed Social, cultural and design changes to successfully manage Nigerian Surface irrigated projects. In (Planing Now for Irrigation and Drainage in the 21st Century ed. Hay, D.R). Proc. of Conference Sponsored by ASCE.

McLean, E.O. (1982). Soil pH and lime requirement in A.L. Page et. al. (ed.) Methods of Soil Analysis. Part II: Chemical and Microbiological properties (2ed.). Agronomy 9 (Part 2): 159-165. Am. Soc. of Agron. Inc. Madison. Wisc.

Muazu, S. and S. Abdulmumin (1990). Environmental implications of large scale irrigation systems. A soil perspective: In (farmer participation in Irrigation Development and Management, ed. Maurya et. al.) Proc. of National Workshop. Samaru-Zaria, pp.149-155.

Muazu, S. and P.O. Nwadukwe (1991). Hydraulic properties of the soils of Kano River Project Area. Technical paper submitted to Irrigation Research Programme, IAR/ABU, Zaria. Sub. Project 1.1.5.

Muazu, S., P.O. Nwadukwe, P.R. Maurya; A. Ahmed and J.J. Owonubi (1991). Groundwater table in various irrigation projects. Tech. Report of Irrigation Res. Programme (Cropping Scheme Meeting) IAR, pp. 22-23.

Nelson, D.W. and L.E. Sommers (1982). Total carbon, Organic carbon and Organic matter. In A.L. Page et. al. (ed.) Methods of Soil analysis Part II: Chemical and Microbiological properties (2ed.). Agronomy 9 (Part 2): 539-594.

Nwa, E.U. (1981). Studies on border, furrow and basin irrigation for wheat and rice at Kadawa. Progress report on Irrigation Research Programme, SR/ABU, Zaria.

Nwa, E.U. (1982). Ground water problems of the Kano River Irrigation Project of Nigeria. In: Proc. fourth Afro-Asian Regional Conference of ICID, Lagos, Vol. II 123-137.

Philip, J.R. (1957). Evaporation and moisture and heat fields in the soil. J. Meteorol. 14: 354-366.

Remson, I. and G.S. Fox (1955). Capillary losses from Groundwater. Trans. Amer. Geophys. Union Vol. 36 No. 2: 304-310.

Shalhevet, J. and P. Reiniger (1964). The development of salinity profiles following irrigation of field crops with saline water. Israel Jour. Agric. Research 14: 187-196.

Sutor, J. (1969). Soil moisture distribution function in non-isothermic conditions: In water in the unsaturated zone. (Proc. of the Wageningen symp.) Vol. II pp. 790-798. IASH/AIHS-UNESCO.

Szabolcs, I. and J. Lesztak (1969). The movement of different salt solutions in soil profiles. In water in the unsaturated zone (proc. of the Wageningen symp.) Vol. II pp. 611-621. IASH/AIHS-UNESCO.

Thomas, G.W. (1982). Exchangeable cations. In A.L. Page et. al. (ed.). Methods of soil analysis Part II: Chemical and Microbiological properties 2ed. Agronomy 9 (Part 2): 159-165. Am. Soc. of Agron. Inc. Madison Wisc.

Wiegand, C.L. and S.A. Taylor (1962). Temperature depression and temperature distribution in drying soil columns. Soil Sci. 94:75-79.

Wild, A. (1993). Soil and the environment: an introduction. Cambridge Univ. Press pp 97-98.

APPENDIX 1: Quality of Irrigation Water, Determined by the Test-Kit Method

Water Location	Electrical Conductivity (EC) Microhms Cm^{-1}	Sodium Absorption ratio (SAR)
Yobe river at Yau	150	Low
Lake Chad at M/Fatori	270	Low
Mobuli river near Warge	400	Low
Rima river - Goronyo	300	Low
Rima river - Warno	250	Low
Kwarre lake	400	Low
Sokoto river near Sokoto	350	Low
Sokoto river - Argungu	340	Low
Sokoto river - Bunza Raha	300	Low
Zanfara river	160	Low
Dankwai lake	160	Low
Torras river - Babbar Ruga	120	

Kano river waters are classified in the lowest USDA salinity and sodium class

Source: Muazu and Abdulmumin, 1991.

Appendix 2: Frequency distribution of mean depth to water table at Kadawa sector of Kano River Project during an irrigation season

Weekly mean depth to water table	Frequency
0-49cm	0
50-59cm	7
60-69cm	27
70-79cm	27
80-89cm	24
90-99cm	3
100-109cm	2
110-119cm	0

Source: Muazu and Abdulmumin, 1990

Appendix 3: Chemical Analysis of Ground water at Kadawa

*Water Samples	pH water	Electrical Conductivity mmhoscm^{-1}	HCO_3^-	SO_4^{2-}	Cl^-	$NH4^+$	NO_3^-
			ppm				
A	6.2	0.3	1.7	54.25	0.8	-	-
B	7.1	0.45	6.0	24.5	0.6	3.0	7.0
C	6.7	0.32	-	17.5	0.7	1.4	1.4

*A - Ground water underlying soil profile under continuous cultivation all year round.

B - Ground water underlying soil profile under rainfed cultivation only.

C - Ground water underlying soil profile under palm cultivation.