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Evaluation of the Effect of Salt Affected Soil on Selected Hydraulic Properties of Soils in Meki Ogolcha Area in East Showa Zone of Oromia Region, Ethiopia

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Abstract
Saturated hydraulic conductivity and infiltration rate measurement was made on soils irrigated by water from three sources and rain fed cultivated field to determine effect of soil salinity on hydraulic conductivity. Accordingly, surface and sub surface layers of field 1 and surface layers of field 3 and 4 were classified into low infiltration rate where as the surface and sub surface layers of field 2 were classified into medium infiltration rate. On the other hand, soil saturated hydraulic conductivity (Ks) of all layers of P1 were grouped into moderate permeability classes with some variation in value. The layers 1 and 2 of P2 were grouped into moderately rapid class whereas, layers 3 and 4 were grouped in to moderately slow class. Hence, the study result indicated that with similar sand and clay content in respective layers of profile 1 and 2, the permeability relatively reduces as alkalinity increases.
Keywords: Salt affected soil, permeability, hydraulic conductivity, infiltration rate

INTRODUCTION

Now days, worldwide including Ethiopia, many soils have been and are being changed into the class of problem soils due to different natural hazards and poor agricultural practices. Among these are salt affected (saline, saline-sodic and sodic) soils, which are caused by excessive accumulation of soluble salts of varying composition, concentration and saturation of the soil exchange complex by sodium (Tezera, 1984; Szabolcs, 1989) that affects the permeability of the soil for proper root growth.

In Ethiopia, salt affected soils have been reported to occur for the most part in the Rift Valley Zone (Mesfin, 1980; Heluf, 1985) and other areas that are characterized by higher ET rate as compared to precipitation (Tamirie and Heluf, 1986). According to Kefyalew *et.al*. (2011), also the surface and sub-surface soils of the Meki-Ogolcha area that were irrigated from water sources of Lake Zeway and ground water were found to be saline sodic and sodic soils.

When salt are present in excess, they kill growing plants. Poor physical conditions of sodic soils are caused due to destructive nature of sodium. Saline sodic soils are also a class of salt affected soils containing both soluble salts and exchangeable sodium in quantities high enough to interfere with growth of most crops (James *et al*., 1982). Therefore, the negative effect on growth of plants is the result of reduced permeability of the soil to both water and air that in turn restricts root development, establishment, growth and final yield of crops

In saturated soil with stable structure, as well as, in porous medium such as sandstone for instance, the hydraulic conductivity is characteristically constant and its order of magnitude is that about 10^{-2}-10^{-3} cm/second in a sandy soil and 10^{-4}-10^{-7} cm/second in clayey soil. However, hydraulic conductivity may be affected by soil structure and texture (Hillel, 1971). In many soils, the hydraulic conductivity does not in fact remain constant. Because of various chemical, physical and biological processes, hydraulic conductivity may change as water permeates and flows in to a soil. The changes occurring in the composition of the exchangeable ion complex, as when the water entering the soil has different concentration of solute than the original soil solution can greatly change the hydraulic conductivity (Reeve *et al*., 1954). In general, the conductivity decreases with decreasing concentration of electrolyte solutes (Reeve, 1957), due to the swelling of clays and dispersion of soil colloidal particles, which are also affected by the species of cations present.

According to Kefyalew *et.al*. (2011), based on criteria established by US Salinity Laboratory Staff (1954) for salt affected soil classification, Meki-Ogolcha irrigated fields with water from Lake Zeway and ground water sources were saline-sodic and sodic. On the other hand, soils of Meki River irrigated field and Rainfed cultivated field were non saline, non saline-sodic and non sodic. Thus, this study was designed to identify the effect of salt effected soil on hydraulic conductivity and infiltration rate of soils at the Meki-Ogolcha areas of east Showa Zone, Oromia region.

MATERIALS AND METHODS

Description of the Study Area

The study was conducted in Meki-Ogolcha area, which is located with grid references between 6^0 91' and 8^0 12' north and 38^0 46' and 38^0 59' east (Figure 1). The area is part of the southern Rift Valley of the country, which includes the zone from Lake Chewbahir on the Kenya border to Lake Koka on the southeast of Addis Ababa.

The Meki-Ogolcha area is irrigated from three water sources namely, Lake Zeway, Meki River and the ground water of the area. The local farmers and investors irrigate different vegetables and legume crops, like onion, cabbage, tomato, pepper and haricot beans, while other crops mainly cereals are usually produced using rainfall. The natural vegetation is composed of sparsely grown Acacia trees and bushes/shrubs of various species as well as grasses.

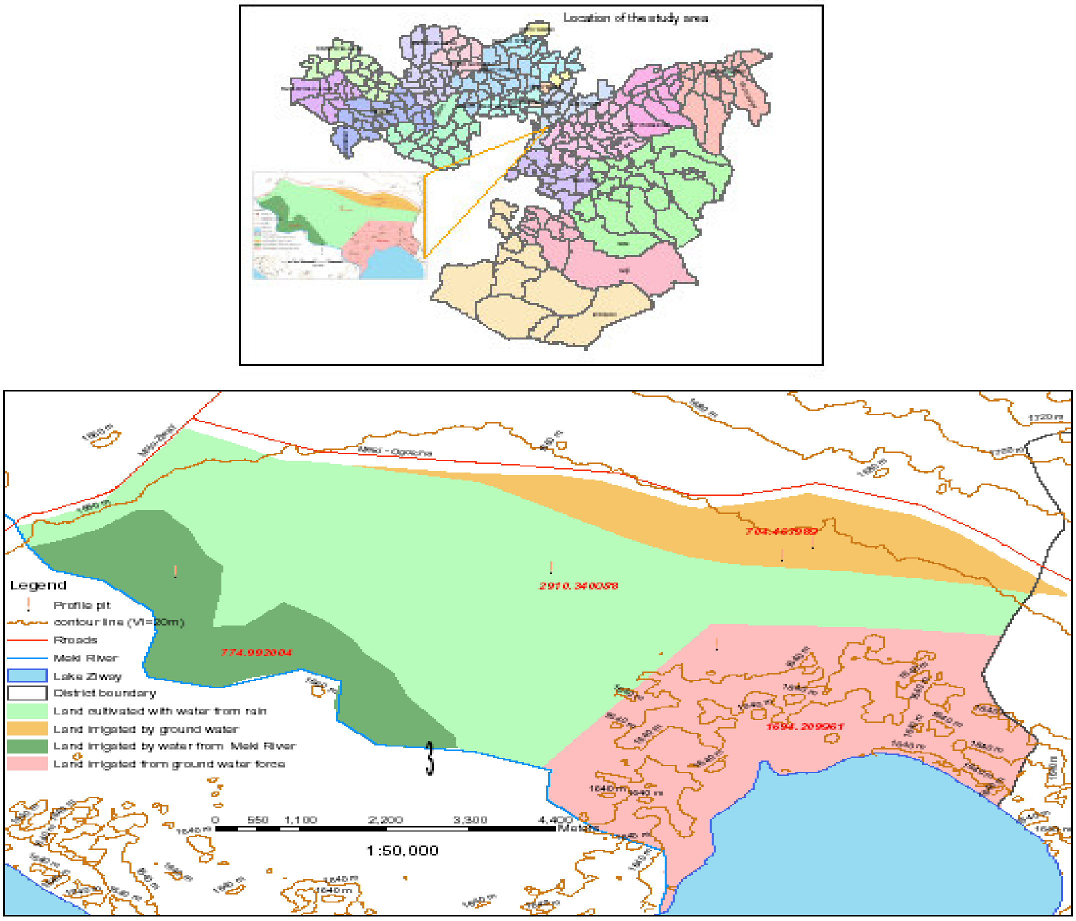

Figure 1. Location map of the Meki-Ogolcha area and soil profile sampling sites as well as double ring infiltration measurement site.

As the study area is part of the Southern Rift Valley System of Ethiopia, the geology is complex (UNDP and FAO, 1984). The parent materials include tertiary pyroclastics and quaternary basalt where much of the area around numerous Rift Valley Lakes is covered by lacustrine deposits of various origins. The soils of the area are derived from basalt, ignibrite, lava, volcanic ash, pumice, reverine and lacustrine alluvium parent materials (EGMOA, 1975). Generally, the soils textural classes of the area range from sandy loam, loam to sandy clay loam with some clay loam and a few clay soils (Murphy, 1959). In addition to salt crust (white and deep shiny black salt crust), the soils of the area are also characterized by numerous gray-to-gray brown termite mounds.

The Meki-Ogolcha area is characterized by a semi arid climate having an altitude range of 1641-1680 masl. Based on eleven years (1997-2007) analyzed meteorological data of the area, the area is found to have long-term average annual rainfall of 677.84 mm and minimum and maximum temperatures of 14.4 and 27.8°C, respectively. Humidity, wind speed, sunshine hours and solar radiation were 51.7%, 147 km/day, 8.5 hours and 21.6 MJ/m^2/day, respectively. The analysis of the meteorological data also indicates that precipitation of the area exceeds evapotranspiration (ET) only in the month of July during which the area receives high rainfall.

Figure 2. White salt crusts (saline soil) and shiny black alkali (sodic soil) surfaces observed on a field of study area.

Soil Sampling

Representative sites selected by Kefyalew *et.al* (2011) for characterization and classification of irrigated soils were recognized and similar location were used for this particular study. Then, soil samples from profiles for different soil physical and hydraulic conductivity analysis as well as in situ infiltration rate measurement was taken at location indicated on Figure 1; One from field irrigated by water from Lake Zeway, the other three fields were farmers' fields, two of which are under irrigation from ground water and Meki River water and one from the rainfed cultivated field of the area. The profiles were all divided in to layers based on their pedogenic horizon development. Sampling (one disturbed sample and two core samples, 1 for bulk density and water retention, and 1 for hydraulic conductivity) and description of the layers were made based on guidelines for soil profile description (FAO, 1990). The soil colors were interpreted using Munsell color chart (Munsell Color Campany, 1975).

Table 1. Description of profile sampling sites

Profile No	Depth (cm)	Site description
P1	0-200	Field which has been irrigated from Lake Zeway water source with tomato and onion in rotation for about 15 years.
P2	0-118	Field which has been irrigated from ground water source with tomato and onion in rotation for 3 years.
P3	0-200	Field which has been irrigated from Meki River water source with tomato and onion rotation for about 15 years.
P4	0-105	Field which has been cultivated for maize, beans and teff in rotation using rainfall.

Laboratory Analysis of Soil Physical Properties

For laboratory analysis, soil samples were prepared and analyzed using standard method as follows: soil particle size distribution was determined by the Bouyoucos hydrometer method (FAO, 1984). The soil water contents at field capacity (FC) at -1/3 bar and permanent wilting point (PWP) at -15 bars were determined using pressure plate apparatus and the plant available water holding capacity of the soil was calculated as the difference between water content at FC and PWP (Klute, 1965). Soil hydraulic conductivity was determined by the volumetric flask method and infiltration rate was measured by double ring infiltrometer. Soil bulk density was determined on undisturbed soil samples using the core-sampling method and particle density of soil was determined by the pycnometer method (Blake, 1965). Total soil porosity was calculated from the values of bulk density (ρb) and particle density (ρs) as: total porosity (%) = $(1- \rho_b/\rho_s) \times 100$ where as, saturation percentage of the soils was determined as the ratio (percentage) of the water retained at saturation to the oven dry weight of the soil sample.

RESULTS AND DISCUSSION

Some morphological properties and physical properties of the soils represented by the profile opened at different land are presented in Table 1 and 2, respectively. All of the soil profiles described were structurally differentiated but have got weak horizon development. The structure of soil under different representative field showed slight variation. The surface layers of Pedons 3 and 4 had strong, very coarse granular structure while medium, fine granular and moderate, medium granular structures characterize the surface layers of Pedon 1 and Pedon 2, respectively. This slight variation could be due to type of farm implements used, management practices followed, and variation in soil organic matter and sodicity levels. For instance, the profile opened on the field irrigated by water from Lake Zeway has been cultivated by tractor for more than 10 years and is found to be saline sodic while the fields on which Pedons 3 and 4 were opened are found to be non-saline non-sodic soils and were dominantly cultivated by oxen plow.

As indicated in the Table 2, soils texture were loam throughout the profile for P1 and 2, except the second layer of P2 (21-47 cm),and sub-surface of p4, while all layers of P3 and surface layer of P4 (0-25 cm) were silty clay. The contents of sand, silt and clay in most profile did not show any consistent trend with soil depth. The particle density of most layers of profiles 2, 3 and 4 were almost similar to the average values for mineral soils as indicated by Brady and Weil (2002), while that of p1 and second layers of P2 and P3 were somewhat below the average values for mineral soils world-wide which areis 2.65 (Table 2).

The water content retained at FC, PWP and AWHC varied in layers of all profiles with relatively high value in the soils of P3 and 4. According to result of the study, the value of water contents at FC, PWP and AWHC registered in the layers with the highest clay content were not strongly related to soil particle size distribution for soils of P1 and 2 whereas, the result indicated the influence of clay content on the water holding capacity of the soil for P3 and 4 was strongly related to soil particle distribution (Table2). Thus, the results confirm the effect of salt (sodic) on soil structure which in turn affects the water holding capacity of soil (Table 3).

Soil Infiltration Rate and Hydraulic Conductivity

Figure 2, 3, 4 and 5 indicate infiltration rate and cumulative intake measured using double-ring infiltrometer method for the surface and sub-surface layers of the field irrigated from Lake Zeway and ground water, and for surface layers of fields irrigated from Meki River and rainfed cultivated, respectively. At the beginning, the infiltration rate of the surface layer of field 1 was very low (1.5 cm/hr) and fairly constant as compared to the subsurface layer (5.1 cm/hr). However, both layers reached similar steady-state value (0.8-0.9 cm/hr) after 14-15 hours . This low and constant infiltration rate during the initial stage of the process in surface layer could be due to soil sodicity that tends to disperse soil aggregates, create poor structure and reduce infiltration capacity. Based on Miller and Donahue (1997), infiltration rate of the two layers at steady state were classified in to low infiltration rate (Table 2).

The initial infiltration rate of surface and sub-surface layers of the field 2 were high with values of 8.0 and 7.5 cm/hr, respectively, whereas their steady state infiltration rate was 1.7 cm/hr and 1.4 cm/hr (Figure 3). This high steady state value of surface layer could be due to the counteraction of the salinity on the effect of sodicity in maintaining good soil structure and porosity. Based on Miller and Donahue (1997), infiltration rate of the two layers at steady state were classified in to medium infiltration rate.

The initial infiltration rate of field 3 was high (8.7 cm/hr) indicating the existence of porous surface conditions, good structure and/or high hydraulic conductivity of the soil and it reach steady state infiltration rate at 0.8 cm/hr. In spite of the high antecedent moisture content (38.31%) at which the process of infiltration was started, it took 15 hours to reach the steady-state infiltration rate with cumulative intake 45 cm that might be due to high clay content. According to Miller and Donahue (1997), infiltration rate of the surface layer at steady state was classified in to low infiltration rate.

Table 2. Selected physical properties of the soil profiles opened on the lands irrigated from Lake Zeway, ground water sources, Meki River water and rainfed cultivated field

Depth (cm)	Particle size (%)			Textural class	*SP (%)	ρs (g cm^{-3})	ρb (g cm^{-3})	TP (%)	Water content (% wt)			BIR (cm hr^{-1})	Ks (10^{-6} m s^{-1})
	Sand	Silt	Clay						FC	PWP	AWHC		
Soil profile on land irrigated from Lake Zeway water													
0-30	49	30	21	Loam	55.8	2.50	1.26	49.6	15.14	8.60	6.54	0.8	7.487
30-73	43	40	17	Loam	50.4	2.49	1.23	50.6	18.19	10.98	7.21	0.9	6.677
73-96	47	40	13	Loam	45.7	2.59	1.29	50.2	15.57	9.54	6.03	ND	6.939
96-200	35	44	21	Loam	56.2	2.61	1.29	50.6	14.71	9.78	4.93	ND	6.354
Soil profile on land irrigated from ground water source													
0-21	39	36	25	Loam	57.1	2.58	1.30	49.6	21.60	13.39	8.21	1.7	7.697
21-47	67	22	11	Sandy loam	51.0	2.68	1.33	50.4	11.82	9.34	2.48	1.4	10.667
47-75	27	46	27	Loam	63.8	2.58	1.31	49.2	19.58	12.70	6.88	ND	1.168
75-118	45	30	25	Loam	52.1	2.66	1.32	50.4	18.52	14.33	4.19	ND	0.748
Soil profile on land irrigated from Meki River water													
0-31	17	42	41	Silty clay	64.7	2.62	1.30	50.4	23.08	15.30	7.78	0.8	2.181
31-73	9	40	51	Silty clay	68.3	2.52	1.23	51.2	27.52	17.41	10.11	ND	2.000
73-200	15	40	45	Silty clay	67.2	2.60	1.32	49.2	22.63	17.54	5.09	ND	1.580
Soil profile on the rainfed cultivated field													
0-25	17	42	41	Silty clay	65.1	2.55	1.28	49.8	23.58	15.69	7.89	0.6	7.730
25-51	21	48	31	Clay loam	61.6	2.63	1.35	48.7	24.56	16.78	7.78	ND	6.790
51-105	27	40	33	Clay loam	59.9	2.56	1.36	46.9	22.87	17.14	5.73	ND	5.513

*SP = Saturation percentage; ρs = Particle density; ρb = Bulk density; TP = Total porosity; wt = Weight; FC = Field capacity; PWP = Permanent wilting point; AWHC = Available water holding capacity; BIR = Basic infiltration rate; Ks = Saturated hydraulic conductivity; ND = Not determined.

Table 3. Exchangeable chemical composition and properties of the soil profiles sampled from lands irrigated from Lake Zeway and ground water sources

Depth (cm)	pH (KCl)	ΔpH	Exchangeable cations (cmol(+)/kg soil)				CEC (cmol(+)/kg)	PBS	ESP	$CaCO_3$ (%)
			Na	K	Ca	Mg				
Soil profile on land irrigated from Lake Zeway water										
0-30	7.24	1.44	4.34	2.8	10.55	3.13	26.09	79.80	16.64	1.06
30-73	7.00	1.59	4.05	1.79	10.11	2.90	23.83	79.10	17.00	1.05
73-96	7.92	1.59	3.42	1.45	7.87	2.40	21.50	70.42	15.91	1.86
96-200	7.68	1.70	3.56	1.36	10.14	3.20	27.03	67.56	13.17	0.41
LZIL	7.24	1.42	5.37	3.99	10.6	3.13	34.88	65.54	15.97	3.19
Soil profile on land irrigated from ground water source										
0-21	6.31	1.46	3.36	3.64	9.93	2.71	21.32	92.12	15.76	0.84
21-47	6.25	1.43	1.84	2.09	7.09	2.59	20.45	66.55	9.00	0.52
47-75	6.99	1.33	5.97	3.55	9.91	4.60	30.80	78.02	19.38	2.59
75-118	7.19	1.14	9.13	4.45	8.10	3.53	27.68	91.08	32.98	3.04
GWIL1	7.33	0.98	5.40	4.34	12.08	3.21	31.87	78.54	16.94	2.57
Soil profile on land irrigated from Meki River water										
0-31	6.31	1.14	1.78	2.13	14.27	3.30	36.19	59.35	4.92	2.18
31-73	6.44	1.46	1.85	1.95	13.14	4.10	36.92	56.99	5.01	1.76
73-200	6.12	1.70	2.00	2.07	12.47	3.76	35.26	57.57	5.67	1.04
MRIL	6.24	1.52	1.88	2.53	21.51	3.52	37.77	77.95	4.98	1.27
Soil profile on the rainfed cultivated field										
0-25	6.12	1.66	1.71	3.68	14.03	3.20	37.95	59.60	4.51	1.07
25-51	6.78	0.94	1.80	2.79	13.10	4.95	35.88	63.10	5.02	2.95
51-105	6.75	0.72	2.34	3.66	17.34	4.20	25.63	107.45	9.13	1.85
RFCL	6.99	0.51	2.41	4.28	13.21	3.74	31.50	75.05	7.65	2.33

** S (For all) = Surface composite soil sample; LZIL = Lake Zeway irrigated land; GWIL = Ground water irrigated land; MRIL = Meki River irrigated land; RFCL = Rainfed cultivated land; CEC = Cation exchange capacity; PBS = Percent base saturation; ESP = Exchangeable sodium percentage.

Infiltration rate of the surface layer of the rainfed-cultivated field (Figure 5) soil was low (3.7 cm/hr) and gradually decreased with time until it reached a constant value of 0.6 cm/hr at 15 hrs. This could be due to the high moisture content of the field during the start of measurement (39%). The steady state infiltration rate observed in this specific soil is similar to experimental result that obtained steady state infiltration values of 0.75 cm/ hr, for clay loams with good structure (Wiesner, 1970 as cited in Thompson, 1999). According to Miller and Donahue (1997), infiltration rate of surface layer at steady state was classified in to low infiltration rate.

On the other hand, soil hydraulic conductivity of the P1 was almost similar in all layers (Table 4) with slight variation and according to Baruah and Barthakur (1997), all were grouped into moderate permeability classes with some variation in value. Contrary to the findings of this study, results of previous works (Bouwer, 1986) have showed that the hydraulic conductivity decreases with depth as subsoil layers are more compact and have smaller number of macro-pores compared to the surface layer. Thus, the similarities in hydraulic conductivity values of different soil depth obtained in this study could be due to the increment of bulk density with depth that might have compensated for the effects of sodicity and particle size distribution at the upper layers.

The saturated hydraulic conductivity of the soil profile opened on fields irrigated from ground water source revealed high variation between layers from as high as 10.667 x 10^{-6} m s^{-1} in the second layer (21-47 cm depth) to as low as 0.748 x 10^{-6} m s^{-1} at the extreme bottom layer. These values also signify the effect of sodicity as well as soil texture and bulk density on soil hydraulic conductivity, i.e., at layer 21-47 cm depth highest sand sized particle proportion and non-sodicity of the soil resulted in high hydraulic conductivity whereas, sodicity of the soil of the two bottom layers resulted in lowest hydraulic conductivity. According to the permeability classification set by Baruah and Barthakur (1997), layers 1 and 2 (0-21 and 21-47 cm) of the pedon were grouped into moderately rapid class whereas, layers 3 and 4 (47-75 and 75-118 cm depths) were grouped in to moderately slow class.

According to the classification criteria suggested by Baruah and Barthakur (1997), the saturated soil hydraulic conductivity of the surface layer of the profile on land irrigated from Meki River is grouped into moderate permeability class while layers 2 and 3 of the same profile fall in to the slow permeability class. This moderate to low permeability is apparently due to the high proportion of the fine soil particles (silt + clay) ranging from 83 to 91%.

The saturated hydraulic conductivity (Ks) of the soil under rainfed cultivation decreased consistently with increasing soil depth from 7.73 x 10^{-6} m s^{-1} at the surface layer to 5.51 x 10^{-6} m s^{-1} at the bottom subsoil horizon (Table 2). According to the classification by Baruah and Barthakur (1997), the soil permeability classes of the profile ranges from moderate at the bottom layer to moderately rapid at the surface layer and the layer below the surface horizon. This could be due to relatively higher bulk density at the bottom layer.

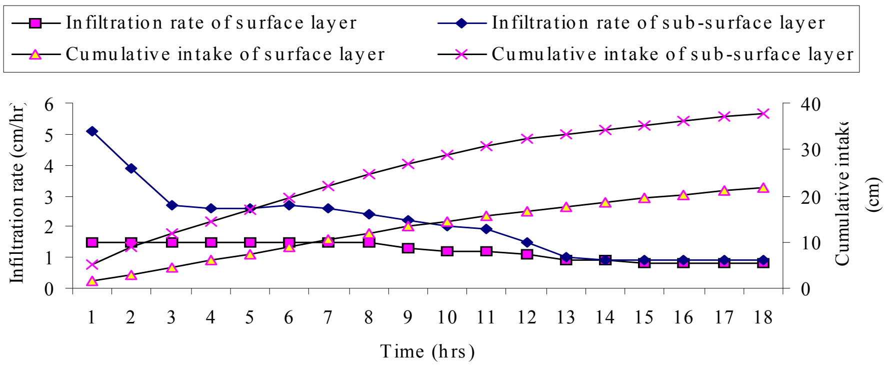

Figure 3. Infiltration rate and cumulative intake for the surface and sub-surface layers of the field irrigated from Lake Zeway

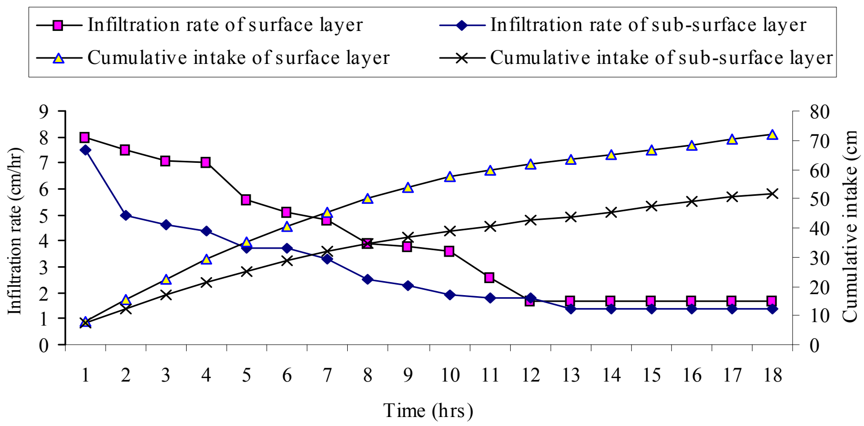

Figure 4. Infiltration rate and cumulative intake for surface and sub-surface layers of the field irrigated from ground water

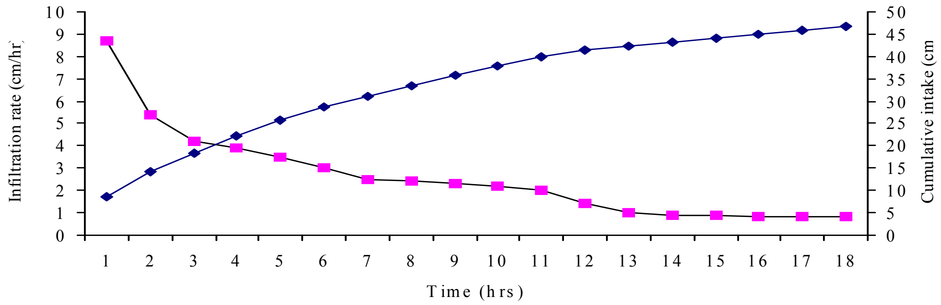

Figure 5. Infiltration rate and cumulative intake of surface layer of the field irrigated from Meki River

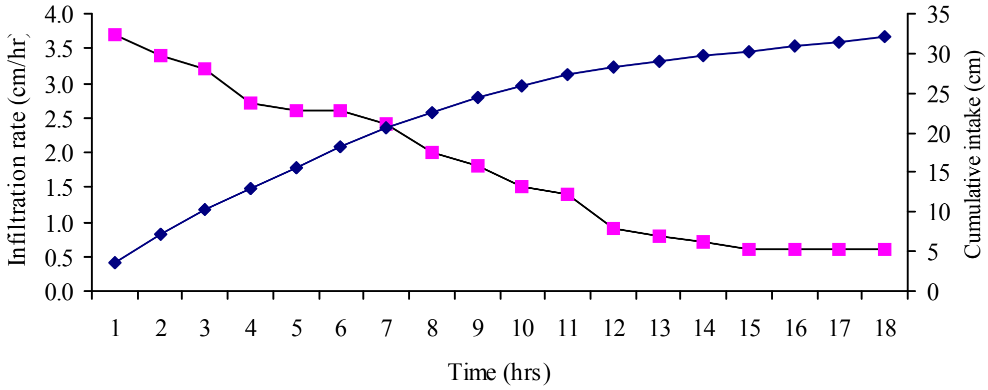

Figure 6. Infiltration rate and cumulative intake of the surface layer of the rainfed cultivated field

CONCLUSIONS AND RECOMMENDATIONS

Assessment of saturated hydraulic conductivity and steady state infiltration rate of Meki-Ogolcha area of Oromia Region were made to assess the effect of soil salinity and sodicity level on it. In line with infiltration rate, based on Miller and Donahue (1997), infiltration rate of the surface and sub surface layers of field 1 and surface layers of field 3 and 4 at steady state were classified in to low infiltration rate while medium infiltration rate for field 2. In these steady state infiltration rate measurement, the result were signifies the effect of clay content on field 3 and 4 and the effect of sodic soil on field 1 as well as the effect of counter action of salinity on sodisity on field 2. On the other hand, according to criteria set by Baruah and Barthakur (1997) for soil saturated hydraulic conductivity (Ks) classes, layers 1 and 2 of P2 and the surface layer and layer immediately below surface layer of P4 were classified into moderately rapid; all layers of P1, surface layer of P3 and bottom layer of P4 were grouped into moderate permeability classes and layers 3 and 4 of P2 were grouped in to moderately slow class where as layers 2 and 3 of P3 fall in to the slow permeability class.

Based on the findings of the study, hydraulic conductivity and infiltration rate of soil was highly affected by sodicity that in turn affected plant growth. Therefore, proper management of irrigation water and proper selection of water for irrigation become quite important.

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