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Testing of Two Algorithms in Simulating Soil Water Dynamics in a Drip Irrigated Tomato under Different Irrigation Frequencies and Depths in Ogbomoso, Nigeria

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Abstract: A good knowledge of soil water dynamics in the plant root zone is very important in developing modern environmental-friendly drip irrigation practices. The objective of this study was to determine the adequacy of soil water balance (WB) approach and HYDRUS 1D model in simulating soil water dynamics of an Alfisol grown to tomato (*Lycopersicon esculentum* M.) under different irrigation regimes in Southwestern Nigeria during the 2014 dry season. The experiment was a 2 factorial, laid out in a randomized complete block design (RBCD), with split-plot arrangement in three replications. The main plot consisted of irrigation frequency: 7 day (F1), 5 (F2) and 3 day (F3) intervals, while the subplots were 100 (D1), 75 (D2) and 50% (D3) of water requirement (ETc). Soil water content (SWC) of the 0-5, 5-10, 10-20 and 20-30 cm layers of the experimental plots was monitored every two days using gravimetric technique. Sequential daily soil water balance (SWB) was used to estimate excess, deficit and total soil water availability (RSW) in the soil profile while HYDRUS 1D model was used to simulate soil water content (SWC) of each layer. The observed total soil water (TSW) curve followed the trend of the RSW estimated by the SWB approach, with Willmott`s index of agreement (*d*) of 0.94. The HYDRUS 1D model performance when calibrated using the treatment combination of full irrigation and 3 days irrigation interval (F3D1) showed that the root mean square error (RMSE) ranged from 4.74 to 6.96; *d* ranged between 0.30 and 0.50; while percent bias (PBias) ranged from -3.23 to -23.51. The line 1:1 graph indicated that the model overestimated the soil moisture content for all soil layers except at 5-10 cm soil layer. The adequacy results using the remaining eight treatments showed that the RMSE for all soil layers varied between 4.38 and 7.15, *d* values were between 0.35 and 0.55, while PBias varied from -0.47 to -23.62. The study showed that both the SWB approach and HYDRUS 1D model can be successfully used to simulate soil water dynamics of agricultural fields in any region of this humid tropical climate. However, validation studies are required in another growing season.

Key words: Drip irrigation frequency · Soil water dynamics · Soil water balance · HYDRUS 1D model · Water management · Vegetable

INTRODUCTION

Irrigated agriculture is the biggest consumer of water in the world, accounting for more than 70% of global withdrawals and in some countries more than 90% [1]. As important as water is, it could be sustained for crop production through the use of irrigation agriculture to ensure all year production and to reduce over dependence on seasonal rainfall. In areas with dry climates, crop irrigation requires from 50 to 85% of total water use ([2]; [3]). The efficient utilization of water in agriculture and tackling the issue of optimal water use are needed to balance water supply and demand [4]. The appropriately use of these scarce water resources in the design and

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management of drip irrigation system requires the understanding of soil water content, it dynamics and redistribution within the wetted soil volume. In a drip irrigation method, some parts of soil usually become wetted; depending on discharge of emitter, distance among emitters, distance of laterals from each other, type of soil, slope of land and period of irrigation [5]. Abouzeid [6] examined the effect of initial soil water content and the pulsed water application from the emitters on soil water dynamics to drip irrigation management.

The behaviour of water in the soil alongside with the movement of irrigated water through the unsaturated zone allowed interaction between complex ecological system and hydrological cycle which contribute to the development of eco-hydrologic and soil-plant-atmosphere models ([7]; [8]; [9]; [10]). In this context, the study of water balances (WB) has been very useful for better understanding of water dynamics in a soil profile and it has been intensively used in the evaluations of water relations in several cropping systems to determine the contribution of the different components to the final soil water status [11]. Several authors cite the WB as a convenient methodology to quantify the soil available water to plants (e.g. [12]; [13]; [14]; [11]). The WB equation is an expression of the mass conservation law applied to an elemental soil volume with the soil-atmosphere interface as the upper boundary and a plane passing through the crop rooting zone as the lower boundary [15].

Another model which has been widely used to simulate water and solute movement in agricultural fields is the one-dimensional HYDRUS model, known as HYDRUS 1D. The program numerically solves the Richards equation for variably-saturated water flow [16]. According to [17], HYDRUS 1D was simulated using the van Genuchten equation with an air entry value of 2 cm was adequate to estimate soil water contents and pressure heads for a silt loam soil profile located in Can Vila basin, in spite of the differences obtained between observed and predicted data, the results are comparable to those obtained by other authors (e. g. [18]; [19]), then it could be concluded that under natural conditions of silt loam soil profile, the algorithm of HYDRUS 1D solved correctly the Richards equation. Also, [20] compared the patterns in observed and simulated soil moisture contents to understand whether modeling leads to a substantial loss of information or complexity. The information measures of simulated soil moisture content were close to those of the measurements, indicating the successful simulation of patterns in the data. Hinckley *et al.* [21] in their work on aspect control of water movement on hill slopes near the rain–snow transition of the Colorado Front Range reported that simulation results of soil water content for north-facing and south-facing plots shows that the South-facing slopes have larger simulated soil-water contents relative to observed values at 5- and 20-cm depths and soil-water dynamics in response to melt pulses are overestimated to a greater degree than the north-facing slope. Based on these simulation results and the minimal sensitivity to melt flux reductions, it was suggested that the HYDRUS 1D not simulating the preferential flow component of unsaturated zone flux, are forcing all of the melt flux to move through the subsurface as matrix flow, thus causing the soil-water contents to be overestimated, in particular on the south-facing slope. Barão *et al.* [22] also worked on simulation of water dynamics in two irrigated soil in which the results for water content distribution obtained with HYDRUS, RZWQM and MOHIDLAND models were compared with field data. Results show a good agreement between model simulations and field measurements for the three models. There is scarce literature on modeling of soil water content in Nigeria. The objective of this study was to determine the adequacy of soil water balance (WB) approach and HYDRUS 1D model in simulating soil water dynamics of an Alfisol grown to tomato (*Lycopersicon esculentum* M.) under different irrigation regimes in Southwestern Nigeria during the 2014 dry season.

MATERIALS AND METHODS

Description of Experimental Site: The experiment was carried out at the Department of Agricultural Engineering Teaching and Research Farm of LadokeAkintola University of Technology, Ogbomoso, (8° 10^{1}N and 4°10^{1}E) in Southwest Nigeria. The experiments were conducted between February and June 2014 early cropping season. Ogbomoso is characterized by bimodal rainfall pattern, peaking in July and September with annual rainfall depth of about 1200 mm [23] while the mean annual maximum and minimum temperature are 33 and 28°C respectively. The climate of the area is cold and dry from November to March and then warm and moist from April to October, it could also be described as a hot humid tropical which falls in southern Guinea Savannah of Nigeria with mean relative humidity of about 74% all year round except in the month of December to February when it is low as a result of dry wind (harmattan) that blows from the north [24]. The main soil type of the experimental field is Alfisol, with sandy loam texture [25].

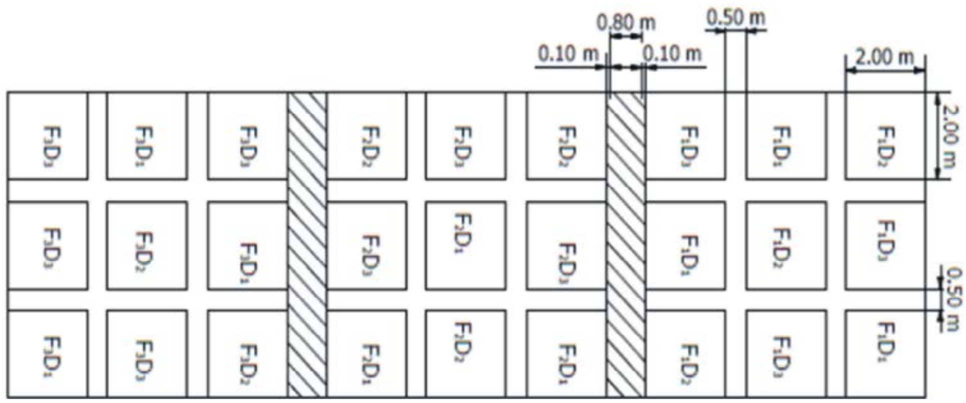

Fig. 1: Field layout of the experiment

Experimental Design and Field Management: The experiment was a 3 x 3 factorial laid out in Randomized Complete Block Design (RCBD) with a split plot arrangement in three replications. Irrigation frequency constituted the main plot while application depths were the subplots. The irrigation frequency treatments were F_1 (weekly), F_2 (every 5 days) and F_3 (every 3 days) while depth of irrigation application are 100 (D1), 75 (D2) and 50% (D3) of tomato water requirement. Marking out of plot and sub-plots were done according to the experimental design with each of the main block measuring 7 m × 7 m, separated by 1 m pathway and each subplot was 2 m × 2 m and 0.5 m apart, constituting a total area of 7.5 m × 25 m. The field layout is shown in Figure 1.

The field was ploughed and harrowed according to normal tillage operations. To allow easy transplanting of seedlings, the positions for the tomato seedlings were marked with pegs according to the recommended spacing of 0.5 x 1 m [26]. Apart from irrigation treatments, all other agronomic and management practices, such as weeding, fertilizer application (10 g / 0.26 m^2), crop protection, etc., remained the same in all the plots and sub-plots throughout the growing cycle.

Soil Sampling and Analysis: Prior to imposing the irrigation treatments, undisturbed soil samples were collected for the determination of physical properties using core samplers in the middle of soil layers 0-5, 5-10, 10-20 and 20-30 cm. Samples were kept in sealed plastic cans and transported to the laboratory for analyses. The samples were analyzed in the laboratory to determine soil bulk density [27], water retention at 0, -1, -6, -10, -33, -100, -500, -1000 and -1500 kPa were determined using undisturbed samples in Richard's pressure chamber [28] while the saturated hydraulic conductivity (Ksat) was determined using the constant-head permeameter [28]. Water retention parameters were fitted using [29] model through RETC program [29].

Soil Moisture Content Monitoring: Soil mositure monitoring during growth cycle were was carried out using gravimetric technique [30]. The depth of soil sample collected are 0-5, 5-10, 10-20 and 20-30 cm soil layers using soil auger every 2 days interval throughout the growing season. The sealed samples were weighed in the laboratory, thereafter the samples were oven dried at 105°C for 48 hours to determine the soil gravimetric moisture content. The soil volumetric water content was determined according to [31] using the values of bulk density already obtained proir to the conmmencement of the irrigation treatments.

Weather Data and Soil Water Balance: The maximum and minimum daily temperature as well as wet and dry-bulb temperature were measured *in situ*. The precipitation data were obtained using a rain gauge installed at the center of the field.

The sequential soil water balance (SWB) for the experimental field during the tomato growth period was calculated in EXCEL MICROSOFT® Spreadsheet developed by [32] according to the algorithm of [33], using the classical mass conservation equation.

$$\pm \Delta S = P + I - Etr + A - D - SR \quad (1)$$

where ΔS is the change in soil water storage in the 0.3 m soil layer, P is precipitation, mm; I is the irrigation, mm; ETr is real evapotranspiration, mm; A is capillary rise, mm, D is deep percolation below the 0.3 m depth, mm and SR is runoff, mm.

Table 1: Crop coefficient and lengths of developmental stages for transplanted tomato in the tropics

Crop	Total Growing Period (day)	Initial stage	Crop dev. Stage	Mid-season stage	Late season Stage
Tomato	120	28	32	40	20
Kc	-	0.45	0.75	1.15	0.8

Sources: [34]

The calculation sheet of [32] does not calculate separately all components of equation (1) it calculates the sum $A + D + SR$ and calls it excess (EXC) and since in our case, the water table is usually more than 5 m from the soil surface, hence A was considered as zero ($A = 0$), we have $EXC = D + SR$. Under dry conditions, i.e. when P < ETr and the available soil water is reduced, the balance calculates a deficit (DEF), corresponding to AWC reduction. Maps of variation of soil water which reveals the periods of excess and deficiency in soil water status were generated.

The maximum available water capacity (AWC), the difference between field capacity (FC) and permanent wilting point (PWP), for the experimental site was 47 mm for the 0-30 cm layer considered, while the average daily temperature and precipitation were used as climatic input data. The reference evapotranspiration, *ETo*, was computed in the Excel spreadsheet using Thornthwaite method and from the (K_C) values for tomato, the real crop evapotranspiration during the growing period was calculated. The crop coefficient value (K_C) for each growth stage of tomato was adopted from FAO Paper No 56 (Table 1) while the crop coefficient curve for entire tomato growth cycle was estimated using equation 2, as suggested by [34].

$$K_{ci} = K_{Cprev} + \left[\frac{i - \varepsilon \sum (L_{prev})}{L_{stage}}\right](K_{Cnext} - K_{Cprev}) \quad (2)$$

where K_{Ci}; is thecrop coefficient on day i; is the day number within the growing season (=1, …length of growing season; L_{stage} is the length of growth stage under consideration (days); L_{prev} is the sum of lengths of all previous stages (days); K_{Cnext} is the K_C value at the beginning of the next stage; K_{Cprev} is the K_C value at the end of the previous stages; ΣL_{prev} is the sum of lengths of all previous stages.

Hydrus 1D Model

Model Description: The HYDRUS 1D is a software package for simulating one-dimensional movement of water, heat and multiple solutes in variably saturated media. The detailed description of this model can be found in [16].

Model Calibration: The model was calibrated using input data parameters including soil hydraulic properties, crop parameters and climatic data. The soil input data are those parameters obtained from soil water retention data as well as soil bulk density, saturated hydraulic conductivity and volumetric soil moisture content monitored during the tomato growth cycle. Crop input data included the sowing date and the rooting depth during the growing period, which was obtained by using the root growth equation suggested by [35], considering a maximum root depth of 30 cm for tomato [36] and a planting depth of 5 cm. The root growth equation, Z_{ei}, is given as:

$$Z_{e_i} = Z_{e_{ini}} + \left[\frac{Z_{e_{max}} - Z_{e_{ini}}}{2}\right] * 1 - Cos\left[\left(\pi^{\frac{1}{F}} * \frac{ST_i}{ST_p}\right)^F\right] \quad (3)$$

where Z_{ei} is the effective root depth at ith day after planting (mm); Z_{eini} is the initial root depth at planting (mm); Z_{emax} is the maximum rooting depth(mm); ST_i and ST_p are the thermal sum (°C. day) at i^{th} day after planting and at maximum rooting depth, respectively and P is a factor pertaining to root growth curve.

$$ST_i = \sum_{i=1}^{n}(T_{m_i} - T_b) \quad (4)$$

$$T_{m_i} = \frac{T_{max_i} + T_{min_i}}{2} \quad (5)$$

T_{maxi} and T_{mini} are the ith daily air maximum and minimum temperatures recorded from a weather station. T_b is the base temperature for crop, consider as 10°C by [37]. T_{mi} is limited between 10 and 30°C. Z_{ei} is calculated from emergence till $ST_i \leq ST_p$. When $St_i > ST_p$, $Z_{ei} = Z_{emax}$. ST_p is the point when the ST_i reaches the maximum, corresponding to the end of the developmental stage.

The climatic input data are crop evapotranspiration, *ETc* and water applied by rainfall and irrigation. The results of soil moisture data of F3D1 treatment was used for calibrating the model. In HYDRUS-1D, the volumetric soil water content measured in the field was taken to be the initial soil water content. The soil input parameters were adjusted (calibration) until there was goodness of fit between the simulated and observed values using the root mean squre error (RMSE), Wilmont's degree of agreement and percentage bias (PBAIS) [38]as desribed below:

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(O_i - X_i)^2} \quad (6)$$

where O_i is the measured value; X_i is the estimated value and N is the number of samples

The Wilmott`s index of agreement ranges between zero (0) and unity (1), with a value of 1 indicating perfect agreement and the equation is illustrated below:

$$d = 1 - \left[\frac{\sum_{i=1}^{n}(S_i - M_i)^2}{\sum_{i=1}^{n}(|S_i - MM_i| + |M_i - MM_i|)^2}\right] \quad (7)$$

where d is the Wilmott's index of agreement; S is the simulated values; M is the measured values MM is the mean measured values.

The optimal value of PBias is 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias and negative values indicate model overestimation bias [39]. PBias, the deviation of data being evaluated, expressed as a percentage is calculated using the equation below.

$$PBias = \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)*(100)}{\sum_{i=1}^{n}\left(Y_i^{obs}\right)}\right] \quad (8)$$

where,

Y_i^{obs} is the observed data and Y_i^{sim} is the simulated data

Model Adequacy: The results of soil moisture data set from eight other treatments were used to test the adequacy of both models, using the root mean squre error (RMSE), Wilmont's degree of agreement, d and PBias.

RESULTS AND DISCUSSION

Soil Physico-Hydric Properties and Water Retention Characteristics: Some soil physical properties of the site before the experiment are presented in Table 2. The texture of all the four layers evaluated were sandy loam, while pH ranged between 6.2 and 7.0 and decreased with soil depth. The average value of soil organic matter (SOM) was highest (1.8%) in the 0-5 cm surface layer and also decreased with soil depth. Soil bulk density (BD) was lowest in the 0-5 cm superficial while the 10-20 and 20-30 cm layers had the highest BD of about 1.70 g/cm^3.

Structural formation after soil mobilization correspond to specific changes in water retention characteristics. In this study, there were differences in the average values of α with soil depth whereas the width of particle size between saturation and air entry pressure (n) did not change. The higher values of α observed in the subsurface layers of the experimental field shows intact pore system due to minimal soil disturbance, whereas soil mobilization by conventional tillage (ploughing and A comparison of the BD values with recommended values showed that they were less than the threshold BD value of 1.75 g/cm^3 [40], indicating that the soil has not reached the condition considered restrictive to root growth, water dynamics and gaseous exchange.

The results of the soil water retention characteristics obtained using [41] model are shown in Table 3. At saturation (0 kPa), the highest value (about 0.454 cm^3 cm^{-3}) of soil water retention was obtained from the 5-10 cm surface soil layer while the lowest value (0.373 cm^3 cm^{-3}) was obtained from the 10-20 cm soil layer. For this soil, the residual soil water content was 0 cm^3 cm^{-3}, indicating the soil could be extremely dry. The van Genuchten parameter α ranged between 0.145 and 1.370 cm^{-1}, with the lowest and highest (about 10 times) values from the 0-5 and 20-30 cm layers, respectively. On the other hand, the parameter n was between 1.119 and 1.177. The van Genuchten parameter α is associated with the air-entry pressure head whereas parameter n is related to the width of particle size between saturation and air-entry pressure. Modifications of soil harrowing) disrupts pore geometry by modifying the size and disrupt pore connectivity, hence the low α value. Ahuja *et al.* [42] pointed out that the changes due to tillage in the retention curve occurred only in the large pore-size range, approximately between the tension of air-entry and 10 times this value. The saturated hydraulic conductivity (Ksat) ranged between 49.6 and 139.5 mm h^{-1}, with the highest and lowest values from the 5-10 cm and 10-20 cm layers, respectively. The higher Ksat from the surface layers was due to increase in the volume of macropores caused by recent soil mobilization while the lowest value from the 10-20 cm layer agrees with the bulk density status (high) of the soil layer. As shown in Table 3, the [41] equation fitted the observed data very well, with high coefficients of determination (R^2) not less than 89%.

Distribution of Rainfall, Evapotranspiration and Soil Water Balance (SWB): The temporal variability of reference and real evapotranspiration as well as irrigation water applied and rainfall received during the tomato growing period is shown in Figure 2a. The maximum rainfall was about 84.2 mm on April 8th. Before this heavy storm, the rainfall amount was not more than 16 mm, with interval more two weeks in most cases. Thus, the scheduled irrigation was not disturbed. After the April 8th,

Table 2: Some soil physical properties of the site before the experiment

Soil depth, cm	pH	SOM%	BD g/cm^3	Sand	Silt	Clay	Texture
				---------------- % ------------------			
0-5	7.2	1.8	1.48	80.5	8.1	11.4	SL
5-10	6.8	1.2	1.62	77.6	12.0	10.4	SL
10-20	6.6	1.2	1.70	79.7	10.1	10.2	SL
20-30	6.2	1.0	1.73	76.3	13.2	11.5	SL

pH: level of alkalinity or acidity, SOM: soil organic matter, BD: bulk density., SL: sandy loam.

Table 3: The soil hydraulic properties (fitted by van Genuchten model) of the different soil layers before the commencement of the experiment in March 2014

Soil depth, cm	θs	θr	α cm^{-1}	n-	m-	Ksat mm h^{-1}	R^2 -
	------ cm^3 cm^{-3} -------						
0-5	0.421	0	0.145	1.119	0.106	131.0	0.95
5-10	0.454	0	0.266	1.120	0.107	139.5	0.98
10-20	0.373	0	0.947	1.136	0.120	49.6	0.89
20-30	0.410	0	1.370	1.177	0.150	66.0	0.96

θs: saturated water content, θr: residual water content, α: air entry parameter, n, m: pore size distribution parameters, Ksat: saturated hydraulic conductivity, R^2: coefficient of determination

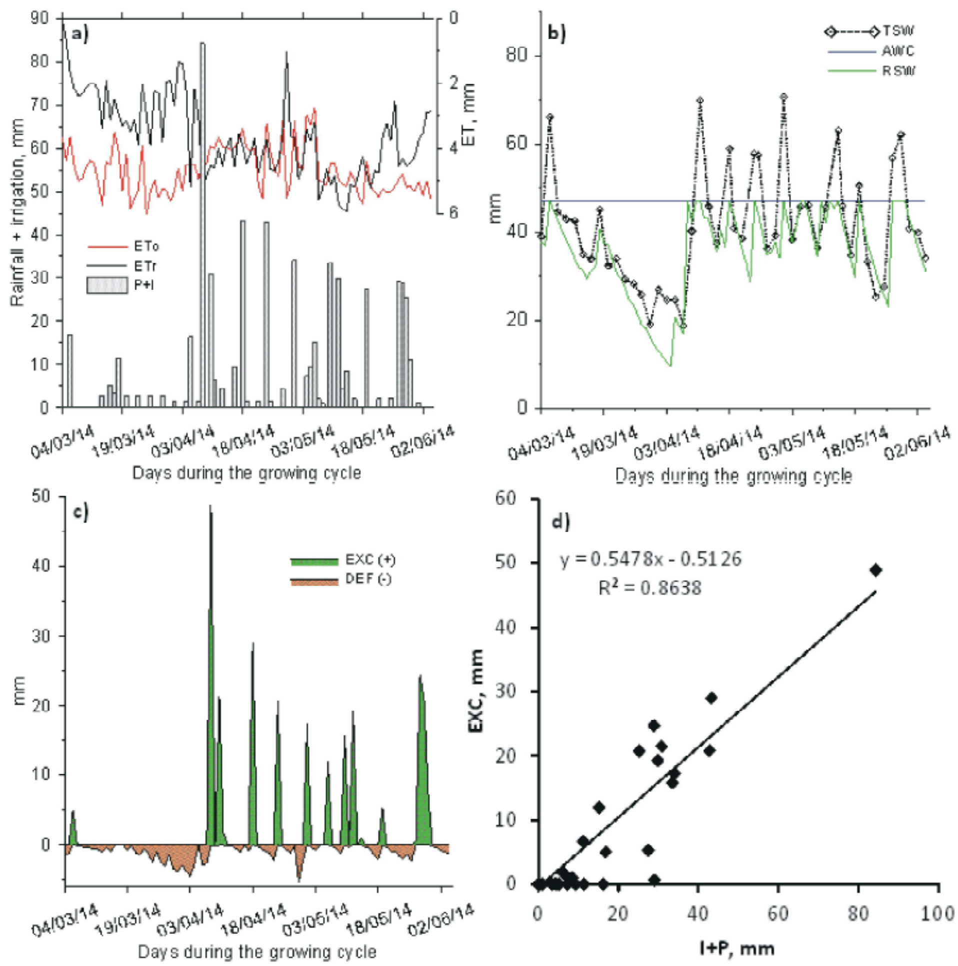

Fig. 2: Results of the sequential soil water balance showing a) rainfall + irrigation, reference and real evapotranspiration, b) excess and water deficit, c) distribution of available water capacity (AWC), actual soil water total (RSW) and measured total soil water (TSW) and d) regression between excess water (EXC) and rainfall plus irrigation (I+P) during the tomato growing period

rainfall was a bit frequent with the amount as high as 43 mm and the interval not more than one week. After the third week in April till early June when the experiment was terminated, there was lower rainfall amount, although more frequent. During this period, supplemental irrigation was practiced. The total monthly rainfall was 36.78, 242.12, 263.6 and 1.16 mm for the months of March, April, May and June, respectively. The atmospheric demand of the atmosphere (*ETo*) ranged between 2.76 and 6.00 mm, with the highest and lowest values obtained in May and March, respectively, with the trend following the course of rainfall. The real crop evapotranspiration (*ETr*) which considers real field conditions of soil water availability and climate was 0 mm at transplanting, reached maximum (5.94 mm) at fruiting period and then decreased towards the end (Figure 2a). Excess water (EXC) in the soil profile was observed during heavy rainfall events (Figure 2b), with the estimated highest values of 48.9 mm when 84.2 mm of rainfall was received while a total EXC of 250.20 mm was estimated. On the other hand, the water deficit (DEF) ranged between 0 and 5.35 mm, with a total DEF estimate of 85.38 mm during the growing period. DEF was more pronounced between March and early April (Figure 2b). Water deficit is the result of SWB in which the total quantity of water entering the soil via precipitation and/or irrigation is less than the quantity of water loss by evaporation and transpiration. On the other hand, excess water occurs when the quantity of water reaching the soil is greater than the quantity of water loss by evaporation and transpiration. In this study, the water loss as runoff and deep percolation (EXC) during the tomato growing period was 250.20 mm, representing 43.4% of total rainfall + irrigation, while during no rainfall or irrigation, about 85.38 mm of water is needed to fill the soil profile. The regression between the excess water and water received (irrigation + rainfall) showed high degree of correlation, with a regression coefficient of 0.9294 (Figure 2d). Bortolotto *et al.* [11] in a study on soil profile internal drainage for a central pivot fertigated coffee crop in Brazil found EXC (taken as *D*) was very large, about 811.5 mm, which accounted for 52.9% of the rainfall. Silva *et al.* [13] employed a difference approach considering *D* equal to the WB EXC discounting SR; knowing that under very wet conditions ETr = ETo, the difference between [EXC – SR] and ETo, is considered equal to *D* and the authors estimated a *D* value of 364.6 mm over two cropping years, corresponding to 15.2% of P. The *D* component, responsible for ground water recharge, is considered negligible in several WB studies, which Pereira (1986) stated could reach values of the order of the ETr. Silva *et al.* [13] maintained that *D* below root zone estimated through Darcy's equation is a very difficult task mainly due to soil spatial variability, hence estimation through SWB could be of great relief. In this study, EXC was considered to be SR + *D*, therefore further studies are needed to measure SR to ensure sole estimate of *D*.

The results of the soil water dynamics, showing the available water capacity, actual soil water stored and total water stored in the 0-30 cm soil profile, are shown in Figure 2b. The available water capacity (blue line) was 47 mm and remained constant through the growing period. The actual water stored (green line) considers the upper limit in which soil water at field capacity was considered for high soil water content, hence the RSW curve did not surpass the AWC line. On the contrary, the measured soil water stored surpassed the AWC line especially during periods of heavy rainfall which is shown as the EXC in Figure 2b. Moreover, the pronounced DEF observed in March was also manifested in the RSW curved (Figures 2b and c). It is interesting to note that the measured TSW curve followed the trend of RSW estimated by the sequential soil water balance (SWB) approach (Figure 2c). The statistical comparison between the observed TSW and simulated RSW gave RMSE of 4.22, PBias of 4.92 and index of agreement of 0.94 (data not shown), indicating the adequacy of the SWB in estimating the profile soil water retention of the drip irrigated tomato field. Bortolotto *et al.* [11] also reported that SWB program is a convenient tool for the evaluation of runoff under field conditions.

Simulation of Soil Moisture by HYDUS 1D: The results of the calibration of HYDRUS 1D model, that is the comparison between simulated and observed soil volumetric water contents for all soil layers of the drip irrigated tomato field using F3D1 treatment (full irrigation) are presented in Figure 3(a, b, c and d) while Table 4 shows the statistical evaluation of simulated and observed soil moisture content (SWC). For all the soil layers, the simulated SWC followed the trend of the observed SWC, however the best trend was obtained from the 0-5 and 5-10 cm surface layers. The root mean square error (RMSE) varied between 4.74 and 6.96. For the Willmott`s index of agreement, *d*, the values were between 0.30 and 0.50, while percentage bias (PBIAS) ranged from -3.23 to -23.5, with the lowest and highest values obtained from 0-5 and 20-30 cm layers, respectively. Both the RMSE and PBIAS increased with soil depth whereas *d* values were similar (about 0.50) for both 0-5 and 5-10 cm surface layers, with lower values from the 10-20 and 20-30 cm subsurface layers. Figure 4 shows the 1:1 lines of the simulated and observed soil volumetric water contents

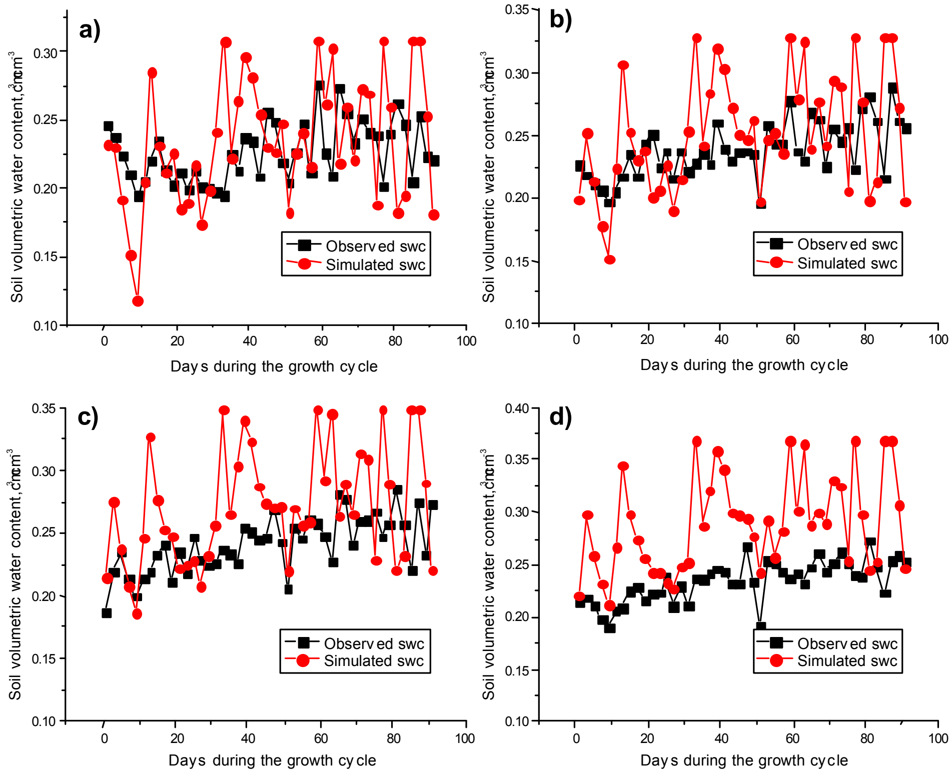

Fig. 3: Calibration results showing the simulated and observed soil volumetric water contents for the (a) 0-5, (b) 5-10, (c) 10-20 and (d) 20-30cm soil layers using F3D1 treatment of the drip irrigated tomato field. swc: soil volumetric water content, $cm^3\ cm^{-3}$

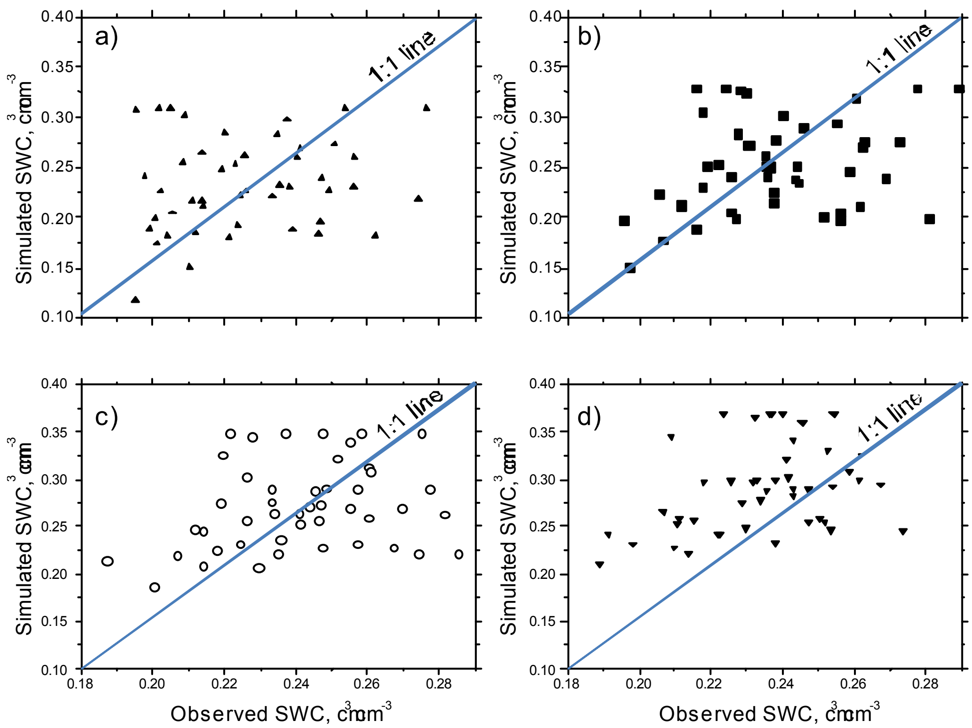

Fig. 4: 1:1 lines of the simulated and observed soil volumetric water contents (SWC) for the (a) 0-5, (b) 5-10, (c) 10-20 and (d) 20-30cm soil layers of the drip irrigated tomato field

Table 4: Performance of model calibration and simulation using F3D1 treatment

Soil depth, cm	RMSE	*d*	Pbias
0-5	4.74	0.46	-3.23
5-10	4.72	0.50	-5.93
10-20	5.39	0.41	-12.59
20-30	6.96	0.30	-23.51

RMSE: root mean square error; *d*: degree of agreement; PBias: percentage bias

Table 5: Evaluation of model adequacy using other irrigation treatments

	Soil layer, cm											
	0-5	5-10	10-20	20-30	0-5	5-10	10-20	20-30	0-5	5-10	10-20	20-30
Trt	RMSE, %				D				PBias, %			
F1D1	4.62	4.68	5.60	6.78	0.49	0.57	0.41	0.34	-0.47	-6.41	-15.26	-20.96
F1D2	4.38	4.61	5.54	6.46	0.49	0.35	0.41	0.36	-2.46	-0.52	-15.13	-19.87
F1D3	4.48	4.64	5.54	6.61	0.49	0.54	0.42	0.33	-3.92	-8.39	-16.34	-21.49
F2D1	4.71	5.45	5.42	6.52	0.51	0.50	0.43	0.34	-2.37	-2.66	-14.08	-19.58
F2D2	4.55	4.92	5.38	6.46	0.55	0.49	0.43	0.39	-4.83	-7.54	-14.03	-20.65
F2D3	4.73	4.66	5.45	6.77	0.48	0.58	0.42	0.34	-5.5	-8.48	-14.12	-22.19
F3D2	4.78	4.77	5.67	6.83	0.47	0.41	0.39	0.36	-4.14	-6.42	-16.17	-23.62
F3D3	6.14	4.62	7.15	6.68	0.43	0.50	0.35	0.36	-1.98	-6.65	-9.57	-22.36

Trt.: Treatments; F1, F2 and F3 are Frequencies of irrigation at weekly, 5 days and 3 days interval; D_1, D_2 and D_3 are depth of irrigation application at 100, 75 and 50% evapotranspiration(ET_C)

(SWC) for all the soil layers of the drip irrigated tomato field. The low values of RMSE indicate strong agreement between observed and simulated SWC, however, the subsurface soil layers showed some degree of overestimation of SWC by HYDRUS model which is shown by the PBIAS values and in the 1:1 line (Figure 4). It is evident that the differences between the simulated and observed soil moisture dynamics values in 0-5 and 5-10 cm soil layers are less compared to the subsurface layers.

We went further to evaluate of the adequacy of HYDRUS 1D model between simulated and observed soil volumetric water contents for all soil layers for other treatments of the drip irrigated tomato field and the results are shown in Table 5. The root mean square error (RMSE) generally increased with soil depth, with the average values varying between 4.38 and 7.15%, the lowest and highest values from 0-5 cm surface layer of F1D2 treatment and 10-20 cm layer of F3D3 treatment, respectively. The Willmott`s index of agreement *d* decreased with soil depth and was not more than 0.58 for all soil layers. The lowest and highest values of *d* were obtained from the 20-30 cm layer of F1D3 treatment and 5-10 cm layer of F2D3 treatment in that order. The average values of percent bias (PBias) were high (in magnitude) for subsurface layers and low for the surface layers, with the lowest (-0.52) and highest (-19.58) value from the 0-5 cm surface layer of F1D1 and 20-30 cm layer of F3D2 treatments, respectively. In all cases, the negative values of PBIAS show that HYDRUS 1D overestimated SWC in comparison with the observed SWC. The results of this study agree with the findings reported in literature. Hussein *et al.* [44] reported that the RMSE values (within 6%) for the calibration model was low for all treatment, indicating a good agreement. Barão *et al.* [22] reported that the water content distribution obtained with HYDRUS, RZWQM and MOHIDLAND models were compared with field data, in which the results show a good agreement between model simulations and field measurements for the three models. In a study on calibration and evaluation of AQUACROP model for simulation soil water content in rice field under different irrigation management, [45] obtained the ranges of RMSE for the different irrigation treatments between 10.42 and 17.32% in 2000 and from 9.15 to 14.59 % in 2001. The results of willmont's index of agreement are similar to that obtained by [46] who reported *d* values between observed and simulated soil water content ranging from 0.36 to 0.62. The performance of PBias from the results was also good, with low magnitude indicating that the model simulation was adequate, although the negative values indicate model overestimation, which also agrees with the results shown in the line 1:1 graphs. The significant of statistical parameter like

RMSE and PBias falling within the acceptable range and average values of *d* in all cases strongly confirm the adequacy of the HYDRUS 1D in simulating the soil water content. Generally, the RMSE, d and PBIAS results obtained from other treatments were consistent with the calibrated results, falling within acceptable range.

CONCLUSIONS

The WB approach and HYDRUS 1D model were used to evaluate soil water status in a drip irrigated tomato field. Prior to transplanting of tomato, soil mobilization modified the structural formation of the field and caused changes in soil water retention characteristics. The SWB approach adequately defined the soil water dynamics during the growing period of the drip irrigated tomato, with the estimated profile soil water availability in agreement with the observed total soil water storage. The HYDRUS 1D model simulated the SWC of the first two soil layers of all the treatments adequately well, whereas there was very high overestimation of SWC in the fourth layer. The study showed that both the SWB approach and HYDRUS 1D model can be successful used to simulate soil water dynamics of agricultural fields in any region of this humid tropical climate.

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