Impact of using two different sources of water quality for simulation of salt and moisture content in unsaturated zone

Qassem Jalut^{1,*}, and Anmar Saleh¹

¹ Department of Civil Engineering, Diyala University, Baquoba, Iraq

Abstract. Monitoring water quality and moisture content throughout the root zone become essential for proper management and for reduction of undesirable and diverse effects caused by using different water quality. In the field level, poor management of using different quality water can cause a huge reduction on the vegetation production. Two field plots were selected in Al-Khalis region in Diyala governorate as a case study. Four scenarios were applied for the data collected for a complete season from a local meteorological station and by using HYDRUS-3D V2.05 software package to simulate water and salt transport through a 1m depth of unsaturated zone. Irrigation scheduling was estimated using FAO method. The net water depth required for a season was 65 mm for 7 days irrigation interval and 21 irrigation events. For depths (20, 40, 60, 80, and 100 cm) the salt concentration were simulated for the four scenarios and for the whole season. For the limit of controlling soil salinity at low level in initial and develop stage of plantation, it has been found that the Fourth scenario has to be chosen.

1 Introduction

Recently a proper management for irrigation in areas using different water qualities is needed. This task become vital in semi-arid and arid lands (Iraq as example). Availability of good quality waters becomes a real problem facing many of the developing countries , Pereira et al. 2009 ,and Gonçalves et al. 2007 [7], [4], among many others emphasized the importance of monitoring the change in soil moisture distribution and salinity profile in unsaturated zone to the use of different water quality in irrigation. Short and long term monitoring process of the effect of using different water quality on soil properties, soil environment and hence crop yield draw a very wide attention. Numerical and analytical modelling become an usual practice for many researcher in this area of research (Jarvis , 1994; Ahuja et al., 2000 and Šimu^onek et al., 2006 ,[6], [1], [10] to mention a few).

Soil moisture and salt distribution in partially saturated zone has been modelled using Richards equation and transport convective – dispersive equation with root water uptake term to take care of the plant stresses on soil water. Because of the non - linearity and complexity of the

govern equations, analytical solution seems to be impossible. Feddes and Raats, 2004, Šimu^onek and Hopmans , 2009, [2] , [11] to mention a few used a numerical approach to solve the govern equation of solute transport in unsaturated zone.

A finite element model HYDRUS (2D/3D) was selected in the present study for simulating solute and also water in partially saturated oil with plant water uptake. The model has the ability to display graphical results such as water contents , pressure heads , concentrations , Root water uptake, velocities , and temperatures [12].

2 Study area

Two fields of tomatoes were selected in Al-Khalis region of Diyala – Iraq , Al-khuyls field (33° 50' 10" N and 44° 32' 50" E) and Al-hashmyat field (33° 46' 02" N and 44° 31' 35" E). The climate in study area is mostly dry sub-humid. Summers are so hot and the winters are moderate . With a scarcity of rainfall and a decrease in fresh water sources during the months of years.

* Corresponding author: anmar_shs@yahoo.com

Al-hashmyat Al-khuyls

Fig. 1. location of Al-khuyls and Al-hashmyat fields .

3 Irrigation water requirement

3.1 Crop water requirements

Tomatoes are often planted in Iraq, in the month of April and the season ends in about five months after planting . The actual evapotranspiration can be estimated using equation (1).

$$ET_0 \times K_c = ET_c \quad (1)$$

Where ET_c is actual evapotranspiration in mm per day, K_c is factor related crop, and ET_0 is potential evapotranspiration in mm per day .

Table 1 . Growth stages duration.

Crop	total (days)	Initial stage	devlop. stage	Mid stage	Last stage
Tomatoes	150	35	40	50	25

Table 2 . The potential evapotranspiration and stages duration from 16 April to 12 September / 2015 .

Month	Apri.	May	Jun.	Jul	Aug.	Sep
ET_0 (mm//day)	4.84	6.29	7.31	7.83	6.7	5.65
K_c (each months)	0.45	0.55	0.763	1.15	1.002	0.8
Growth stage)		S1	S2	S3	S4	
K_c (each stage)		0.45	0.75	1.15	0.8	
Duration (month)		16 Apr-20May	21May-29Jun	30Jun-18Aug	19Aug-12Sep	
Duration(day)		35 day	40 day	50 day	25 day	

The water requirement by crop was 846(mm).

3.2 Irrigation scheduling

Irrigation scheduling was estimated using FAO manuals. The net water depth required for a season was 65 mm for 7 days irrigation interval and 21 irrigation events, these values are shown in Table 3 .

Table 3 . Irrigation scheduling.

Date	18 Apr.	26 Apr.	3 May	10 May	17 May	24 May	31 May
Amount (mm)	65	65	65	65	65	65	65
Date	7 June	14 June	21 June	28 June	5 July	12 July	19 July
Amount (mm)	65	65	65	65	65	65	65
Date	26 Jul.	2 Aug.	9 Aug	16 Aug	23 Aug.	30 Aug.	6 Sep.
Amount (mm)	65	65	65	65	65	65	65

4 HYDRUS (2D/3D) model

HYDRUS is software used for, numerically simulation (2D/3D), solute and water flow in porous media of variably saturated [12]. Below is the description of solution steps of HYDRUS -3D processes used in present research.

4.1 Flow of water

The governing water flow equation in unsaturated zone is described using the Richards equation

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x_i} \left[K \left(K_{ij}^A \frac{\partial h}{\partial x_j} + K_{iz}^A \right) \right] - S \quad (2)$$

Where t is time [T], θ is water content [$L^3 L^{-3}$], k_{ij}^A are the anisotropic hydraulic tensor K^A , x_i ($i=1, 2$) are the spatial coordinates [L], h is the pressure head [L], and K is hydraulic conductivity of unsaturated function [$L.T^{-1}$], S is a sink term [T^{-1}]

4.2 Root uptake

The plant uptake of water (s), is water removed from soil per unit (t) from a unit volume. Feddes et al. in [1978], [3], defined as :

$$S(h) = \alpha(h) S_p \quad (3)$$

Where $\alpha(h)$ is the water stress of response function ,is a prescribed dimensionless function.

4.3 Solute transport

$$-\theta R_k \frac{\partial c_k}{\partial t} - q_i \frac{\partial c_k}{\partial x_i} + \frac{\partial}{\partial x_i} \left(\theta D_{ij,k} \frac{\partial c_k}{\partial x_j} \right) + F_k c_k + G_k = 0 \quad (4)$$

Where, θ is water content ($L^3 L^{-3}$), c is the concentration of solute in liquid (ML^{-3}), D_{ij} [$L^2 T^{-1}$] is an dispersion tensor, q is the volume flux ($L^2 T^{-1}$), F_k , c_k and G_k are coefficients, and R_k constant of universal gas ($ML^2 T^{-2} K^{-1} M^{-1}$).

5 Input data

Irrigation fields are divided into basins with dimension of (6*4*1 m) and the figure below shows the typical geometry and finite element mesh used in HYDRUS-3D , V 2.05.

Fig. 2. Geometry of basin and element mesh used in HYDRUS.

5.1 Initial conditions and boundary conditions

The initial moisture content of soil for both soil profiles of fields was ($0.25 \text{ cm}^3.\text{cm}^{-3}$). Initial for the HYDRUS - 3D solute were specified in term the of (EC_{sw}). All values of chemical and physical characteristic of soil and water use in irrigation are shown in Table 4. Free drainage and atmospheric were put as boundary of bottom and the top surface conditions for each field, respectively and no flow boundary from other sides. Weather conditions were defined using meteorological data from (Al-Khalis meteorological station). As required by model, ETc daily values were split to soil evaporation (E) and crop transpiration (T), and soil evaporation coefficient (Ke) and a basal crop (kcb) are used, where:

$$ETc = (kcb + ke) \times ET_o \quad (5)$$

Table 4. Chemical and physical (initial conditions)^a
(Muneam,2015).

Fields	Al-khuyls			Al-hashmyat		
Depth (cm)	0-30	30-60	60-100	0-30	30-60	60-100
Sand(%)	38.9	4.1	5.2	29.3	15.6	15.8
Silt(%)	32.1	55.9	54.8	69.7	67.4	69.2
Clay(%)	20	40	40	1	17	15
Bulk density	1.43	1.55	1.6	1.61	1.68	1.5
EC_{sw} (ds m^{-1})	5.7	3.7	0.19	8.3	18.9	18.1
EC_{iw} (ground)	(6.51)			(2.68)		
EC_{iw} (fresh)	(0.23)			(0.23)		

a , EC_{sw} , electrical conductivity of soil water ,

EC_{iw} electrical conductivity of irrigation water

There are two different criteria by which degree of salinity of soil can be measured, total dissolved solids (TDS) with

unit milligrams solute per liter (mg/L), and by electrical conductivity of a saturation paste extract (EC_e) with unit deci-simens per meter (ds/m), [formerly micromhos per centimeter, (Mmho/cm)]. And can be converting from (EC_e) to electrical conductivity of soil water (EC_{sw}) by using mathematical relationship Connecting the two values

$$k_{EC} \times EC_e = EC_{sw} \quad (6)$$

Where $K_{EC} = EC_{fc} \div EC_e$ the value between (2 to 4) (EC_{fc}) in situ water of soil at filed capacity and (EC_e) of the water of soil in the saturation extract, [8]. In our study we assumed the value, K_{EC} (2).

5.2 Hydraulic properties

Hydraulic properties of unsaturated soil, $K(h)$, and $\theta(h)$ in equation (2) are in general highly non-linear functions of the pressure. HYDRUS-3D permits the use of 5 different analytical models to find the properties. In our study we use van Genuchten, 1980 [13]. The soil water retention, $K(h)$, and $\theta(h)$, functions according to Genuchten :

$$\theta(h) = \begin{cases} \theta_r + \frac{\theta_s - \theta_r}{[1 + |\alpha h|^n]^m} & h < 0 \\ \theta_s & h \geq 0 \end{cases} \quad (7)$$

Where θ_s – is saturated moisture content [-]; θ_r – is residual moisture content [-]; a , m , n – empirical parameters [cm^{-1}], [-], [-]; S_e is effective saturation [-];

$$K(h) = K_s S_e^l \left[1 - (1 - S_e^{1/m})^m \right]^2$$

Where l [-] pore connectivity parameter = 0.5; K_s is saturated hydraulic conductivity [$cm \cdot d^{-1}$]; $m = 1 - (1/n)$, when $n > 1$, all values of parameters are shown in Table 5.

Table 5. Soil hydraulic and solute transport parameters of the van Genuchten–Mualem functions.

Fields	Al-khuyls			Al-hashmyat		
Depth (cm)	0–30	30–60	60–100	0–30	30–60	60–100
θ_r ($cm^3 cm^{-3}$)	0.075	0.089	0.087	0.030	0.055	0.0599
θ_s ($cm^3 cm^{-3}$)	0.423	0.432	0.417	0.324	0.353	0.390
α (cm^{-1})	0.012	0.010	0.010	0.013	0.007	0.005
$\Pi(-)$	1.437	1.403	1.393	1.491	1.528	1.643
ℓ (-)	0.50	0.50	0.50	0.50	0.50	0.50
K_s ($cm \cdot d^{-1}$)	9.15	3.31	2.58	31.88	5.98	15.75

6 Results and discussion

The HYDRUS-3D start simulation on sixteenth of April (2015) in both fields, at the beginning of tomatoes growing season, and the simulation end on twelfth of September (2015).

Four scenarios were used as follows:

The first scenario using groundwater in all irrigation application, the second scenario using one application freshwater and one application groundwater, the third scenario use two application freshwater and two application groundwater, and the fourth scenario use two application freshwater and one application ground water, for all season.

6.1 Volumetric water contents

Figure 3 shows a significant change in the water content in the depths near the surface of the soil as a result of the large amount of irrigated water, while this effect reduced in the deeper depths. Also, the large change in moisture content in the nearby depths is due to the evaporation of the water from the soil, which is an effect in the shallow depths.

In addition, in the Al-khuyls field the water content in the depths (20, 40 and 60) cm begins change from the day that the watering begins, but in the depths (80 and 100) cm, the change begins from the 8th day, while in the Al-hashmyat field there was a change in the day of watering in all depths of the soil because of its sandy texture. The movement of water was fast since the soil is sandy with high permeability.

The impact of use of different qualities of water is evident. For instant, the second scenario used groundwater throughout the season is different from other scenarios. Especially the effect is evident in the middle season stage when the plant is more water-intensive than the rest of the stages. The water content is increased because its absorption of salt water is less than fresh water. While in the rest of the scenarios the moisture content is reduced due to the presence of fresh water which cause an increase in the plant's absorption of water.

6.2 Overall salinity

Figure 4 shows a significant difference in salinity for both fields, and for all scenarios due to differences in salinity of the irrigation water, as well as the difference in salinity of the initial value of soil water. When applying the second scenario, an increase in the salinity in the Al-khuyls field has been, reaching its peak in the middle stage, whereas in the Al-hashmyat field, a decrease in salinity has been noticed, because the salinity of the soil is higher than the salinity of water used for irrigation water. After this, there is an increase in salinity values

Fig. 3. Simulation of water content in both fields at different depth from April^{16th} - September^{12th} (2015).

20cm 40cm 60cm 80cm 100cm
Fig. 4. Simulation of , EC_{sw} in both fields at different depths from April^{16th} - September^{12th} (2015)

especially in the middle stage due to high evaporation rates. The greatest reduction of salinity was in the fourth scenario. In this scenario the following sequence were used: (freshwater – freshwater – groundwater), in which a 25 % of surface fresh water can be saved.

7 Conclusion

1- A significant moisture content fluctuation has been noticed in shallow depths due to irrigation applications. Then chances tend to die out at deeper depths

2-High permeability in Al-hashmyat sandy soil field causes water to move fast by which soil moisture content is changing at all depths in the day of irrigation.

3-The use of high water salinity causes a direct effect on plant water absorption ,Notice the occurrence decrease in the plant water absorption and hence increase in water content of soil

4-The use of freshwater causes an increase in the plant water absorption and hence decrease in water content of soil

5-The grain size distribution has a direct effect on soil permeability and has a significant effect on soil water content distribution throughout the soil profile.

References

1. Ahuja , L , Rojas, K., Hanson, J., Shafeer, M., . (Ed.), 372 (2000).
2. Ayres. R. and D. Westcott ., FAO,29 (1976) .
3. Feddes, R., and P. Raats . 2004. In R. Feddes et al. (eds.),UR Fronts Ser. 6. Kluwer Acad. Press, Wageningen, The Netherlands pp. 95–141.
4. Gonçalves, J. M., Pereira, L. S., Fang, S. X., & Dong, B. Agricultural water management, 94(1-3), 93-108 (2007).
5. Hanson, B., Hopmans, J. W., & Šimůnek, J. *Vadose Zone Journal*, 7(2), 810-818 (2008).
6. Jarvis, N ., Department. Soil. Sci., Sweden university. Agri. Sci., Uppsala, Sweden, pp, 51(1994) .
7. Pereira, L. S., Cordery, I., & Iacovides, I. Springer Science & Business Media (2009).
8. Roberts, T ., White , S., Warrick, A.,Thompson, T., 2008Agr. Water Mang. 95 , 669–677.
9. Roberts , T., Lazarovitch, N., Warrick, A., Thompson, T.L.,. *Soil Sci. , J. 73* , 233—240(2009).
10. Šimůnek, J., Van Genuchten, M., Šejna, M., technical manual version - 1.0, pc progress, Prague, republic, pp 21(2006.).
11. Šimůnek, J., Hopmans, J., . *Eco. Modell.* 220, 505–521(2009).
12. Šimůnek, J., Van-Genuchten, M. Th., Šejna, M., technic manual version-2, pc- progress, Prague, republic. , pp 21(2012).
13. Van Genuchten, M., . *Sci. So. AM. J.* 44, pp 892–898(1980).