Groundwater salinity and depth effects on soil salinity in a furrow-irrigated area in Kenya

Isaiah I.C. Wakindiki

Department of Soil Science, Egerton University, P.O. Box 536, Njoro 20107, Kenya

Stephen K. Tirop

Department of Soil Science, University of Nairobi, P.O. Box 30197, Nairobi 00100, Kenya

The effect of groundwater salinity and depth on soil salinity was investigated in a furrow-irrigated area of Kenya during consecutive wet and dry seasons. The groundwater salinity was significantly ($P \leq 0.05$, R^2 = 0.75–0.88) related to soil salinity when the groundwater depth fluctuated within 0–1 m depth in both seasons. When the groundwater remained below 1 m, the relationship was not linear. This meant that when saline groundwater existed within 1 m from the soil surface, soil salinity ensued even when low salinity (electrical conductivity = 0.28 dS m^{-1} in the dry season) irrigation water was used. The depth of the groundwater table was different in each season. In general, deep levels occurred during the dry season while shallow water tables existed during the wet season. Thus, leaching of excess salts by rainwater was likely to be compounded by the shallow saline groundwater table and therefore not feasible if the saline groundwater table was <1 m regardless of season.

Keywords: Surface irrigation; Leaching; Groundwater salinity; Soil salinity; Irrigation; Kenya

In most natural environments, the groundwater salinity is not constant throughout the year. During the dry season, the groundwater contains excess dissolved salts and is termed saline. However, during the wet season, groundwater salinity is diluted (Sommerfeldt and Oosterveld, 1977). This seasonal variation in groundwater salinity is caused by extra water that is added to the soil profile by rain. Irrigation water also has similar effects. The additional water causes a rise in the groundwater table or increases the pressure of confined aquifers, creating an upward leakage to water table aquifers (Gupta, 1990). If the groundwater table is substantially high, saline groundwater may be drawn to the soil surface through capillary rise. The salt concentration of the groundwater has been shown to influence the upward movement of salts, which is a product of flow rate, salt concentration, and duration of the groundwater (Ravender and Bhargava, 1993).

The rate of capillary rise decreases with increasing height above the water table. Consequently, the rate of upward salt movement, which is proportional to the rate of upward flow should also decrease. Ravender and Bhargava (1993) evaluated critical water table depths, which is the groundwater depth at which the capillary rise becomes too small for any significant upward salt movement, for soils with varying texture. The critical water table depths were estimated from the relationship between water flux (*q*) and depth of water table (*z*) as expressed by the following equations:

$$q = 14963\left(z\frac{2.476}{\pi}\sin\frac{\pi}{2.476}\right)^{-2.476} \quad (1)$$

for clay soils,

$$q = 12515\left(z\frac{2.513}{\pi}\sin\frac{\pi}{2.513}\right)^{-2.513} \quad (2)$$

for clay-loams soils, and

$$q = 15981\left(z\frac{2.774}{\pi}\sin\frac{\pi}{2.774}\right)^{-2.774} \quad (3)$$

for sandy-loam soils.

The estimated values of the critical water table depth were found to be 163.5 cm for clay, 140.6 cm for clay-loam, and 94.0 cm for sandy-loam soils (Ravender and Bhargava, 1993). Similar effects of soil texture on field-scale variations in sub-surface hydraulic characteristics have also been noted by van Genuchten (1980) and McCuen *et al.* (1981). Rasiah and Aylmore (1998) investigated the sensitivity of four soil water retention functions

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to variations in soil properties and changes in bulk density across and within soils along a 500-m transect. They concluded that soil texture influences hydraulic parameters of water retention functions.

When pure water evaporates at the soil surface, dissolved salts are left behind causing soil salinization. Evaporation of saline groundwater is a common cause of soil salinization in arid and semi-arid climates. Soil salinity is a major obstacle to crop production in dry areas (Rowland, 1993). Extensive areas of Kimorigo irrigation scheme in Kenya are salt-affected (Kanake, 1982). Shallow saline groundwater tables are common in this area (Wakindiki, 1993) and wide variation in the depth of groundwater table was shown by Otieno (1990) to occur during the wet and dry seasons. Wakindiki (1993) measured saturated hydraulic conductivity of 0.009 m day^{-1} in some areas within this irrigation scheme. In such places with low hydraulic conductivity, drainage is likely to be highly impaired, restricting leaching of salts. There was likelihood, therefore, for both groundwater salinity and depth to have a profound effect on soil salinization. Traditionally, farmers in this area abandoned the cultivated fields once salinity became intolerable to the crops. Nevertheless, the new cultivated areas soon become salinized. Efforts to understand the relationship between the groundwater salinity, depth, and soil salinity are therefore necessary so that proposals for better irrigation management can be made. The objectives of this study were to (i) monitor the seasonal variation in the groundwater salinity and water table depth during consecutive wet and dry seasons, and (ii) determine the effects of groundwater salinity and depth on soil salinity.

Materials and Methods

Reconnaissance work was done in 1993 and this study was conducted in 2001 (January–December). The study area is generally known as Kimorigo and encompasses four main irrigation zones, namely, Kimala, Kimorigo, Kamleza, and Kitovo (Figure 1). Kimorigo is located in the southern coast region of Kenya. The area has a semi-arid climate with a long-term (43 years) average annual rainfall of 595 mm distributed almost equally between two wet seasons. The long rain (March–May) and the short rain (November–December) seasons receive about 310 mm and 285 mm, respectively. The annual mean (17 years) temperature is 22°C and potential evapo-transpiration is 1930 mm. Figure 2 shows the long-term average monthly rainfall and potential evapo-transpiration (Otieno, 1990). The main source of surface water is the river Lumi. Irrigation water is diverted from the river Lumi through a network of canals.

Wells were set up in the field at a grid of 1000 m × 500 m. A total of 50 open wells

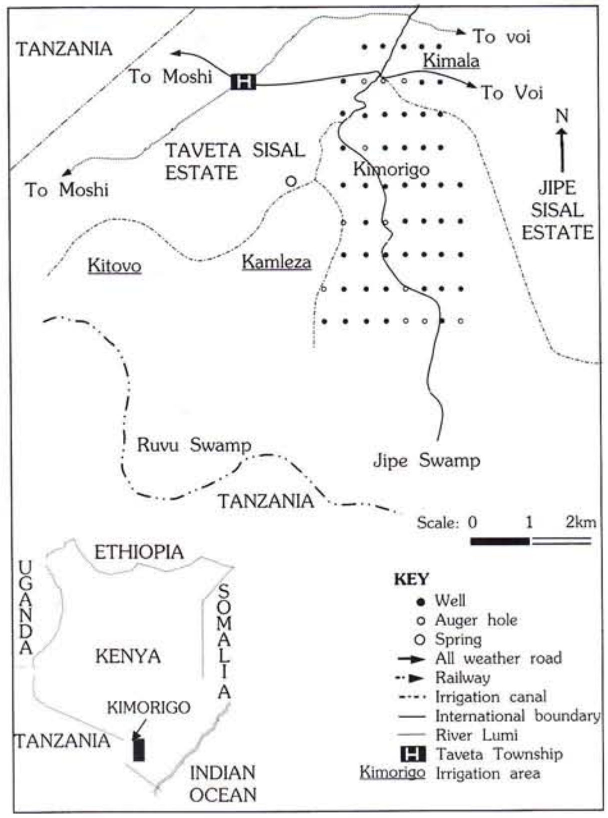

Figure 1 Location of the study area

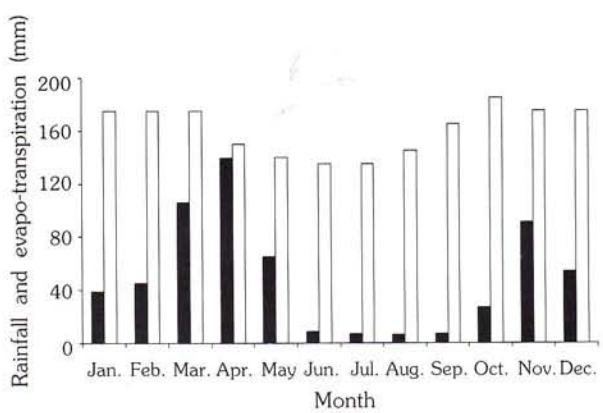

Figure 2 Mean monthly rainfall and potential evapo-transpiration at Kimorigo (Otieno, 1990) ■, Rainfall and □, Evapo-transpiration

and 10 auger holes were dug in the area for the purpose of this study. Water level measurements were done weekly during the dry season and twice per week during the wet season. The depth to groundwater level was measured using a tape measure. The reference point was the top of the well. The groundwater level was found by subtracting the measured depth from the ground surface elevations. Water samples were taken from the wells each time the groundwater level was being determined. Soil samples were taken from the 0–15 cm depth within a 5-m radius from each well for salinity evaluation. These soil samples were separately air-dried and the large aggregates broken by hand. Each soil sample was then passed through a 2-mm mesh sieve. Both the water samples and the soil samples were analysed using procedures described by Richards (1954). The salinity of water from the river Lumi was also assessed before and immediately after the rainfall. Fifteen samples were obtained at various points along the river. Representative soil profiles were opened and characterized according to the depth of groundwater table, i.e., 0–50 cm, 50–100 cm, 100–150 cm, and >150 cm using standard procedures described by Landon (1991). Some soil properties from two representative profiles in the irrigation area are shown in Table 1. The groundwater salinity was chosen as the water salinity indicator and grouped into the four groundwater table depths and regression analysis done as described by Steel and Torrie (1981).

Results and Discussion

Irrigation water salinity was good and did not show significant variation between the two consecutive seasons as shown in Table 2. For this reason the contribution of irrigation water salinity to soil salinity was not significant. Hydrographs for each of the groundwater table depth category are shown in Figures 3, 4, 5, and 6. These illustrations showed that the groundwater table position varied with season. Deep and shallow levels occurred during the dry

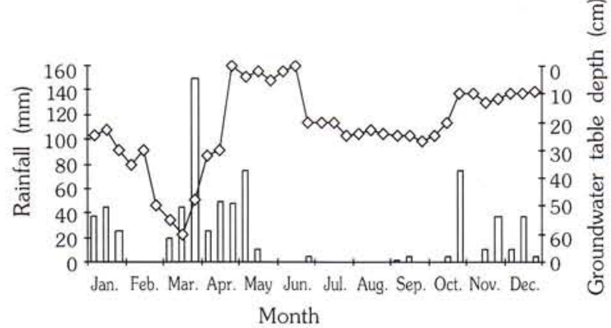

Figure 3 Seasonal variation in groundwater table depth (0–50 cm category) and 10-day monthly rainfall □, Rainfall and ◇, Groundwater depth

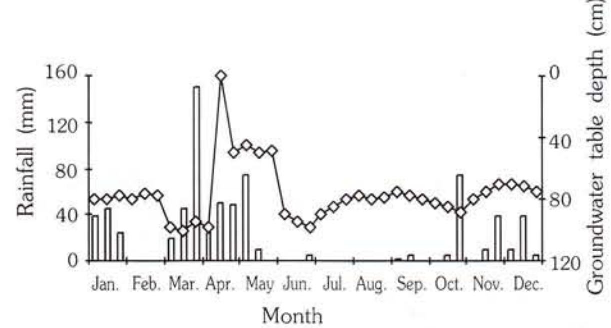

Figure 4 Seasonal variation in groundwater table depth (50–100 cm category) and 10-day monthly rainfall □, Rainfall and ◇, Groundwater depth

Table 1 Some soil physical and chemical properties from two representative profiles in the study area

Location	Depth (cm)	Mechanical composition (%)			EC[3] (dS m^{-1})	CEC[4]	Na^+	Ca^{2+}	Mg^{2+}	pH
		Sand	Silt	Clay		$cmol_c$ kg^{-1}				
Kimorigo[1]	0–17	48	24	28	5.5	30	24	20.4	0.8	8.7
	17–76	46	26	28	5.0	30	22	22.4	0.4	9.0
	76–161	48	25	27	2.0	30	20	24.4	0.4	9.2
Abori[2]	0–18	54	20	26	1.5	16	12	3.4	0.6	8.1
	18–45	46	32	22	3.9	24	10	5.2	2.0	8.2
	45–102	48	16	36	3.5	30	20	29.0	3.0	8.2

[1]Water table depth occurred between 0–0.5 m
[2]Water table depth occurred between 0.5–1 m
[3]EC, Electrical conductivity and pH of saturation extract
[4]CEC, Cation exchange capacity

Table 2 Irrigation water quality of the experimental sites

Sampling	TDS[1] (g L^{-1})	EC[3] (dS m^{-1})	pH	Na^+	Ca^{2+}	Cl^{1-}	HCO^{3-}
				Meq L^{-1}			
Before rain	0.18 (0.01)[2]	0.28 (0.01)	7.2 (0.02)	0.26 (0.01)	2.0 (0.02)	1.0 (0.02)	2.5 (0.01)
After rain	0.16 (0.02)	0.25 (0.02)	7.1 (0.02)	0.26 (0.01)	1.8 (0.02)	0.9 (0.02)	2.0 (0.02)

[1]TDS, Total dissolved solids
[2]Values in parentheses indicate Standard Deviation
[3]EC, Electrical conductivity

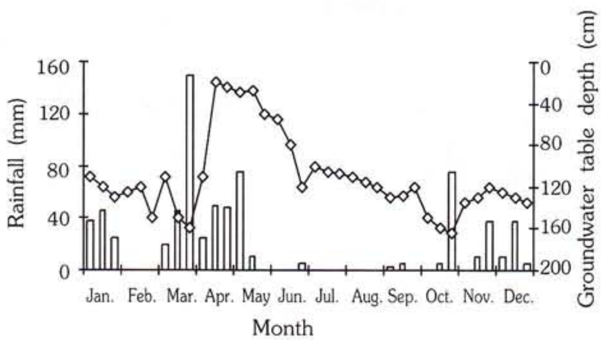

Figure 5 Seasonal variation in groundwater table depth (100–150 cm category) and 10-day monthly rainfall □, Rainfall and ◇, Groundwater depth

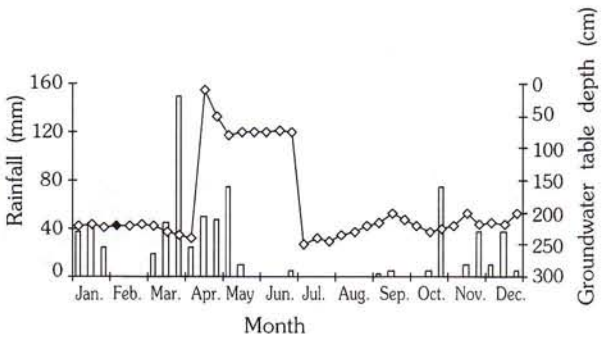

Figure 6 Seasonal variation in groundwater table depth (>150 cm category) and 10-day monthly rainfall □, Rainfall and ◇, Groundwater depth

and wet season, respectively. There was a spontaneous rise in the level of groundwater at the onset of the wet season. This was irrespective of the existing position of the groundwater table. As the dry season set in, the groundwater level monotonically receded to almost constant level within the described depth categories (Figures 3, 4, 5, and 6). These variations could have been in response to the additions of water by rainfall in the wet season or evapo-transpiration in the dry season as proposed by Gupta (1990).

The relationship between the groundwater salinity and soil salinity was found to be significantly ($P \leq 0.05$) linear (Figures 7, 8, 9, and 10). When the groundwater table fluctuated between 0 m and 1 m, an increase in groundwater salinity resulted in a consistent increase in soil salinity. The R^2 values were between 0.75 and 0.88. The texture of the soils that were used in this experiment was clay-loam (Table 1). Ravender and Bhargava (1993) calculated a critical water table depth of 1.406 m using Equation 2 in soils with similar texture. Therefore, it is likely that the soils used in this study had similar water flux and critical water table depth values, thus groundwater depth values <1 m promoted capillary salinization. Extensive white salt crusts were observed in the field. However, when the groundwater table remained below 1 m in both seasons, the groundwater salinity and soil salinity were not significantly ($P > 0.05$) linearly related (Figures 7, 8, 9, and 10). This suggested that beyond 1 m depth, the capillary rise was too small for any significant upward salt movement. In many situations where dryland salinity occurs, salt build-up is assumed to occur only in the dry season (Rowland, 1993). However, this study established that if saline groundwater table existed within 1 m (less that the critical water table depth), there was significant soil salinity build-up even in the wet season (Figures 7, 8, 9, and 10).

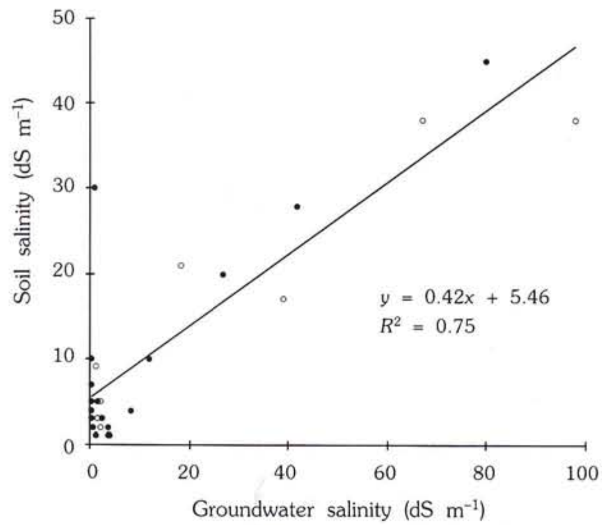

Figure 7 Effect of groundwater salinity on soil salinity, water table depth 0–50 cm ●, Wet season and O, Dry season

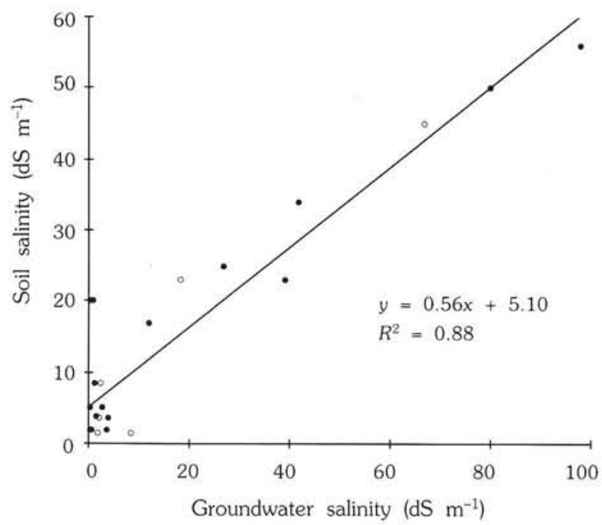

Figure 8 Effect of groundwater salinity on soil salinity, water table depth 50–100 cm ●, Wet season and O, Dry season

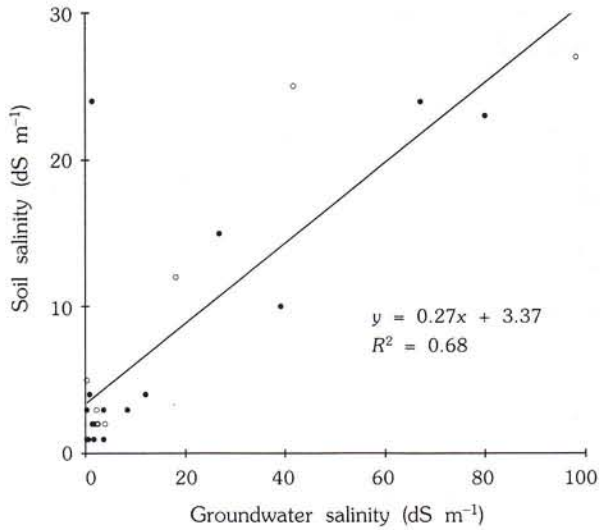

Figure 9 Effect of groundwater salinity on soil salinity, water table depth 100–150 cm ●, Wet season and O, Dry season

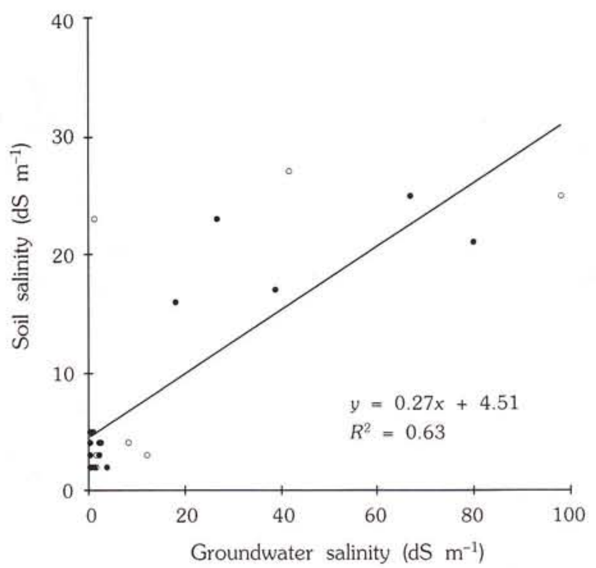

Figure 10 Effect of groundwater salinity on soil salinity, water table depth >150 cm ●, Wet season and O, Dry season

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