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Evaluation of the DSSAT Vertical Drainage Model for Vertisols

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Abstract

The increasing competition for water has led to the need for a better water resources management, especially for crops irrigation. A water balance tool in crop models is useful for the determination of the best agricultural water management practices that maximize the crop yield and the water productivity while avoiding the need for costly field experiments. This requires that crop models simulate water balance accurately. Suleiman and Richie (2004) (SR2004) developed a vertical drainage equation which has been incorporated into the Decision Support System for Agrotechnology Transfer (DSSAT) which is the most widely used crop model in the world. The objective of this study is to test the performance of SR2004 in Vertisols of Jordan. A laboratory trial was conducted on three Vertisols columns. The soil water content was measured daily at different soil depths during drainage cycles to test the vertical drainage model. The root mean square difference between the simulated and measured volumetric soil water contents across the three replicates ranged between 0.0039 and 0.0471 cm^3/cm^3. Excellent estimation was obtained for soil water content during the drainage cycles for columns (1 and 2) at all depths with the nRMSE ranging from 2.6212 to 6.4606 cm^3/cm^3. While for column (3), the soil water content was at an excellent estimated level except at the depths of 12 cm and 16 cm where it was estimated as good. The simulation results obtained revealed that the SR2004 overestimated the soil water content during the drainage cycle, thus, the SR2004 model needs modification to perform better regarding Vertisols.

Keywords: Vertical Drainage, DSSAT, Vertisols.

1. Introduction

The increasing competition for water has led to a pressing need for a better use and management of water resources so that the needs of the people can be met properly. Ones of the major users of water are the agricultural irrigated crops (Ines et al., 2001). A water balance equation can be used to describe the flow of water in and out of a system. A system can be one of several hydrological domains, such as a column of soil or a drainage basin. It can be used in the design of subsurface drainage systems which may be horizontal (i.e. using pipes, tile drains or ditches) or vertical (drainage by wells). To estimate the drainage requirement, the use of hydrogeological water balance and groundwater models may be instrumental (Singh, 1998).

A number of water balance models exist which have different input requirements and achieve slightly different outcomes. All water balance models are aimed at estimating the different components of the water balance such as soil evaporation, deep drainage and runoff. Modeling helps identifying the factors (such as soil properties and weather variables) that may be confounding in experimental studies (Connolly et al., 2002). A model is similar to but simpler than the system it represents. Model validity is an important issue in modeling, where it includes simulating the model under known input conditions and comparing the model output with the system output. Mathematical model classifications include deterministic (input and output variables are fixed values), or stochastic (at least one of the input or output variables is probabilistic); static (time is not taken into account) or dynamic (time-varying interactions among variables are taken into account). Typically, simulation models are either stochastic or dynamic (Law and Kelton, 1991; Nelson. 1995). The accuracy of the models depends on the correct estimation of the input data and on their simplifying assumptions (Panigrahi and Panda, 2003).

The Decision Support System for Agrotechnology Transfer (DSSAT) helps decision-makers analyze complex alternative decisions by reducing the time and human resources required (Tsuji et al., 1998). The DSSAT is a suite of crop models sharing a common simulation of soil processes. Soil water drainage is estimated based on a tipping bucket approach. Drainage takes place if the soil water present in the layer exceeds its field capacity. For the estimation of the soil water dynamics during vertical drainage, a functional model is used. Functional models such as DSSAT need less input than the mechanistic models such as hydraulic conductivity function for each soil layer (Suleiman and Ritchie, 2003). The change in the soil water content caused by vertical drainage is calculated by multiplying the drainable soil water by a coefficient (C, the fraction of drainable soil water that can be drained on a day) (Suleiman and Ritchie, 2003). Ritchie et al. (1986) assumed that C is the function of the soil porosity. Ritchie (1998) assumed that C can be assumed to be constant of 0.55 $days^{-1}$ or different soils, while other studies such as (Gabrielle et al., 1995; Gerakis and Ritchie, 1998) found that the DSSAT drainage model must be calibrated in order to give good estimates of the soil water drainage.

The Suleiman and Richie (2004) SR2004 model

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presented some modifications from the DSSAT vertical drainage model to improve the soil water dynamics estimation and the vertical drainage rate. The performance of the original DSSAT and of the modified DSSAT models as a whole was evaluated for two soils during the summer of 1997. The modified DSSAT with SR2004 equation estimated the daily soil water content reasonably well at the different depths throughout the drainage cycle (maximum root mean square difference (RMSD) < 0.013 m^3/m^3), outperforming the original DSSAT by reducing the RMSD 2–4 fold at most of the soil depths (Suleiman and Richie, 2004).

Vertisols or cracked soils are clay-rich soils that shrink and swell with changes in the moisture content. Among the ten orders of the soils recognized in Soil Taxonomy (Soil Survey Staff, 1992), Vertisols are recognized by their propensity to shrink when dried and to swell when wetted. During dry periods, the soil volume shrinks, and deep wide cracks form (Rycroft and Amer, 1995). Vertisols and the associated soils cover approximately 2,570,000 million m^2 of the earth's surface in seventy-six countries (Dudal and Bramao, 1965). Vertisols form an important part of the agricultural land in Jordan. This soil occupies more than half of the cultivable land in northern Jordan (Battikhi et al, 2010). Due to the properties of these soils, they face various agricultural and engineering problems. When properly managed, they are productive. Although during the first rain or irrigation of the soil, the water infiltrates quickly to large depths via large cracks, subsequent infiltration and permeability are very low. Poor drainage may be a problem and crops may become waterlogged. Since changes in the soil water content is the main governing factor for the shrinking and swelling of soils and the formation of cracking, measuring the soil water content is equally important to measuring the cracks. Numerous studies have been conducted on Vertisols in Jordan with different purposes.

In a study on Vertisols at Mushaqar Agricultural Research Station, Suleiman (1994) found that the bulk density increased from 1.01 to 1.19 g/cm^3 when volumetric water decreased from 40.4% to 24.51%, and the tillage tended to the Vertisols moisture storage from rainfall. This effect was reduced when residues were present on the soil surface. The surface soil water content was higher with the moldboard plow treatment than with the chisel plow treatments. Significant differences disappeared when the soil was too wet (i.e. water content by volume is more than 35 %), or too dry (i.e. water content by volume is less than 10 %), while residue incorporation had no significant effect on the water content. In Jordan, several other studies have been carried out on Vertiosls characterization and management such as Abu-Hammad, 1993; Suleiman, 1994; Battikhi et al., 1998; however, there has been no attempt to evaluate the water balance of any crop simulation models for Vertisols. Therefore, this study is aimed at evaluating the SR2004 vertical drainage model of DSSAT for Vertisols in Jordan.

2. Materials and Methods

2.1 Suleiman and Ritchie (2004) Model Description

Understanding the movement of water in a saturated soil is important in drainage. Darcy's equation works well in describing the soil water flow during vertical drainage for homogeneous soils with a uniform initial soil water content (Youngs, 1957a and b; Philip, 1957). It can be written as:

$$Q = \frac{-KA(h2 - h1)}{z2 - z1} \quad \text{......} \quad 1$$

where Q is the quantity of water per second such as in cubic centimeters per second, often called the "flux"; K, centimeters per second, is the "hydraulic conductivity" (the law defines K); hydraulic heads h1 and h2 and distances z1 and z2 are as shown in Figure1. The reference level here is x=0. The head h1 is the hydraulic head for all points at the bottom of the soil column, that is, at z= z1, and similarly, the head h2 applies to all points at the top of the soil column, z = z2. The length of the column is z2 -z1 = L (Kirkham and Powers, 1972).

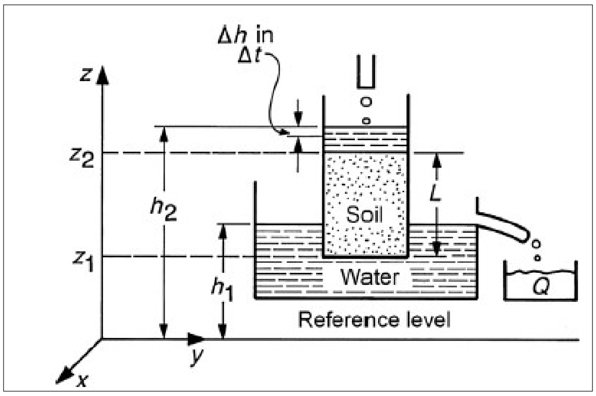

Figure 1. Illustration of Darcy's law. From Kirkham and Powers (1972).

The hydraulic gradient may be assumed to be 1 for the vertical saturated flow or for the soil water flow during vertical drainage without serious errors (Black et al., 1969). Based on such assumption, the soil water flow can be described as (Gabrielle et al., 1995):

$$q = K(\Theta) \quad \text{......} \quad 2$$

When a layer of soil, initially at a uniform water content Θs, has its surface covered, the initial. Assuming that the soil water content is uniform with depth (for each layer) throughout the drainage cycle, the soil water content of a soil layer subject to (the initial and boundary conditions), may be assumed to have an exponential relationship with time (Ritchie, 1985) as:

$$\theta = \theta dul + (\theta s - \theta dul)exp(-Ct) \quad \text{......} \quad 3$$

where C (d^{-1}) is a constant that can vary greatly among soils, and is related to the slope of the drainage curve (Ritchie and Amato, 1990). In DSSAT 4.0,

$$\frac{d\theta}{dt} = -C(\theta - \theta dul) \quad \text{......} \quad 4$$

Equation (4) is used to simulate the daily soil water dynamics caused by vertical drainage using a dt of one day. The minimum value of C in a soil profile is assigned to the whole profile. The soil water drainage of each layer in the profile is assumed to move out of the profile without cascading through the different layers if no restricted layers exist. To study C and its values for different soils, an analysis of soil water redistribution for a couple of days during vertical drainage subject to the initial and boundary conditions mentioned above is presented in Suleiman and Ritchie (2004). Considering that C1 is the fraction of drainable soil water that can be drained from a soil layer on the first day (d^{-1}) subject to (the initial and boundary conditions mentioned above), Eq (4) can be written as:

$$\Delta\theta = -C(\theta_s - \theta_{dul}) \quad \text{......} \quad 5$$

Although using C1 in Eq. (3) and Eq. (5) would produce different results because of the large time step (1 day), theoretically, a value of C1 that gives the correct soil water content after one day of drainage using Eq. (5) can be found for every soil. A quadratic polynomial relationship was developed to estimate C from Θ_{dul}. This equation may be written as:

$$C = 3\theta_{dul}^{2} - 2.6\theta_{dul} + 0.85 \quad \text{......} \quad 6$$

During free drainage, the amount of drainage from a soil layer subject to the initial and boundary conditions depends not only on its hydraulic properties and initial water content, but also on its position in the profile.

The incoming water flow (Qi) defined as the amount of water that drains from and through one layer to the other is the contributor to this vertical soil water dynamics pattern. To account for the impact of the incoming water flow from the above layer on the change of the soil water content of a certain layer during drainage, a new coefficient (F) was added to Eq (4) as follows (Suleiman and Ritchie, 2004):

$$\frac{d\theta}{dt} = FC(\theta - \theta_{dul}) \quad \text{......} \quad 7$$

Having in mind that (1) when Qi = 0, F has to be 1 and (2) when Qi = Ks, F has to be 0, a generic relationship between F and Qi was introduced as follows when Qi <= Ks:

$$F = 1 - \frac{\ln(Q_i + 1)}{\ln(K_s + 1)} \quad \text{......} \quad 8$$

if Qi > Ks, F is 0.

During a drainage cycle, the incoming flow to a particular layer is equal to the cumulative drainage (from the layers above), and can be calculated by summing the change in the soil water content for all the layers (above that particular layer) multiplied by their thickness.

2.2 Laboratory Experiment

A soil sample from Maru Agricultural Research Station Vertisols was collected from the surface layer to evaluate the performance of the drainage model in simulating the soil water dynamics during vertical drainage. The Maru Station is located in the Northern region of Jordan (32°33' N; 35°51' E) with an elevation of 530 m above the sea level. Its soil is classified as: fine, smectitic, thermic, typic chromoxerert. The land slope is less than 6 % (Taimeh and Khreisat, 1988).

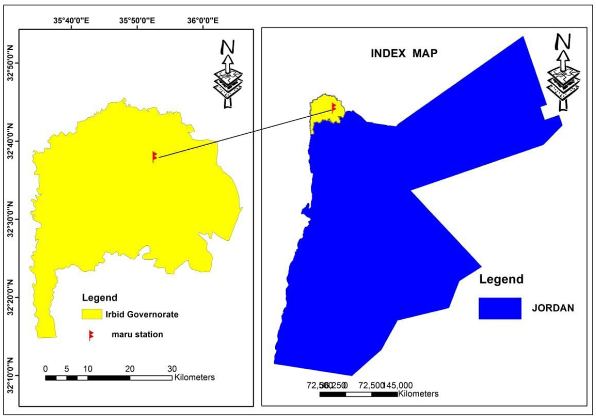

Figure 2. Maru location

Soils of Maru is clayey (59.2 % clay, 12.7 sand, and 1.09 g cm^{-1} bulk density), and dark reddish brown. The organic matter content (1.16 %) was determined by the potassium dichromate method (Schollenberger, 1931).

The soil sample was air-dried, sieved through a 2-mm screen, and was then assembled uniformly into three insulated poly vinyl chloride (PVC) columns of 150 cm in height and 30 cm in diameter by adding soil in small increments while shaking the columns continuously until the soils stopped settling (Suleiman and Ritchie, 2004).

Thirteen 20-cm time domain reflectometry (TDR) probes were installed horizontally at the depths of 4, 8, 12, 16, 20, 30, 40, 50, 60, 70, 100, and 120 cm from the surface. The soil in the columns was saturated from the bottom using a constant head of 150 cm (Suleiman and Ritchie, 2004). These soils were allowed to drain for sixteen days with the surface covered, during this time the soil water content was monitored on a daily basis at these thirteen soil depths. The column was closed by using valve and gravel sand underneath to prevent any soil loss. A digital balance was placed under each column to monitor the total weight of the soil columns on a daily basis at the same time of the soil moisture readings as shown in Figure 3.

Figure 3. Column of soil and the digital balance.

2.3 Soil Physical and Chemical Characteristics

The Maru soil is alkaline because it is mostly derived from calcareous or base-rich parent material pH values ranging from 7.3 to 7.4 (Table 1). The electrical conductivity values of the saturation extracts ECe ranged from 0.28 to 0.46 dS m^{-1}, indicating that the soil is not saline (Table 1). Generally, shrink-swell soils have a relatively high Cation Exchange Capacity (CEC) which ranged from 22.5 to 24.4 cmol kg^{-1} (soil). The basic property of Vertisols that endows them with a high moisture-holding capacity is their clay content, which commonly lies between 40 to 60 %, but it can be as high as 80 % (Dudal 1965, De Vos and Virgo 1969).

Table 1. Soil properties of Maru Site.

Depth (cm)	CEC (cmol kg^{-1})	Ph	EC (dS m^{-1})	Sand (%)	Silt (%)	Clay (%)	Bulk Density (g cm^{-3})
0-20	24.4	7.3	0.5	12.7	28.1	59.2	1.1
20-60	23.5	7.3	0.3	12.8	29.0	58.2	1.1
60-120	24.2	7.3	0.3	13.4	29.9	56.7	1.3
120-150	22.5	7.4	0.4	13.2	27.5	59.3	1.3

The pipette method was used to determine the soil texture (Franzmeier et al., 1977). A core sampler is used with several cylindrical rings of known dimensions driven manually into the soil. The extruded soil from the core sampler or the soils and rings are weighed and oven –dried to a constant weight at 105 °C . The oven- dry weight divided by the volume of the core sampler or cylindrical ring is the bulk density usually expressed in g/cm³ (Rawls and Brakensiek, 1982).

2.4 Volumetric Water Content

The measurements of the volumetric water content were taken using Time Domain Reflectometer (TDR), and were performed manually by taking samples from the site, taking into consideration the calibration between the observed readings and the device. The relationship between the volumetric soil water content, θv, and the soil water potential, ψ obtained by the ceramic plate method can be seen in the Figure 4.

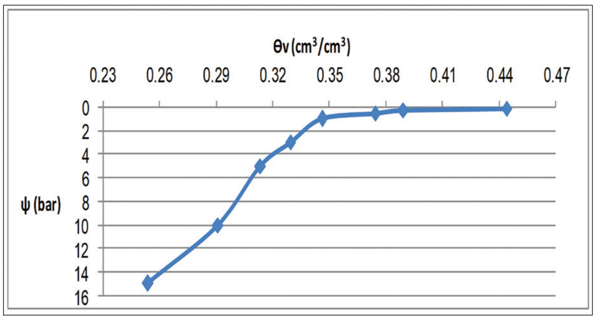

Figure 4. Soil characteristic curve of soil sample.

The calibration of the TDR was performed using samples of the gravimetric water content and the TDR device as shown in Figure (5), where the samples were taken every day for twelve days coupled with TDR readings followed by finding R^2 which was 0.98, 0.91, 0.80 for columns 1, 2 and 3, respectively.

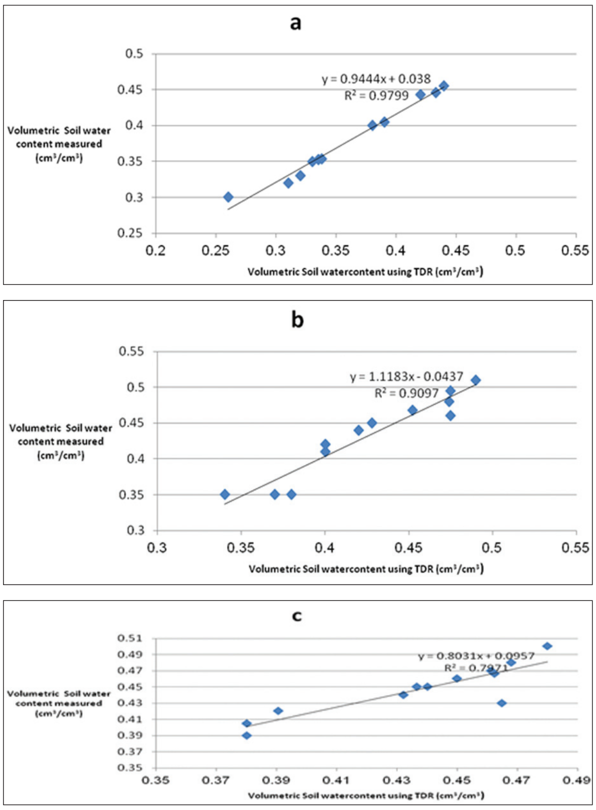

Figure 5. The calibration of TDR device for a. column 1, b. column 2 and c. column 3.

2.5 Statistical Analysis

Different statistical criteria for determining the goodness of fit for the simulation model were used to evaluate the output data and to compare the measured and the predicted results. Root mean square error (RMSE), normalized root mean square error (nRMSE) (Loague and Green 1991), and the degree of agreement index (d-index) (Willmott et al., 1985) were implemented. The predicted values are considered excellent when the nRMSE is less than 10 %. They were considered good when nRMSE ranged from 10 % to 20 %, fair if greater than 20 % to less than 30 %, and poor if nRMSE exceeded 30 % (Jamieson et al., 1991).

For d-index, the better the agreement for a certain variable between the observed and simulated values, the closer the index value is to one. The RMSE, nRMSE and d can be computed as follows:

$$\text{RMSE}= \sqrt{\sum_{i=1}^{n}(Pi-Oi)^2/n}$$

$$\text{nRMSE}= \text{RMSE}*100/M$$

$$d = 1-\left(\sum_{i=1}^{n}\frac{(Pi-Oi)^2}{n}/(\sum_{i=1}^{n}(|P'i|+|O'i|)^2\right)$$

where Pi and Oi indicate predicted and observed values for the studied variable, respectively, n is the number of used observations, M is the mean of the observed variable, P'i=Pi-M and O'i=Oi-M.

3. Results and Discussions

3.1 Suleiman and Ritchie (2004)

The volumetric soil water content (Θv) at the end of the drainage cycle (day 16) at each soil depth was assumed to be the drained upper limit (dul) at that depth. The dul in column (1) ranged from 0.39 to 0.42 cm³/cm³ and at column (2) the dul ranged between 0.38 and 0.42 cm³/cm³, while for column (3) it fluctuated from 0.31 to 0.46 cm³/cm³ (Table 2).

Boote et al. (2008) concluded that the tipping bucket soil water balance model in DSSAT generally works better when the soil water-holding properties (a drained upper limit (dul), and a lower limit of plant-extractable soil water, (ll)) are estimated properly, and when the rooting depth and root length distribution are predicted adequately. Nevertheless, the approach is inherently more than the soil water flow calculations used in many hydrological models such as HYDRUS-1D, which can estimate soil moisture distribution in the soil profile with more accuracy (Scanlon et al., 2002).

Table 2. Drained upper limit (dul) (cm³/cm³) in three soil columns.

Depth (cm)	Column 1	Column 2	Column 3
	Θv at F.C(dul) (cm³/cm³)	Θv at (dul) (cm³/cm³)	Θv at (dul) (cm³/cm³)
4	0.380	0.380	0.380
8	0.380	0.380	0.381
12	0.380	0.432	0.430
16	0.380	0.437	0.437
20	0.380	0.391	0.391
30	0.380	0.315	0.315
40	0.445	0.380	0.380
50	0.429	0.462	0.463
60	0.421	0.465	0.463
70	0.419	0.461	0.460
80	0.392	0.424	0.436
100	0.392	0.426	0.436
120	0.391	0.420	0.446

The C values estimated from dul for the SR2004 model ranged from 0.287 to 0.293 days^{-1} for column 1, and from 0.287 to 0.295 days^{-1} for the column 2. They ranged from 0.287 to 0.329 days^{-1} for column 3 (Figure 6). The C values did not change much for the three columns at the different soil depths because C is dependent on dul which did not vary a lot in the different columns. The highest C value was at the soil depth of 40 cm of column 3 because it had the lowest dul as C and is inversely related.

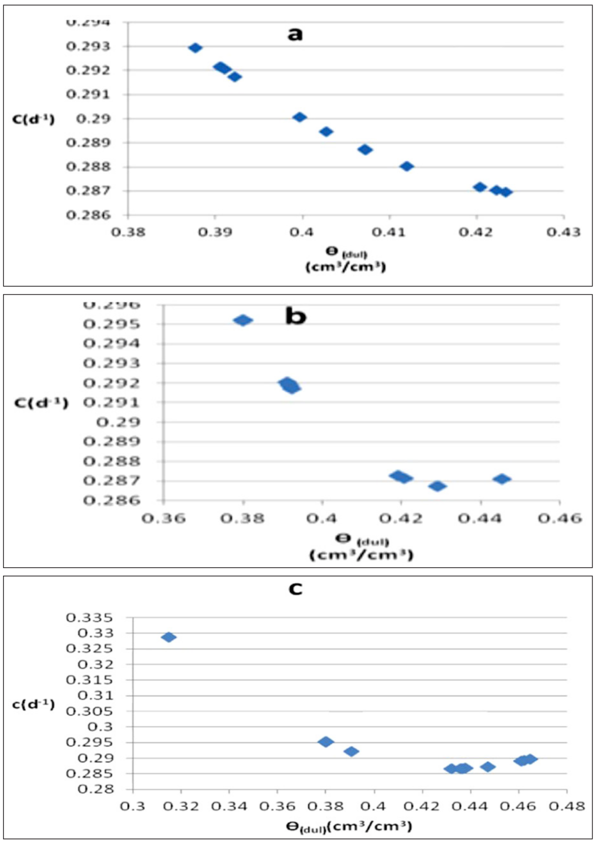

Figure 6. Relationship between C (SR2004) and Θ dul for the three columns of Vertisols for a. column 1, b. column 2, and c. column3.

3.2 Measured Volumetric Soil Water Content:

Column (1) and column (2) had a higher initial soil water content because of the Vertisols having a high water-holding capacity. The initial soil water content in column 1 and column 2 was similar ranging from 0.52 cm^3/cm^3 at the depth of 4 cm and 0.44 cm^3/cm^3 at depth of 120 cm, while in column 3 the volumetric soil water content ranged between 0.38 and 0.58 cm^3/cm^3 at different depths (Figure 7 and 8). The initial Θv for column (1) was higher at the soil depths of 4, 8 and 12 cm than at the lower depths.

At the end of the drainage cycle, Θv was the least at the depth of 4 cm, while at the depth of 40 cm Θv was the highest. The initial value of Θv for column (2) was the highest at the depth of 8 cm and the lowest at the depth of 120 cm. At the of the drainage cycle, the lowest Θv was at an 8 cm soil depth, while the highest Θv was at a soil depth of 30 cm. The initial value of Θv for column (3) was the highest at the depth of 20 cm and lowest at the depth 40 cm. At the the drainage cycle, the lowest Θv was at a 4 cm soil depth, while the highest Θv was at a soil depth of 50 cm. Soil moisture content decreases faster on the first three days.

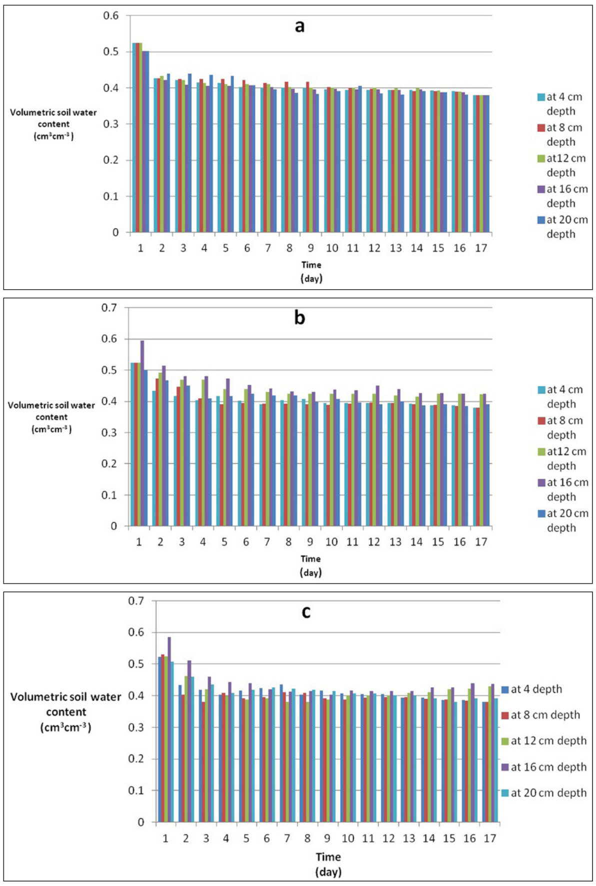

Figure 7. Volumetric Soil Water Content at the depths of (4, 8, 12, 16, 20 cm) for a. columns 1, b. columns 2, and c. columns 3.

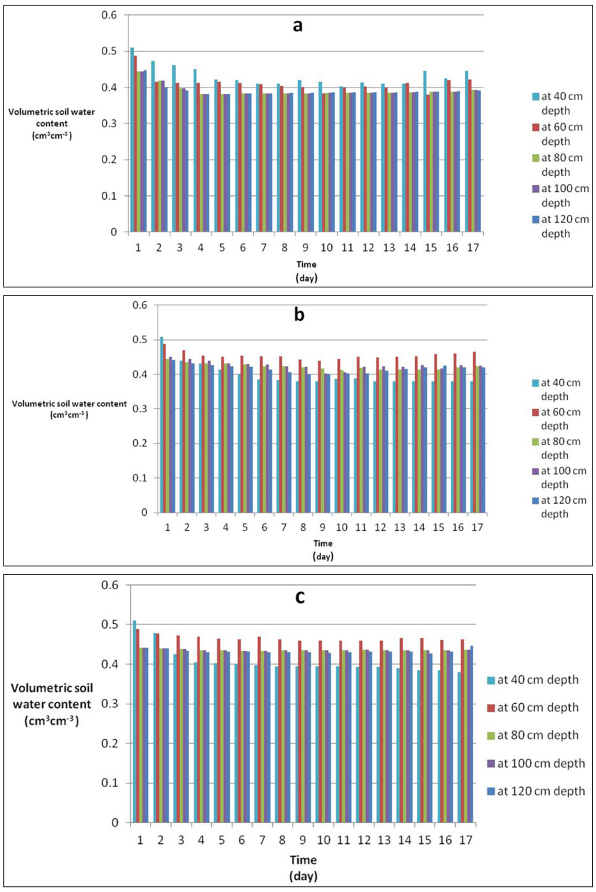

Figure 8. Volumetric Soil Water Content at the depths of (40, 60, 80, 100, 120 cm) for a. columns 1, b. columns 2, and c. columns 3.

3.3 Comparison between the Simulated and Measured Soil Water Content

Soil moisture simulations from SR2004 models were evaluated to determine the accuracy of the simulated soil water content. The differences between the simulated and measured Θv are shown in Figures 9, 10, and 11. The simulated value of the soil water content Θv column (1), column (2) and column (3) overestimated the soil water content for Vertisols at the different soil depths.

The soil water content at all depths was overestimated except at the depths of 4, 8, 12, and 16 cm, where it was close to the measured values. For the first four days and at all the soil depths except at 4, 16, and 20 cm,,Ritchie (1998) estimated the soil water content relatively well in Case 3, then tended to underestimate it for the rest of the days. Concerning, the soil depths of 9 and 12 cm in Case 3, Ritchie (1998) overestimated the soil water content. For column (1) at the soil depth of 4 cm, the measured Θv was more than the simulated Θv within the first four days, and from day ten to sixteen.

The simulated Θv after the depth of 40 cm was more than the measured ones throughout the drainage cycle. The simulated Θv after depth 50 cm was more than the measured Θv. The simulated change in Θv showed a similar pattern of the three columns with the highest change being on day 1, and the least change being at the last day of the drainage cycle. In a study done in Spain, the original DSSAT drainage simulation was unable to reproduce the small drainage amounts occurring over extended periods of time (Martinez et al., 2013). It exhibited a steep curve with strong variations of drainage in a short period of time. The drainage simulation improved after the optimization. In their study, the original DSSAT underestimated the soil water content at all depths from surface to 170 cm.

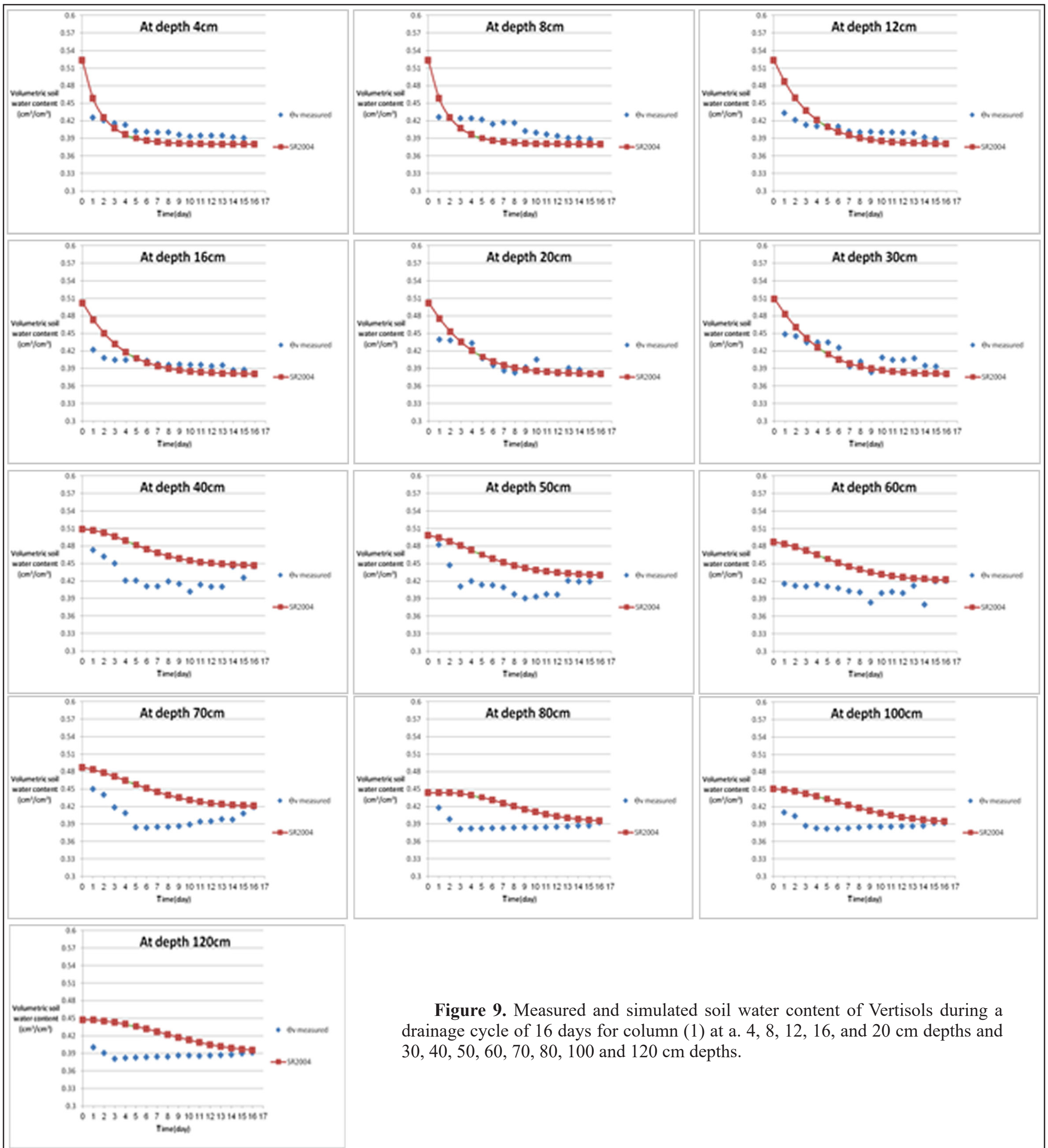

Figure 9. Measured and simulated soil water content of Vertisols during a drainage cycle of 16 days for column (1) at a. 4, 8, 12, 16, and 20 cm depths and 30, 40, 50, 60, 70, 80, 100 and 120 cm depths.

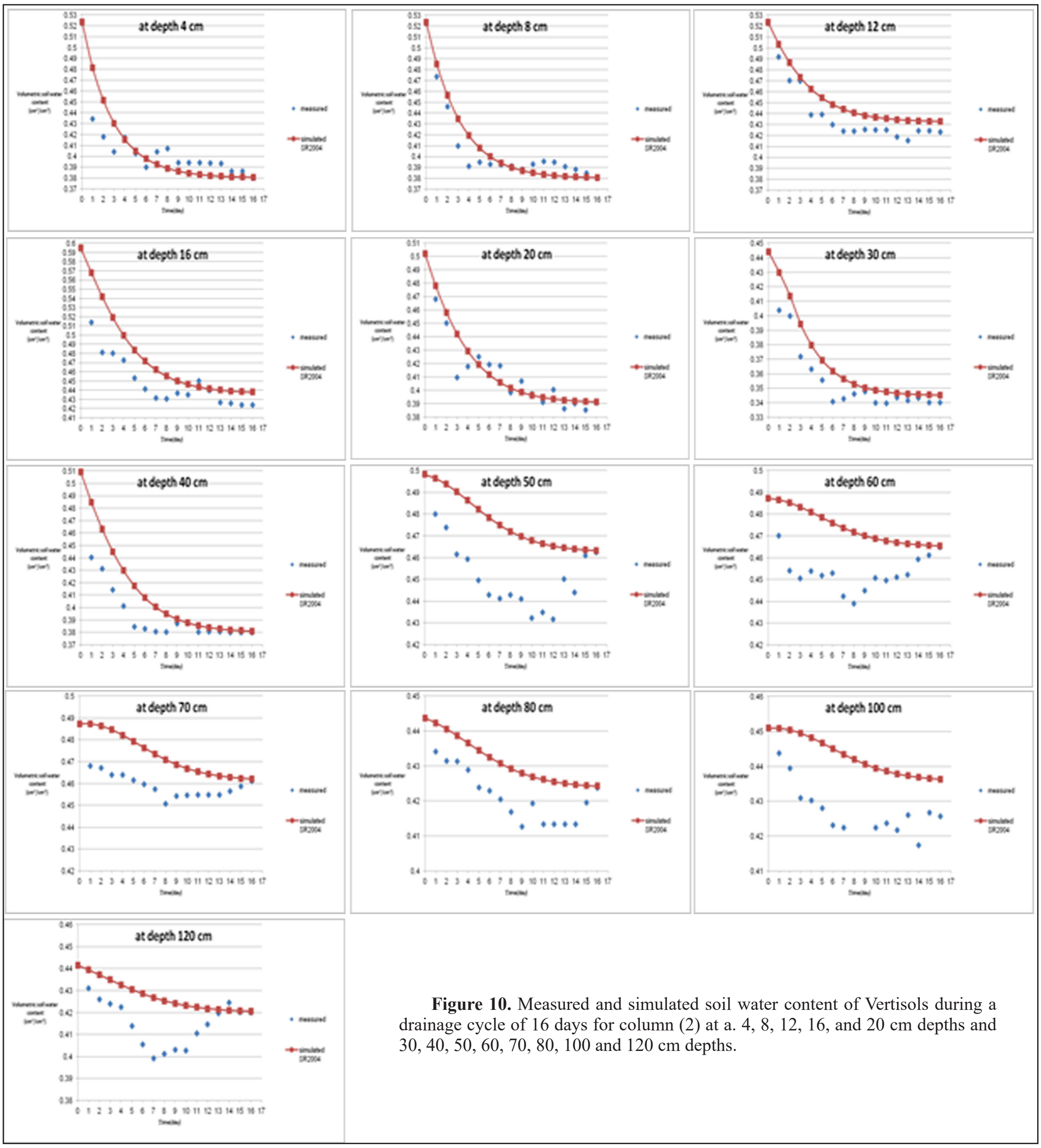

Figure 10. Measured and simulated soil water content of Vertisols during a drainage cycle of 16 days for column (2) at a. 4, 8, 12, 16, and 20 cm depths and 30, 40, 50, 60, 70, 80, 100 and 120 cm depths.

The root mean square difference (RMSD) between the simulated and measured soil water content, ranged from 0.0103 to 0.0279cm^3 m^{-3} for column (1). For column (2), it was between 0.0098 and 0.028, and for column (3) it ranged between 0.0039 and .0471 (Table 3). This demonstrates that the drainage model overestimated the soil water contents at different depths and days for the Vertisols. In the lab experiment, the RMSD for column (1) was 0.0177, 0.0118, 0.0279, 0.0108, 0.0103 and 0.012 cm^3 cm^{-3} at 4, 20, 40, 80, 100 and 120 cm soil depths, respectively. One would conclude that the SR2004 at column (1) performed best at the depth of 100 cm, then at 80 cm, 20 and 120 cm, respectively. The least was at 40 and 4 cm depths. While, for column (2) the RMSD was 0.0175, 0.0103, 0.0206, 0.0098, 0.0192 and 0.0146 cm^3 cm^{-3} at 4, 20, 40, 80, 100 and 120 cm soil depths, respectively.

One would conclude that the SR2004 at column (2) performed best at 80 cm, then at 20 cm, 120 and 4 cm, 100 cm, respectively. The least was at a 40 cm depth. Also, the RMSD for column (3) was 0.0223, 0.0131, 0.0165, 0.0039, 0.0041 and 0.0073 cm^3 cm^{-3} at 4, 20, 40, 80, 100 and 120 cm soil depths, respectively. One would conclude that the value for SR2004 in column (3) performed best at 80 cm, 100 cm, 120, 20 and 40 cm, respectively, and the least performance was at a 4 cm depth.

The results of a study conducted by (Suleiman and Richie, 2004) showed that the RMSD between the simulated (by the DSSAT) and the measured soil water contents, ranged from 0.002 to 0.37 m^3 m^{-3} at the end of the drainage cycle for the sandy loam soil, and from 0.003 to 0.27 m^3 m^{-3} for the loamy soils. The RMSD between the simulated water contents using the modified DSSAT and the measured soil water contents, ranged from 0.002 to 0.013 m^3 m^{-3} at the end of the drainage cycle for the sandy loam soil and from 0.002 to 0.01 m^3 m^{-3} for the loamy soils.

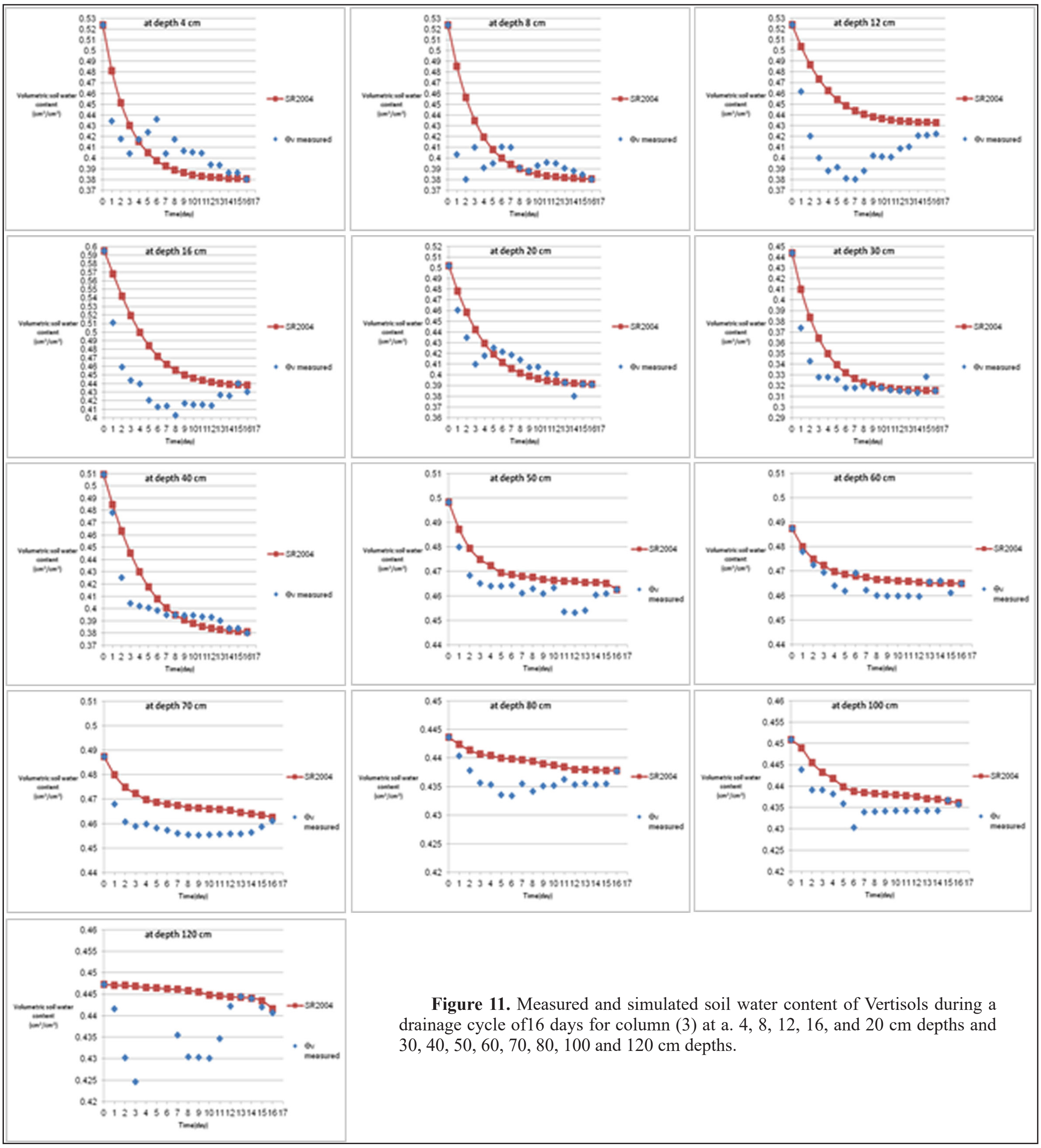

Figure 11. Measured and simulated soil water content of Vertisols during a drainage cycle of16 days for column (3) at a. 4, 8, 12, 16, and 20 cm depths and 30, 40, 50, 60, 70, 80, 100 and 120 cm depths.

Based on nRMSE, the simulation of soil water content which resulted from the SR2004 model, exhibited excellent simulation for volumetric soil water content in Vertisols in column (1) and column (2) during the drainage cycle at all depths with nRMSE ranging from 2.6212 to 6.4606 cm^3/cm^3. The simulation for volumetric soil water content was excellent for column (3) except at the depths of 12 and 16cm where they were estimated as good.

A value of 1 for d means a perfect agreement, while a value of 0 for d means a poor agreement (Krause et al., 2005). The d-test was conducted between the simulated values and the values ranging between 0.7437 and 0.9687 for column (1), for column (2) between values from 0.8159 to 0.9857, and for column (3) between values ranging from 0.3802 to 0.9546. The perfect agreement between the measured and the simulated values was for column (2) as in (Tables 3, 4 and 5).

Table 3. Root mean square difference (RMSD) and some statistical indices between the simulated and measured soil water contents for the Vertisols for column 1.

	RMSE (Column 1)	n RMSE (Column 1)	d-test (Column 1)	Simulation Level
Depth	SR2004	SR2004	SR2004	SR2004
4	0.0177	4.3354	0.9349	Excellent
8	0.0205	4.9634	0.9153	Excellent
12	0.0198	4.8176	0.9198	Excellent
16	0.0189	4.6776	0.8988	Excellent
20	0.0118	2.888	0.9687	Excellent
30	0.0166	3.9828	0.942	Excellent
40	0.0279	6.4606	0.8898	Excellent
50	0.024	5.703	0.8717	Excellent
60	0.0246	5.9839	0.7437	Excellent
70	0.0258	6.3347	0.7805	Excellent
80	0.0108	2.7721	0.9208	Excellent
100	0.0103	2.6212	0.9321	Excellent
120	0.012	3.0807	0.9083	Excellent

Table 4. Root mean square difference (RMSD) and some statistical indices between the simulated and measured soil water contents for the Vertisols for column 2.

	RMSE (Column 2)	n RMSE (Column 2)	d-test (Column 2)	Simulation Level
Depth	SR2004	SR2004	SR2004	SR2004
4	0.0175	4.2898	0.9384	Excellent
8	0.0119	2.912	0.9764	Excellent
12	0.0143	3.2474	0.9778	Excellent
16	0.0281	6.1638	0.964	Excellent
20	0.0103	2.4919	0.9745	Excellent
30	0.0127	3.543	0.9857	Excellent
40	0.0206	5.155	0.9168	Excellent
50	0.0259	5.7112	0.9508	Excellent
60	0.0219	4.8166	0.963	Excellent
70	0.0142	3.0883	0.9856	Excellent
80	0.0098	2.3113	0.9416	Excellent
100	0.0192	4.5076	0.8798	Excellent
120	0.0146	3.5152	0.8159	Excellent

Table 5. Root mean square difference (RMSD) and some statistical indices between the simulated and measured soil water contents for the Vertisols for column 3.

	RMSE (Column 3)	n RMSE (Column 3)	d-test (Column 3)	Simulation Level
Depth	SR2004	SR2004	SR2004	SR2004
4	0.0223	5.3910	0.8979	Excellent
8	0.0297	7.3782	0.8342	Excellent
12	0.0471	11.3947	0.6512	Good
16	0.0460	10.4566	0.7832	Good
20	0.0131	3.1414	0.9546	Excellent
30	0.0179	5.3857	0.9353	Excellent
40	0.0165	4.0553	0.9469	Excellent
50	0.0077	1.6472	0.8665	Excellent
60	0.0045	0.9667	0.9014	Excellent
70	0.0105	2.2873	0.6620	Excellent
80	0.0039	0.8907	0.5164	Excellent
100	0.0041	0.9497	0.8099	Excellent
120	0.0073	1.6869	0.3802	Excellent

4. Conclusions

Water balance is a useful tool in crop models that can be used to find the best agricultural water management practices that maximize the crop yield and water productivity while avoiding the need for costly field experiments. An evaluation of the SR2004 model for the simulation of vertical drainage in Vertisols was conducted in this study. From the current results, the root mean square difference (RMSD) between the simulated and measured Ɵv, ranged from 0.0103 to 0.0279cm^3 cm$_{-}^{3}$ for column (1), and between 0.0098 and 0.0281 for column (2). For column (3), it ranged between 0.0039 and 0.0471.

Excellent estimation was obtained for the soil water content during the drainage cycles for columns (1 and 2) at all depths with nRMSE ranging between 2.6212 and 6.4606 cm^3/cm^3. While for column (3) estimation was excellent except at the depths of 12 cm and 16 cm where it was estimated as good.

The index of agreement (d) between the simulated and the measured values for the volumetric soil water content indicated that the measured and SR2004 simulated values were very similar for column (2) at all depths, then column (1). While in column (3) and at the depths of 60, 80 and 120 cm, the values of d index were very low. Generally, the SR2004 model overestimated the soil water content during the drainage cycle, thus it needs modification to perform better concerning Vertisols.

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