



DRAINMOD – Calibration and Validation for Prediction of Drainage Coefficient and Water Table Depth

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Authors' contributions

This work was carried out in collaboration among all authors. Author AS wrote the first draft of the manuscript on DRAINMOD- calibration and validation for prediction of drainage coefficient and water table depth. Authors GT, SV, IM and KR read and approved the final manuscript.

Article Information

DOI: 10.9734/CJAST/2020/v39i930607

Editor(s):

(1) Dr. Md. Hossain Ali, Bangladesh Institute of Nuclear Agriculture (BINA), Bangladesh Agricultural University, Bangladesh.

Reviewers:

(1) Zuzana Vranayova, Technical University of Kosice, Slovakia.

(2) Stavros Yannopoulos, Aristotle University of Thessaloniki, Greece.

Complete Peer review History: <http://www.sdiarticle4.com/review-history/56336>

Received 26 February 2020

Accepted 02 May 2020

Published 11 May 2020

Original Research Article

ABSTRACT

DRAINMOD model predicts the effects of drainage and associated water management practices on water table depths and drainage coefficients. It simulates the performance of a given system for a long period of weather record. The field evaluation of this model has been carried out by comparing model predicted drain flow and depth to water table with the observed data collected from water table management system installed at A-block of Eastern Farm, Agricultural Engineering College and Research Institute Kumulur during the year 2015-2016. The comparison between predicted and observed drainage coefficient and depth to water table with treatment of different drain spacing (7.5, 10, 12.5 and 15 m) and drain depth (75 and 60 cm) is made. The statistical measures indicated that, there was a close relationship between predicted and observed drainage coefficient

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during the calibration and validation period as indicated by average root mean square error value ranges from 12.3 to 15.7 and 19.63 to 26.19 and average Chi-squared test value ranges from 0.010 to 0.725 and 0.01 to 0.28. Similarly for water table depth, the average root mean square value ranges from 7.630 to 17.20 and 16.67 to 21.54 and average Chi-squared test value ranges from 1.19 to 2.365 and 3.90 to 5.02.

Keywords: DRAINMOD; drainage coefficient; optimal drainage design; subsurface drainage and water table.

1. INTRODUCTION

DRAINMOD is a computer simulation model developed at the Department of Biological & Agricultural Engineering, North Carolina State University, Raleigh, NC, in 1980. It is a process-based, distributed, field-scale model developed to describe the hydrology of poorly drained and artificially drained soils. The model is based on water balances in the soil profile, on the field surface, and, in some cases, in the drainage system [1]. The model simulates the hydrology of poorly drained, high water table soils on an hour, daily basis for long periods of climatological record (e.g. 50 years). The model predicts the effects of drainage and associated water management practices on water table depths and drainage coefficient. In the last 20 years, the model's capability has been extended to predict the effects of drainage and water management practices on the hydrology and water quality of agricultural and forested lands both on field and watershed scale. To provide trafficable conditions for seedbed preparation in the spring and harvest in the fall. It simulates the performance of a given system for a long period of weather record. By making multiple simulations, the least expensive system that will satisfy the water management objectives for a given situation can be chosen. The generalized likelihood uncertainty estimation procedure was used to evaluate the uncertainty in DRAINMOD predictions of daily, monthly, and yearly subsurface drain flow [2].

It was used to modify the curves which are obtained from solutions to the Boussinesq-Equation to predict drainage flux. Standard version DRAINMOD-5.1 was used Hooghoudt's and Kirkham's equations to predict drainage flux for Elliptic and ponded water tables at the surface respectively [3]. DRAINMOD 5.1 accurately simulated the timing and magnitude of subsurface drainage events. The model also simulated the pattern of water table fluctuations with a good degree of accuracy [4]. It is estimates for soil water flux in the unsaturated

zone. These modifications enabled DRAINMOD to be linked to a model to estimate the interaction between irrigation, drainage and salinity in arid regions [5]. Wright et al. [6] studied the impacts of water table management (WTM) practices on water quality were modeled. The water management model DRAINMOD to predict soil salinity as affected by irrigation water quality and drainage system design [7]. Luo et al. [8] predicted the field hydrology in cold conditions with modified DRAINMOD. DRAINMOD could predict water table in soils with and without a perimeter ditch. It was calibrated for each soil plot using measurement of *in situ* saturated hydraulic conductivity, soil water characteristic, depth to impermeable layer, depth of rooting and rainfall [9]. Hence the objective of the study is to calibrate and validate mathematical model for water table management system to optimize design spacing, depth and dimensions of drain tubes.

2. MATERIALS AND METHODS

2.1 Study Area

The experiment was laid out in A-block of Eastern farm, Agricultural Engineering College and Research Institute Kumulur which is located at 56° 34' 05" N latitude and 78° 49'34" E longitude and at an altitude of 40.29 m above mean sea level. Topography of the experimental plot was uniform and level. The project site has a serious problem of waterlogging due to seepage of water from the lake located adjoining to the study area, which is the water harvesting source for Kumulur watershed. Sandy loam soil is the soil type of the experimental area. The soil is sodic in reaction with a pH of 9.1, electrical conductivity of 0.14 dS m⁻¹ and Exchangeable Sodium Percentage in 28 per cent.

Controlled drainage operates as a traditional drainage system during wet periods; excess water is removed from the field through a system of underground drain tubes under controlled mechanism of opening and closing of drain tubes

at a specific period which conveys outlet to a main drain pipe. It should remove the excess waterlogging and keep the crop in congenial condition.

The experiment was laid out in split plot design with three replications. Four level of spacing of drain pipes viz., 7.5 m spacing between drains, 10 m spacing between drains, 12.5 m spacing between drains and 15 m spacing between drains are the main plot treatments and the two levels of depth and diameter of drain pipes viz., Depth of drain at 75 cm + 75 mm drain diameter, Depth of drain at 75 cm + 63 mm drain diameter, Depth of drain at 60 cm + 75 mm drain diameter and Depth of drain at 60 cm + 63 mm drain diameter are the subplot treatments.

2.2 DRAINMOD

DRAINMOD was developed as a field-scale model to describe the hydrology of poorly or artificially drained lands. In addition to the drainage and related drainage water management systems. It is a process-based, distributed model that conducts water balances on hourly and daily time scales. Hydrologic variables (infiltration, subsurface drainage, surface runoff, evapotranspiration, vertical and lateral seepage, water table depth, and drained or water-free pore space in the soil profile) are predicted, and summary outputs are available on daily, monthly, yearly, and ranked bases, at the option of the user. The model inputs are soil property inputs, hydraulic conductivity, soil water characteristics, Drainage volume- water table depth relationship, upward flux, Green- Ampt equation parameters, crop input data, Drainage system parameter, Surface Drainage and Effective drain radius.

2.3 Preparation of Input Files

The following input files are required to run the model and project setting window of DRAINMOD 6.1 model was presented.

1. General information
2. Weather information
3. Drainage design
4. Soil
5. Irrigation
6. Crops

2.4 Drainage Coefficient

The drainage coefficient for determining drain spacing can be arrived by considering general

water balance of the area using the following water balance equation

Drainge coefficient (q) = recharge from rainfall + recharge from irrigation = [Average rainfall in monsoon season – (20 percent of average rainfall) as effective rainfall] + [crop water requirement – (Average deep percolation losses as 25 percent of irrigation water delivered to field)]/ crop period

2.5 Model Calibration

This is carried out by comparing the values of variables like drain flow, and depth to water table those are observed in the field as well as predicted by the model. In present situation the model was calibrated by using observed data set from the period from 2015 to 2016. Volumetric soil moisture at 0 cm head, drainage coefficient and depth to impervious layer were considered as calibration parameters with a specific range. Model was run the number of times by adjusting the values of above considered parameters and fixed the values with minimum errors. Statistical Analysis was also done with the help of observed and predicted data set. The following statistical measures were calculated

1. Standard Deviation (SD) of Observed data
2. Standard Deviation (SD) of Predicted data
3. Coefficient of Deviation (CD) of observed data
4. Coefficient of Deviation (CD) of predicted data
5. Root Mean Square Error
6. Chi-squared test

2.5.1 Standard Deviation (SD)

The following relation are used for calculation of Standard deviation

$$SD(O) = \sqrt{\sum_{i=1}^N (O_i - O \text{ bar})^2 / (n - 1)} \quad (1)$$

$$SD(P) = \sqrt{\sum_{i=1}^N (P_i - P \text{ bar})^2 / (n - 1)} \quad (2)$$

Where,

O_i & P_i are observed values and predicted values
 $O \text{ bar}$ & $P \text{ bar}$ are averages of observed and predicted values
 N = Number of values

2.5.2 Coefficient of Deviation (CD)

$$CD = \frac{\{\sum_{i=1}^N (O_i - O \text{ bar})(P_i - P \text{ bar})\}^2}{\{\sum_{i=1}^N (O_i - O \text{ bar})^2 \sum_{i=1}^N (P_i - P \text{ bar})^2\}} \quad (3)$$



Plate 1. Installation of controlled drainage

2.5.3 Root mean square error

$$RMSE = 100/Pbar \sqrt{\left(\frac{1}{N} \sum_{i=1}^N (P_i - O_i)^2\right)} \quad (4)$$

2.5.4 Chi-squared test

$$\text{Chi - squared test} = \frac{(\text{observed} - \text{predicted})^2}{\text{predicted}} \quad (5)$$

2.6 Model Validation

The calibrated model was validated by comparing the predicted and observed variables like drain flow and depth to water table. The same statistical parameters were supplied during the calibration process and were used to test the reliability of model predictions during the validation period.

3. RESULTS AND DISCUSSION

The field evaluation of DRAINMOD model has been carried out by comparing model predicted drain flow and depth to water table with the observed data collected from water table management system installed at A- block of Eastern farm, Agricultural Engineering College and Research Institute, Kumulur during the year 2015 and 2016.

3.1 Model Calibration

The variables considered for calibration include drain flow and water table depth. The volumetric soil moisture at 0 tension, drainage co-efficient and depth to restricted layer were adjusted during model calibration. Based on the soil moisture characteristics provided, the model utility programmed and estimated water table

depth versus volume drained and water table depth versus upward flux relationships.

3.1.1 Comparison of predicted and observed drainage coefficient during calibration period

The comparison between predicted and observed drainage coefficient, with the treatment of different drain spacing of 7.5, 10, 12.5 & 15 m and drain depth of 75 and 60 cm is represented in Figs. 1 & 2, which indicated that there was good correlation between both the values. Statistical analysis was carried out to check the reliability of the model performance and showed in Table 1.

The statistical measures considered that, there was a close relationship between predicted and observed drainage coefficient during the calibration period as indicated by average root mean square error value ranges from 12.3 to 15.7 in main plot treatments and average Chi-squared test value ranges from 0.010 to 0.725. Among the main plot treatment of different spacing, 12.5 m (S₃) observed the maximum root mean square error of (15.7) whereas the minimum root mean square error of (12.3) was recorded in 15 m (S₄) drain spacing. Among the subplot treatment of different depth, 75 cm drain depth (D₁) was observed maximum root mean square error of 14.91 whereas the minimum root mean square error was obtained in treatment of (12.74) 60 cm drain depth (D₂). The average Chi-Squared Test value was observed (0.018 to 0.3640) at 75 cm (D₁) and 60 cm (D₂) drain depth. [10] reported that the error relative to natural variation of observed values and predicted values vary from 5 to 30 per cent. [11]

concluded that model reliably predicted water table depths with a RMSE (15.49 cm); drain discharges with RMSE of 0.1876 m /day.

3.1.2 Comparison of predicted and observed water table depth during calibration period

The comparison between predicted and observed depth to water table with the treatment

of different drain spacing (7.5, 10, 12.5 and 15 m) and drain depth (75 and, 60 cm) is represented in Figs. 3 & 4. The water table level reached nearer to the ground surface during the monsoon period. A close match was observed between predicted and observed depth to water table and it showed good performance of model. Statistical analysis was carried out to verify the reliability of the model predictions and statistical measures are showed in Table 2.

Table 1. Statistical measures of DRAINMOD 6.1 model performance in drainage coefficient during calibration period

Main plot	Root mean square error			Chi-squared test		
	Sub plot			Sub plot		
	D ₁	D ₂	Mean	D ₁	D ₂	Mean
S ₁	11.32	14.39	12.6	0.012	0.007	0.010
S ₂	14.96	14.59	14.8	0.020	1.430	0.725
S ₃	16.65	14.69	15.7	0.021	0.015	0.018
S ₄	16.72	8.480	12.3	0.022	0.004	0.013
Mean	14.91	12.74		0.0188	0.3640	

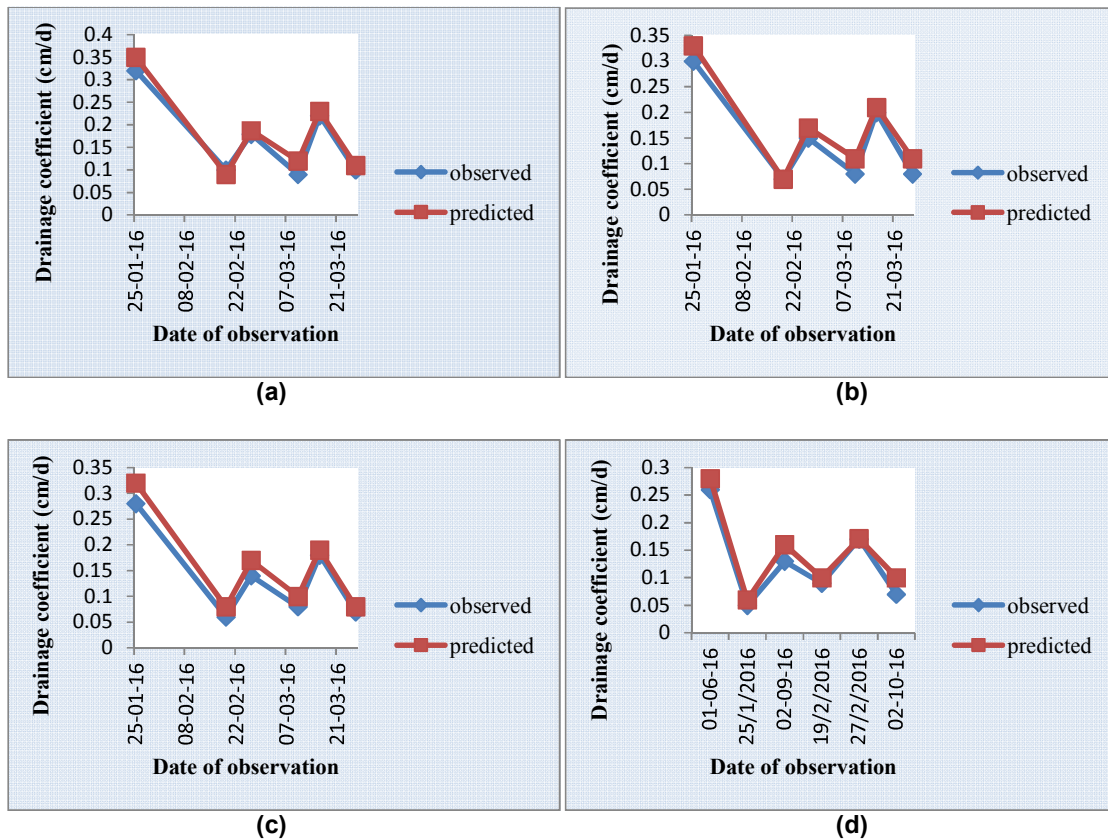


Fig. 1. Comparison of predicted and observed drainage coefficient at (a) 7.5 m (b) 10 m (c) 12.5 m and (d) 15 m drain spacing with 60 cm drain depth during calibration

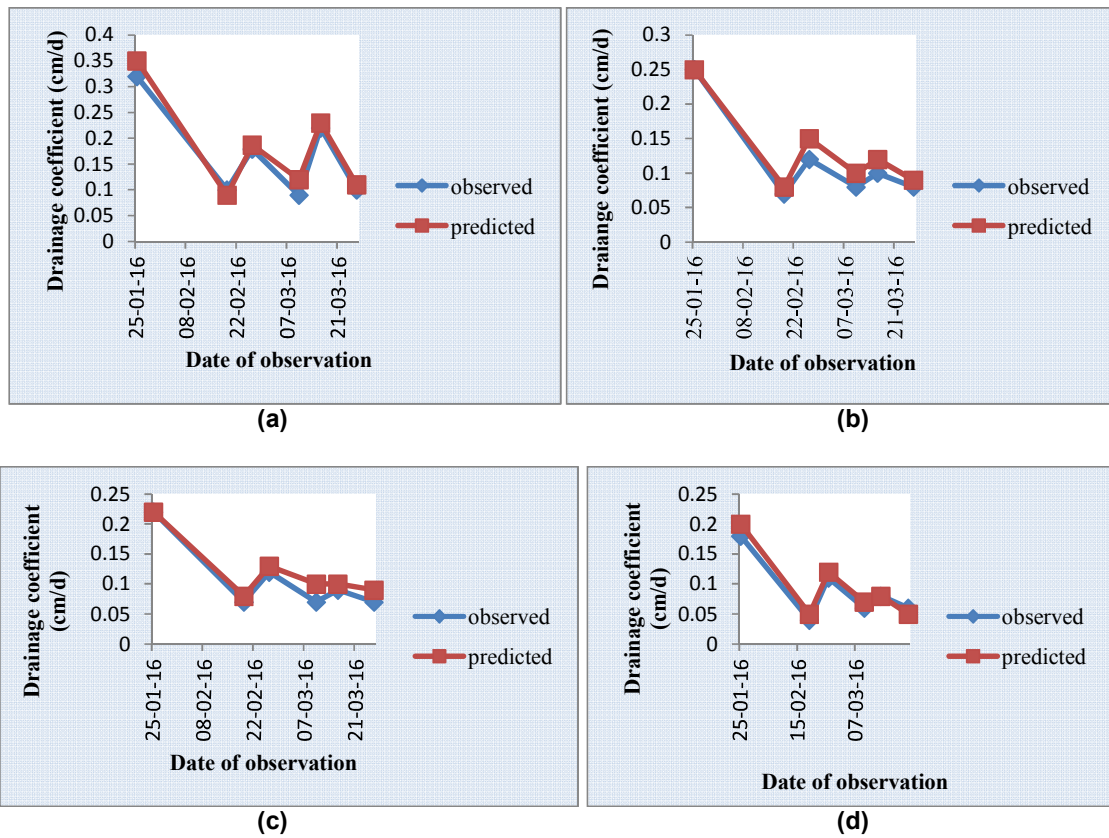


Fig. 2. Comparison of predicted and observed drainage coefficient at (a) 7.5 m (b) 10 m (c) 12.5 m and (d) 15 m drain spacing with 60 cm drain depth during calibration

Table 2. Statistical measures of DRAINMOD 6.1 model performance in depth to water table during calibration period

Main plot	Root mean square error			Chi-squared test		
	Sub plot			Sub plot		
	D ₁	D ₂	Mean	D ₁	D ₂	Mean
S ₁	5.81	9.45	7.630	0.69	1.54	1.19
S ₂	7.64	14.35	10.99	1.15	3.88	2.55
S ₃	11.03	13.11	12.07	2.12	1.81	1.96
S ₄	15.74	18.79	17.20	3.04	1.69	2.36
Mean	10.05	13.92		1.75	2.28	

The statistical measures indicate that, there was a close relationship between predicted and observed water table depth for the calibration years from 2015 to 2016. The average root mean square value ranges from 7.630 to 17.20 in main plot treatments and average Chi-squared test value ranges from 1.19 to 2.365. Among the main plot treatment of different spacing, 15 m (S₄) observed the maximum root mean square error of (17.20) whereas the

minimum root mean square error of (7.63) was recorded in 7.5 m (S₁) drain spacing. Among the subplot treatment of different depth, 60 cm drain depth (D₂) was observed maximum root mean square error of 13.92 whereas the minimum root mean square error was obtained (10.05) in treatment of 75 cm drain depth (D₁). The average Chi-squared test value was observed (1.75 & 2.28) at 75 cm (D₁) and 60 cm (D₂) drain depth.

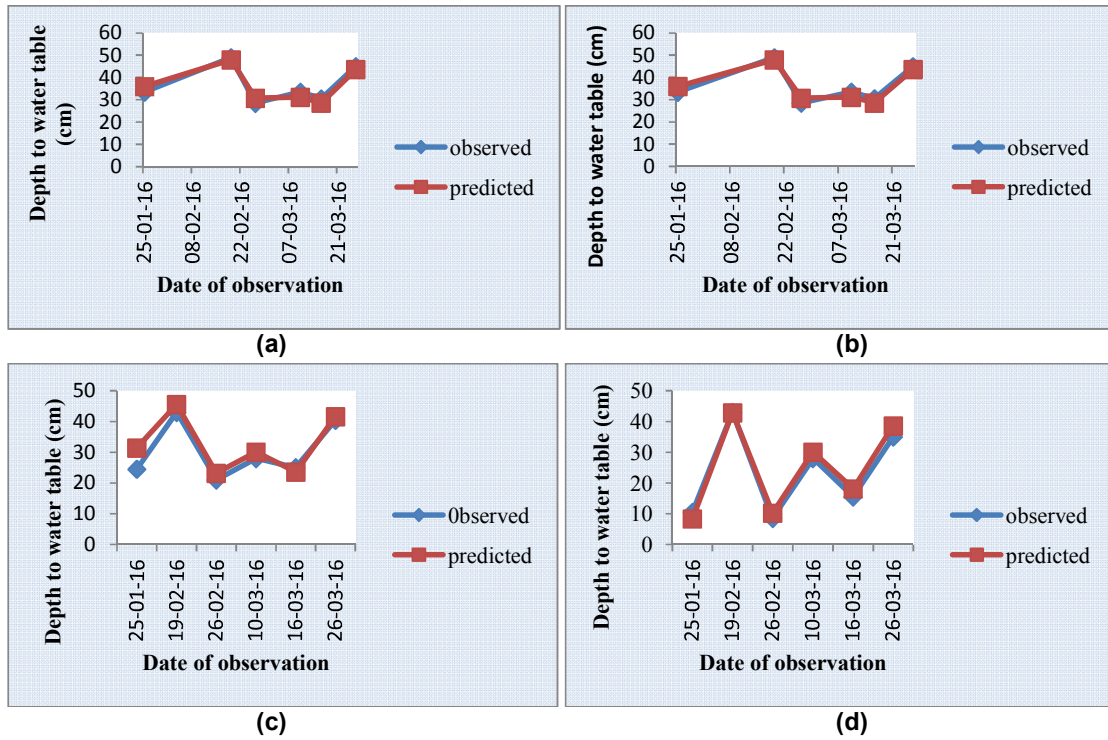


Fig. 3. Comparison of predicted and observed depth to water table at (a) 7.5 m (b) 10 m (c) 12.5 m and (d) 15 m drain spacing with 75 cm drain depth during calibration

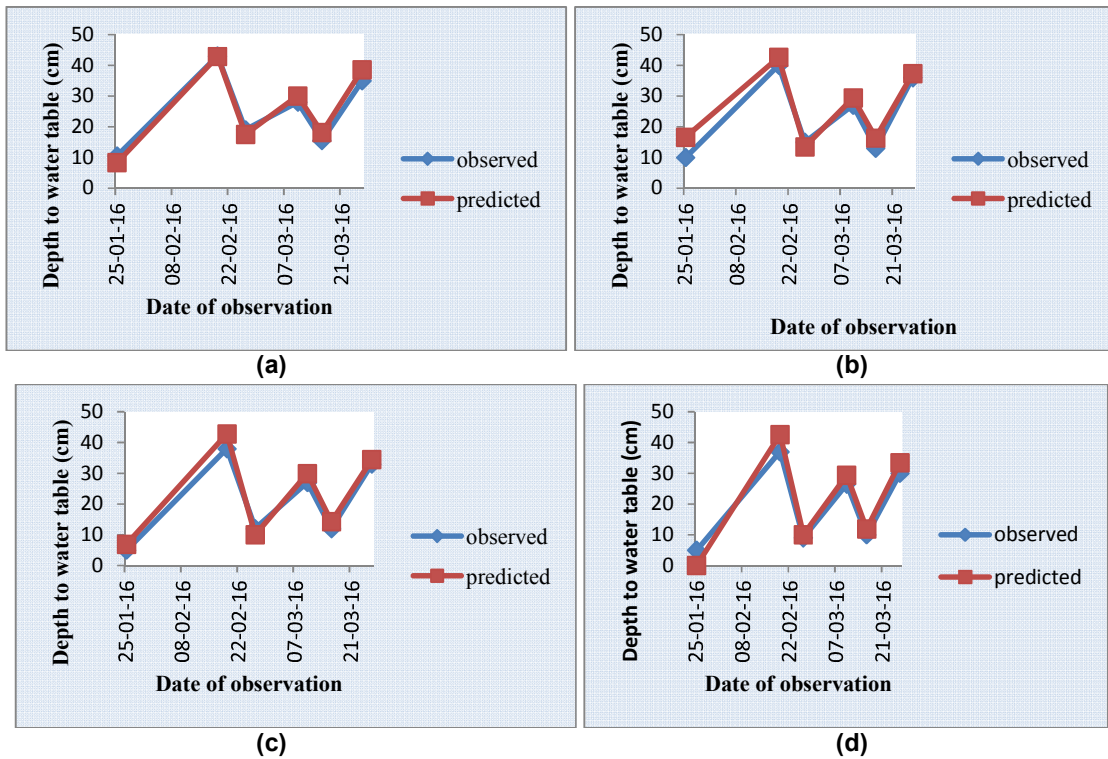


Fig. 4. Comparison of predicted and observed depth to water table at (a) 7.5 m (b) 10 m (c) 12.5 m and (d) 15 m drain spacing with 60 cm drain depth during calibration

3.2 Model Validation

The calibrated model was validated by comparing the predicted and observed variables like drain flow and depth to water table.

3.2.1 Comparison of predicted and observed drainage coefficient during validation period

The comparison between predicted and observed drainage coefficient with the treatment of different drain spacing (7.5, 10, 12.5 and 15

m) and drain depth (75 and 60 cm) is represented in Figs. 5 & 6, which indicated that there was same trend between both the values. Statistical analysis was carried out to check the reliability of the model performance and showed in Table 3.

The statistical measures indicate that, there was a close relationship between predicted and observed drainage coefficient during the validation period as indicated by average root mean square value ranges from 19.63 to 26.19 in main plot treatments and average Chi-Squared

Table 3. Statistical measures of DRAINMOD 6.1 model performance in drainage coefficient during validation period

Main plot	Root mean square error			Chi-squared test		
	Sub plot			Sub plot		
	D ₁	D ₂	Mean	D ₁	D ₂	Mean
S ₁	26.54	25.85	26.19	0.07	0.04	0.05
S ₂	22.84	26.62	24.73	0.03	0.53	0.28
S ₃	20.14	19.13	19.63	0.02	0.01	0.01
S ₄	19.01	23.00	22.50	0.01	0.05	0.03
Mean	22.13	24.40		0.03	0.15	

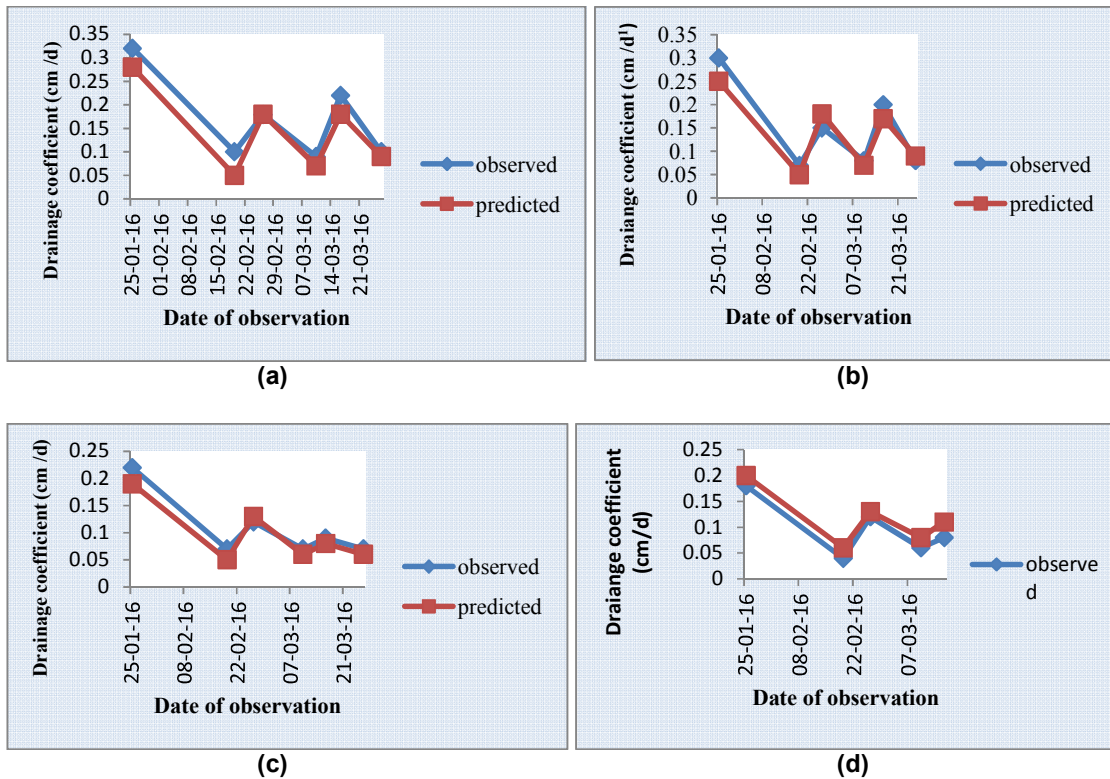


Fig. 5. Comparison of predicted and observed depth to water table at (a) 7.5 m (b) 10 m (c) 12.5 m and (d) 15 m drain spacing with 60 cm drain depth during validation

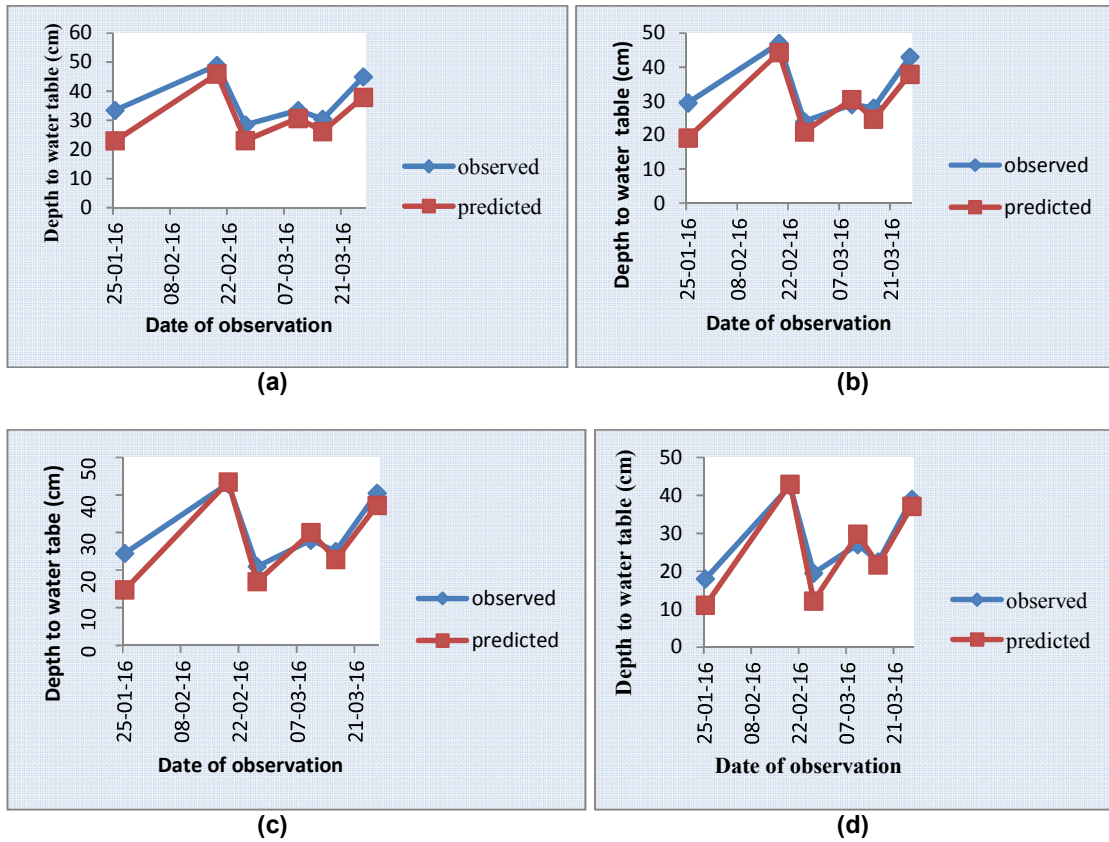


Fig. 6. Comparison of predicted and observed depth to water table at (a) 7.5 m (b) 10 m (c) 12.5 m and (d) 15 m drain spacing with 75 cm drain depth during validation

Test value ranges from 0.01 to 0.28. Among the main plot treatment of different spacing, 7.5 m (S_1) observed the maximum root mean square error of (26.19) whereas the minimum root mean square error of (19.63) was recorded in 12.5 m (S_3) drain spacing. Among the subplot treatment of different depth, 60 cm drain depth (D_2) was observed maximum root mean square error of 24.40 whereas the minimum root mean square error was obtained in treatment of (22.13) 75 cm drain depth (D_1). The average Chi-squared test value was observed (0.03 & 0.15) at 75 cm depth (D_1) and 60 cm depth (D_2). The value of RMSE for water table depth obtained was within the acceptable ranges as reported by [12] and [13].

4. CONCLUSION

The field evaluation of DRAINMOD model has been carried out by comparing model predicted drain flow and depth to water table with the observed data. The comparison between predicted and observed drainage coefficient and

depth to water table with treatment of different drain spacing (7.5, 10, 12.5 and 15 m) and drain depth (75 and 60 cm). The statistical measures considered that, there was a close relationship between predicted and observed drainage coefficient during the calibration and validation period as indicated by average root mean square error value ranges from 12.3 to 15.7 and 19.63 to 26.19 and average Chi-squared test value ranges from 0.010 to 0.725 and 0.01 to 0.28. Similarly water table the average root mean square value ranges from 7.630 to 17.20 and 16.67 to 21.54 and average Chi-squared test value ranges from 1.19 to 2.365 and 3.90 to 5.02.

ACKNOWLEDGEMENT

I am grateful to Agricultural Engineering College and Research Institute (AEC&RI) Kumulur and Tamil Nadu Agricultural University Coimbatore for the approval of my research work.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:

The peer review history for this paper can be accessed here:
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