INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
1560–8530/2001/03–1–31–34
http://www.ijab.org

Role of Computer Models in Simulating the Effect of Tillage Practices on Drainage Parameters of Soil

A.R. TAHIR, F.H. KHAN AND D.J. MULLA†
Department of Farm Machinery and Power, University of Agriculture, Faisalabad-38040, Pakistan
†Washington State University, Pullman, USA

ABSTRACT

Computer models are one of the latest management tools, which may be used to predict or monitor the effect of different cultural practices on the hydrologic properties of soil. Tillage practices play critical role in controlling the hydrologic characteristics of the soil and consequently the drainage efficiency of surface and subsurface drains. Attempt was made to simulate the effect of moldboard plowing and harrowing on the infiltration rate, drainage coefficient, recharge and seepage (lateral flow) under sloping lands using two and one-dimensional finite element computer models (FEMWATER and HYDRUS). The simulation of FEMWATER indicated more infiltration to occur under moldboard-plowed soil and lateral flow under harrowed soil where plow pan had developed due to excessive use of disc harrow. This model also indicated seepage to occur at middle slope position due to lateral flow. A good agreement was found between observed and simulated pattern of seeping water. Drainage coefficient and recharge simulated with two and one-dimensional models compared closely with the observed or studied earlier.

Key Words: Computer models; Tillage; Drainage parameters; Saline sodic soils

INTRODUCTION

Tillage is the first and most important cultural practice undertaken to attain desired soil surface configuration and soil physical properties. Tillage practices such as puddling, ridging, bordering, etc. are used to reduce water infiltration rate and manage crop water requirement. Whereas, subsoiling, chiseling, moldboard plowing, etc. promote water infiltration rate and drainability of soils. Pakistan with 25 million hectares of cultivable land has 23% as saline soils. Sixty per cent of the saline area is saline sodic. More than 70% of saline sodic soils have an impermeable soil layer or sodic pan and are categorized as poor draining soils which are hard to reclaim with chemical amendments. These soils can be made permeable and hence reclaimed by employing deep tillage such as subsoiling, chiseling, etc. It may be stated here that repeated use of tillage implements may lead to the formation of plow pan under the soil surface, which retards drainage capacity of soil.

Considerable research has been published regarding the use of chemical amendments in reclaiming agricultural soils of Pakistan. Studies have also been undertaken to make use of deep plowing in the reclamation process of soil. The movement of water in the vadose zone is a complex process and is affected by physical properties of soils, which in turn are managed by an appropriate tillage tool. To predict the effect of tillage practices on the drainage parameters of soil, computer models may be employed to achieve following specific objectives.

1. To simulate drainage coefficient and recharge under tillage practices and soil topography.
2. To estimate lateral subsurface flow/seepage developed due to plow/hard pan under sloping lands.

MATERIALS AND METHODS

The study area was characterized as rolling hills with steep slope (15%) at the top and middle, and gentle at the bottom. It was located in the proximity of Washington State University, Pullman, USA. To conserve soil and moisture at different slope positions, deep plowing with moldboard at the top and harrowing at the lower slope positions are recommended tillage practices for the area. Two computer models (FEMWATER and HYDRUS) were used to simulate lateral flow and recharge occurring at top-, back- and toe-slope positions. Lateral subsurface flow at top-slope position was hypothesized due to repeated use of moldboard plow. FEMWATER is a Finite Element Model for Water (Yeh, 1987) and suits well for different shaped elements as shown in Fig. 1. This model was used to simulate recharge and lateral subsurface flow under mould board plowing and harrowing tillage practices. The elements of the domain possessed different physical and hydrological properties due to deep plowing and accommodate different boundary conditions. HYDRUS, a one-dimensional finite element model (Kool & van Genuchten, 1989) was used to simulate recharge at top, back and toe-slope positions. The results of two models were compared with each other and the earlier studies

RESULTS AND DISCUSSION

Lateral flow. The study site is characterized with hilly topography where lateral (subsurface) flow at the upper slope positions possibly occurs. Estimation of lateral flow was important to apply different tillage practices and agrochemicals to promote crop yield and control weeds.

Fig. 1. FEMWATER grid showing different shaped elements and node numbers

Drainage of soil water beneath the upper-slope positions is greatly reduced because of lateral flow. On the other hand, seepage at back slope position would contribute to shallow water table at lower slope positions. More agrochemicals from the upper slope positions may be transported to lower slope positions by lateral flow.

Table I. Ratio of q_x to q_z at different depths of top and back-slope positions and the ratio of back to top-slope q_x and q_z on 145th day of simulation

Depth (cm)	Top-slope q_x/q_z	Back-slope q_x/q_z	q_x Back/ q_x Top	q_z Back/ q_z Top
0	5.2	4.2	1.1	1.4
40	5.0	4.0	1.1	1.4
80	5.5	2.0	1.9	5.2
120	0.2	1.9	4.5×10^3	4.6×10^2

Table II. Ratio of q_x to q_z with time for top and back-slope positions and the ratio of back to top-slope q_x and q_z just below the soil surface

Time (day)	Top-slope q_x/q_z	Back-slope q_x/q_z	q_x Back/ q_x Top	q_z Back/ q_z Top
83	5.0	4.3	5.4	6.1
114	4.4	4.2	3.4	3.5
145	5.2	4.2	1.1	1.4
173	5.0	4.4	2.0	2.3
212	5.6	4.6	1.8	2.2
240	5.1	4.2	0.6	0.8

Table I shows the simulated flux components (q_x and q_z) on day 145 in the top 200 cm at the top and back-slope positions. Day 145 gave the largest value of q_x during a nine-month simulation with FEMWATER. As discussed earlier, the top 200-cm of the soil profile was characterized using 40-cm deep element to represent tillage practice and different layers of material. At any slope position, lateral flow was dominant if q_x was greater than q_z. At the top and back-slope positions lateral flow occurred within the top 80 cm of the soil profile. Below a depth of 120 cm, vertical flow dominated, especially at the back-slope position. The results indicated that lateral flow is mainly a surface phenomena. Table II depicts the ratio of q_x to q_z at the top and back-slope positions in the top 120-cm of the soil profile. In addition, Table II also shows the ratio of back to top slope-position fluxes in the x and z directions. The ratios of q_x to q_z (Table II) at the top-slope position, indicate that the horizontal flow (q_x) is about 5 times higher than the vertical flow (q_z) up to a depth of 80 cm after which vertical flow dominated.

At the back-slope position, the lateral (horizontal) flow is about 2 to 4 times higher than vertical flow at all depths. These results support the hypothesis that significant lateral flow occurs at the upper slope positions. The comparison of back to top-slope position fluxes (Table II, q_x back/q_x top and q_z back/q_z top) reflects the tendency for greater lateral and vertical flow at the back-slope position than at the top-slope position. This comparison of fluxes at different slope positions very clearly reveals the effect of different tillage practices on the components of flow.

Most of the lateral flow (Table II) at the top-slope position occurred from the middle of January (114 days of simulation) to the end of April (212 days of simulation). At the back-slope position, lateral flow developed earlier (December 23, after 83 days) than at the top-slope position and continued up to the end of April (i.e. 212 days of simulation). The results of Table II indicated that horizontal flow at the top and back slope positions is about 4 to 5 times higher than vertical flow for most of the winter and early spring.

In general, the lateral flow component (q_x) at the back-slope position is significantly higher than at the top-slope position during early winter after which the difference tends to diminish. Prediction of lateral flow by FEMWATER at the upper slope positions is consistent with field observations of a stable water table at these slope positions. Field observations of seepage flow from the lower part of the back-slope position in spring were possibly the result of lateral flow. The results of Table II support the hypothesis that lateral flow is a subsurface phenomenon at the upper slope positions.

Seepage/runoff from different slope positions. Seepage is another flow process observed in sloping lands. Seepage is believed to be a result of lateral flow which develops at the upper slope positions usually after snow melt and spring rain. The bars of Fig. 2 represent 15 days of accumulated seepage except the first bar, which is three days of accumulated seepage. Most of the seepage as depicted by Fig. 2 occurred from February through April when snow melts and spring rainfall occurred. Predicted seepage from all slope positions (Fig. 2) may be compared with measured surface runoff (Fig. 3). Daily surface runoff was measured from October through June with two different flumes installed at the site. Flume measurements were converted to represent the cross-sectional runoff for easy comparison with model results. It should be kept in mind that the time of occurrence of maximum seepage is as important as the magnitude of seepage flow for the evaluation of management strategies involving agri-chemicals. Fig. 3 shows two runoff events (121 and 151 days) of considerable magnitude. The predicted occurrences of maximum seepage (Fig. 2) are in good agreement with the measured events. Two small runoff events some time during early and late December (between 61 and 91 days) are also fairly well predicted by FEMWATER.

Fig. 2. Total seepage simulated from all slop positions for rainfall season

Fig. 3. Surface runoff measured with flumes from October to June

Recharge simulation with FEMWATER. The model predicts lower recharge at the top and back-slope positions and a significantly higher recharge at the foot and toe-slope positions. At the back-slope position, about 1.0 cm of recharge was predicted which is about half of the top-slope position (2.1-cm). Recharge at the toe and toe-slope positions was predicted to be about 32.0 and 24.4 cm, respectively. The recharge estimates at the top and back-slope positions are vastly smaller than recharge at the lower slope positions mostly due to lateral flow from the upper slope positions where little infiltration towards the deep water table occurred. The recharge from RHS boundary (Fig. 1) was predicted to be about 412 cm for a period of nine months.

Recharge simulation with HYDRUS. Recharge estimation is important for management of groundwater resources in any area. Hilly topography with deep tillage at top and shallow tillage at the bottom facilitates lateral movement at upper slope positions and ponding at the bottom-slope position where herbicides may easily leach down with percolating water. A negative recharge (upward flow) especially at bottom-slope position can also occur during summer when evapotranspiration exceeds available moisture in the soil profile.

Table III documents annual infiltration, net recharge, runoff, and evaporation using HYDRUS for different slope positions at the site over a simulation period of one year. Recharge at the top slope was estimated using three soil profiles with different bottom boundary conditions. Simulation of a 5-m deep profile resulted in an annual drainage of 1.22 cm. This simulation used a constant flux (unit gradient) bottom boundary condition in the unsaturated zone of soil. A second simulation extended down to the water table (22.6 m) where a constant head (zero potential) bottom boundary condition was specified. Simulation of the second profile resulted in 3.0 cm of annual recharge. A third simulation of the soil profile extended down to the bottom of piezometer P4 (28 m deep) and resulted in annual recharge of 3.0 cm.

Table III. Annual recharge (drainage) simulated for different slope positions of study site using HYDRUS

Profile Depth (cm)	Bottom Boundary	Infiltration (cm)	Evaporation (cm)	Runoff (cm)	Recharge (cm)
		TOP-SLOPE			
500	Unit Gradient	56.37	29.98	0.80	1.21
2260	Water table	52.16	28.36	5.21	3.07
800	Prescribed pressure head	50.45	27.68	6.76	3.05
		BACK-SLOPE			
460	Water table	32.24	24.65	24.96	3.50
1700	Prescribed pressure head	32.51	25.30	24.68	3.60
		TOE-SLOPE			
500	Prescribed pressure head	50.72	87.01	6.45	-36.40

Changes in piezometric pressure with time were used as the bottom boundary condition in this third simulation. Simulations at the back-slope position using different bottom boundary conditions resulted in annual recharge of 3.5 cm for a water table boundary condition and 3.6 cm for a prescribed piezometric pressure head boundary condition. At the toe-slope position the water table was encountered at a depth of about one-meter. A piezometer at 5 m was used to specify bottom boundary conditions for all simulations at this slope position. Fig. 4 shows the pattern of recharge over a year in response to fluctuations in water table position. It is interesting to note that a maximum recharge (downward flow) of about 19.0 cm occurred from January through March (first 130 days) when the water table rose about 60.0 cm in response to snow melt and winter precipitation. From days 150 to 300 (May through September) a linear decrease in recharge occurred resulting in a net annual upward flow of about 36.4 cm. High crop-water requirements in summer and sporadic rainfall allowed the water table at the toe-slope position to fall during this time. In October, the water table started rising again in response to fall precipitation.

Fig. 4. Cumulative recharge simulated at the toe-slope position with prescribed pressure head bottom boundry

The results of recharge simulation using both two- and one-dimensional models are comparable with each other and with those of other researchers such as Muniz (1991), Lum *et al.* (1990), Baur and Vaccaro (1990) and Ralston (1989) who reported recharge in the range of 2.5 to 10.3 cm/year for the study area.

CONCLUSIONS AND RECOMMENDATIONS

The results of FEMWATER and HYDRUS show that tillage practices at different slope positions have a significant effect on flow and transport processes. For better characterization of tillage practices at different slope positions and their impact on flow and transport phenomenon, the following recommendations are made.

1. Seepage and lateral flow at the top and back-slope positions are subsurface phenomenon and are very sensitive to tillage practices, that control hydraulic properties of soil. Soil hydraulic properties in the top 2-m of the soil need to be carefully measured to obtain representative data for the models.
2. Soil biological, physical, and hydraulic properties continue to change because of tillage and other natural events. Data should be collected before and after tillage operations from time to time to take into account the effect of tillage on model simulation.

REFERENCES

Kool, J.B. and M.Th. van Genuchten, 1989. HYDRUS: One-dimensional variably saturated flow and transport model, including hysteresis and root water uptake. Version 3.2. Hydrogeologic Inc., 503 carlisle Drive, Suite 250, Herndon, Virginia 22070.

Lum II, W.E., J.L. Smoot and D.R. Ralston, 1990. Geohydrology and numerical model analysis for groundwater flow in Pullman-Moscow area, Washington and Idaho. *U.S. Geological Survey, Water Resources Investigations Report,* 89–4103.

Muniz, H.R., 1991. Computer modeling of vadose zones groundwater flux at a hazardous waste site. *M.Sc. Thesis,* Washington State University, Pullman, WA, USA.

Ralston, D.R., 1989. Groundwater in the Pullman-Moscow area. A water supply for the future?. Idaho Water Resources Research Institute, Univ. of Idaho, Moscow.

Yeh, G.T., 1987. FEMWATER: A finite element model of WATER flow through saturated-unsaturated porous media. Pennsylvania Stat Univ., Univ. Park, PA.

(Received 15 November 2000; Accepted 10 December 2000)