Soil Water Dynamics on Irrigated Garlic and Pepper Crops Using Hydrus–1D Model in the Lake Tana-Basin, Northwestern Ethiopia

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Abstract. Soil water is an important variable in regulating and predicting hydrological process for optimal irrigation. Hydrus-1D was used to simulate soil water dynamics under overhead irrigation in Dengeshita watershed at the plot level. Experiments were carried out from October-February 2017/2018 and from March – June 2018. The treatments were conservation agriculture (CA) and conventional tillage (CT). Irrigation depth, crop phenology, meteorological and soil parameters were determined. Soil parameters were estimated using a K-nearest neighbor approach (KNN) pedotransfer functions for tropical soils and fitted using retention curve optimization program. Sensitivity analysis result showed saturated soil water content (θs), saturated hydraulic conductivity (Ks), and pore size distribution (n) were the most important parameters for the model. The model performance using measured soil water content (SWC) was good with R^2 of (0.64–0.77) and errors; RMSE of 0.021–0.063 and ME of 0.0013–0.040. Based on overall evaluation, CA plots had higher average SWC (0.39–0.40 $cm^3.cm^{-3}$) than CT plots (0.36–0.37 $cm^3.cm^{-3}$). The average seasonal actual transpiration was lower for CT (88.76%) than CA (93.46%) plots due to higher evaporation loss (CT = 7.69% and CA = 1.15%); the difference is statistically insignificant. Seasonal deep percolation from CT and CA plots was 0.38% and 3.15% respectively. Therefore, CA was better than CT due to store more water for plants.

Keywords: Soil water dynamics · Hydrus-1D · Hydraulic parameters · Conservation agriculture · Conventional tillage · Overhead irrigation

1 Introduction

1.1 Background

Using water efficiently by improving water management is the primary objective of irrigated agriculture to minimize risks on available water resources (Siebert et al. 2010).

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To improve the irrigation water management, the major losses of irrigation water should be pointed out and quantified by relatively accurate methods. Soil water is water stored in the unsaturated part of the soil profile, i.e. between the soil surface and ground water level (Van der Kwast 2009). Analyzing the spatial and temporal distribution of soil water is essential in regulating and predicting a range of hydrological processes like Plant water availability (Böhme et al. 2016, Mulebeke et al. 2013, Qiu et al. 2001). Soil water flow prediction in the unsaturated zone is important for efficient agricultural water use (Yadav et al. 2009). Optimal irrigation water management, design, and management of irrigation regimes required a comprehensive knowledge of the distribution and movement of soil water in the root zone (Mei-Xian et al. 2013). Soil water content information is an important variable for the estimation of plot-catchment scale water balance (Sánchez et al. 2012). Soil water in the unsaturated zone is also important resource of water for plants and helps to monitor plant water consumption for crop growth (Liang et al. 2015).

For a better understanding of soil water dynamics, good quality soil moisture time series data is required (Gabiri et al. 2018). Therefore, continuous and exhaustive field measurement of soil water content is necessary for investigation and understanding of soil water dynamics (Espejo-Pérez et al. 2016). As stated by Jurik et al. (2012) and Šimunek et al. (2012), realization of field soil water monitoring could be characterized as extremely time and money consuming. Water movement in the unsaturated zone is an incredibly complex process due to the heterogeneous nature of the soil and variable atmospheric boundary conditions at the soil surface over a short period (Saifadeen and Gladneyva 2012). Li et al. (2014) also stated that water flow in the soil is the interaction of complex processes, their observation and evaluation under field condition is relatively difficult, costly, and time consuming. Besides, Šimunek et al. (2012) pointed out that direct field soil water monitoring could be characterized as extremely time and money consuming.

Tools such as TDR, neutron probes and capacitance probes, which are used to measure soil water with high temporal resolution, are instructive and lack the necessary spatial resolution to capture heterogeneities in soil properties (Kuhl et al. 2018). As the acquisition of field data is costly and time consuming, models are alternative ways to manage systems once they are well validated (Arnold and Allen 1996). Numerical simulations are efficient approaches to investigate soil water dynamics for optimal irrigation management practices (Chauhan et al. 2003). In this study, a widely used soil water model, Hydrus-1D by Simunek et al. (2005), which simulates one dimensional water, heat and solute transport in variably saturated and unsaturated media, was applied to simulate the soil water dynamics.

Models such as MODular Hydrologic Modeling System (MODHMS) (Varut et al. 2011) and Hydrus-2D and-3D (Šimunek et al. 2012) can be adopted to simulate soil water dynamics. However, they are data demanding, required considerable computer resources, and are difficult to adapt to the investigated study area because of complex boundary condition (Gabiri et al. 2018). Hydrus-1D, in comparison, is less data demanding and useful tool for evaluating various water fluxes in agricultural fields with different crops and various irrigation schemes (Kandelous et al. 2012). It has been successfully applied in numerous studies for predicting soil water content and movement under different conditions (Beyene et al. 2018, Chen et al. 2014, González et al. 2015, Zhang et al. 2016).

Therefore, the purpose of the present study was to evaluate the soil water dynamics using Hydrus-1D on irrigated Garlic and pepper crops under overhead irrigation application method to quantify the significant losses of irrigation water in the plant root zone. Specifically to analyze the vital soil water balance components in the root zone, to evaluate the effect of CA on soil water dynamics and test the applicability of Hydrus-1D model for the study area.

2 Materials and Methods

2.1 Study Site

This study was conducted at Dengeshita watershed located in Dangila district in Amhara region of Awi Administrative zone. Dangila is one of Agricultural Growth Program (AGP) and feeds the future woredas in the region. It is located about 80 km south west from Bahir Dar (the capital city of Amhara region), having latitude and longitude of 36.83° N and 11.25° E respectively with a mean elevation of 2137 m above sea level. The study area was within Dengeshita watershed. Experimental plots were selected from farmer's fields within the watershed; plots have surface soils of clay texture (0–60 cm) and very high clay content (heavy clay soil) to a depth of 90 cm. The watershed covers an area of 57 km^2 with mainstream length of 43 km and is 8 kms away from Dangila town. The livelihood of the area is based on both crop and livestock production. Crop production mainly includes cereals like maize, teff, and finger millet; legumes like beans; irrigated crop production such as garlic, onion and pepper. Ground water is the primary water source for irrigation. Pulleys together with manual water lifting device are widely used in the area (Fig. 1).

2.2 Field Experimentation and Data Collection

For this study on-farm research experiment was designed to evaluate soil water dynamics under smallholder irrigated plots. The plot size was set to be a 10 m x 10 m, just for manageability depending on water resources of the study area. Accordingly, five experimental plots were selected by purposive sampling technique during the first irrigation period. Garlic and pepper crops produced during the first and second season, respectively. Each plot divided in to CA and CT subplots. Farmers used ground water for irrigation. Eight raised beds designed in each plot having a length of 10 m, width of 80 cm with 40 cm bed spacing were prepared. CA, with overhead irrigation conducted on the half of the scenarios (4 beds) and CT with overhead irrigation was performed on the remaining half (4 beds). Fertilizer and other manure applications were set common for both treatments.

Daily soil water content was measured at the top 10 cm depth at 8 points (4 times from CA and 4 times from CT) from each plot using Time Domain Reflectometer (TDR probe). For this study 1 m × 1 m × 1 m pit was excavated from one of the representative plot to determine soil physical properties. Soil physical properties such as texture, bulk density, field capacity (FC), permanent wilting point (PWP), organic matter, cation exchange capacity (CEC) and PH were determined by taking soil samples

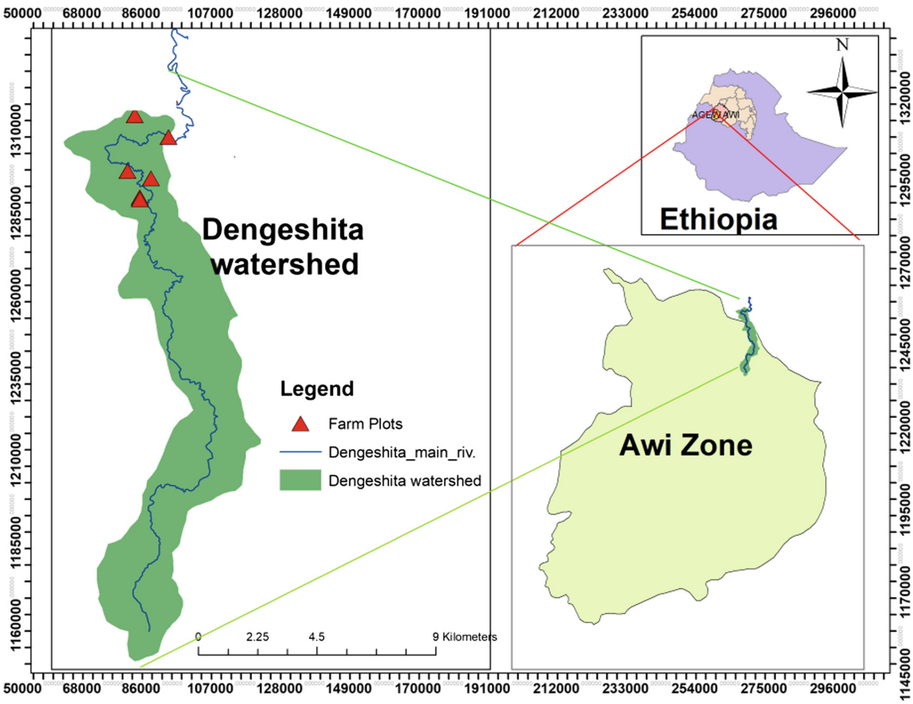

Fig. 1. Location of study area

at each horizon to estimate model parameters. Bulk density determined from undisturbed soil samples taken at each horizon using core sampler having a diameter of 4.38 cm and length of 5.14 cm. Soil samples analyzed at Amhara design and supervision works enterprise soil laboratory.

Seasonal plant height and root depth were measured using the meter at each development stage from CA and CT plots. The amount of irrigation determined by counting the number of already measured container (10 L bucket) by which the farmers apply irrigation. Therefore, multiply the number of buckets by 10 L to get the total volume of flooding. Then convert irrigation volume (m^3) to irrigation depth dividing it by plot size (area); assuming the water uniformly distributed throughout the plots. The effective root depth (the depth within which most plant roots are concentrated) of garlic is 0.3–0.5 m and maximum root depth for pepper is 0.5–1.0 m (Allen et al. 1998).

Because ground water table was in-depth during the experiment it does not have any contribution to crop soil-water use and an effect on soil water variation around the root zone of the plant; therefore ground water level variation was not monitored during the simulation periods. Due to lack of water resource and manual overhead irrigation system at the study area excess water was not generated as surface runoff due to irrigation from experimental plots.

2.3 Hydrus-1D Model

2.3.1 Model Description

The one dimensional Hydrus-1D computer program (Šimůnek et al. 2008) which based on Richards equation was selected to simulate soil water dynamics in experimental plots. Hydrus-1D model was freely available for download from PC PROGRESS website. Since water flow in the soil profile between the soil surface and groundwater table (unsaturated zone) is predominantly in the vertical direction, there was no need to use a model such as Hydrus (2D or 3D) that would consider multiple dimensions (Li et al. 2015, Van Dam et al. 2005). Therefore Hydrus-1D model can be used to study soil-water dynamics. Several researchers like (Chen et al. 2014, Daniel et al. 2017, Li et al. 2015, Rubio and Poyatos 2012) preferred Hydrus-1D and successfully applied it for unsaturated zone soil water dynamics.

The governing one dimension water flow equation for partially saturated porous medium is described using the modified form of the Richards equation, under the assumptions that air phase plays an insignificant role in the liquid-flow process and that water flow due to heat gradient neglected:

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[k(h)\left(\frac{\partial h(\theta)}{\partial z}\right) + \cos\alpha\right] - s \quad (1)$$

Where, θ is the volumetric soil-water content [$cm^3\ cm^{-3}$], t is time [day], z is the vertical coordinate [cm] (positive upward and its origin is the soil surface), h is the water pressure head [cm]. S is the sink term in the flow equation [$cm^3 cm^{-3}\ day^{-1}$] accounting for root water uptake by plants (transpiration), α is the angle between the flow direction and the vertical axis (i.e., $\alpha = 0^{\circ}$ for vertical flow, 90° for horizontal flow, and $0^{\circ} < \alpha < 90^{\circ}$ for inclined flow), and k (h) is the unsaturated hydraulic conductivity function [$cm\ day^{-1}$]. The sink term (S) in Eq. (1) is defined as the volume of water derived from a unit volume of soil per unit time by plant roots. It accounts for actual root water uptake equivalent to actual transpiration, calculated by the model using Feddes equation (Soylu et al. 2011).

2.3.2 Estimation of Soil Hydraulic Parameters

The van Genuchten soil hydraulic parameters θs, θr, α, n and m (Table 1) required by Hydrus-1D were estimated using KNN pedotransfer function and optimized using the retention curve parameter optimization (RETC) software by fitting retention data, θ (h). Points on the soil water retention curves for each soil horizons were estimated with KNN pedotransfer functions of tropical soils (Botula et al. 2013). The service requires the measured particle size distribution, organic matter content, bulk density, soil water content at field capacity, at permanent wilting point, CEC, and PH. Then the RETC program was used to fit the predicted data and to derive the unsaturated soil hydraulic parameters (θr, θs, n, α, and m). Retention curve uses a nonlinear least-squares optimization approach to estimate unknown model parameters from observed retention data (Van Genuchten et al. 1991). The pore connectivity parameter (l) was assumed equal to the average value of 0.5 for many soils.

2.3.3 Initial and Boundary Conditions of Hydrus-1D

The initial condition was defined using SWC measured during the crop planting period. The soil surface subjected to the atmosphere with specified values of irrigation and evaporation. The upper boundary condition in the model defined by an atmospheric boundary condition with surface runoff using potential evapotranspiration (ETo). ETo was calculated using the Penman-Monteith equation (Allen et al. 1998) using recorded meteorological data. Ground water table was deep enough so exclude its influence on water movement in the plant root zone by capillary rise. Due to this reason, free drainage (irrigation water infiltrates beneath plant root zone) was specified to describe lower boundary conditions of the soil profile. Daily meteorological data such as maximum air temperature, minimum air temperature, relative humidity, sunshine hour, and wind speed, which used as an input to Hydrus-1D obtained from Dangila meteorological stations located in the study site of Dengeshita watershed. During simulation measured irrigation depths were considered as time variable boundary condition. Two soil layers (0–30 cm of thickness 1 and 30–60 cm of width 2) found for simulation purpose.

3 Result and Discussion

3.1 Hydraulic Parameters Used for Hydrus-1D Model

Hydrus-1D soil hydraulic parameters (i.e., θr, θs, a, n, and Ks) derived from the observed soil physical properties using the K-nearest neighborhood pedotransfer function for tropical soils used to evaluate soil water dynamics stated in Table 1. The retention curve parameter optimization program for unsaturated soils was used to optimize the parameters. Calibration for Hydrus-1D was performed by fitting the observed soil water contents using the retention curve parameter optimization program (RETC).

Table 1. Hydrus-1D optimized soil hydraulic parameters

Depth (cm)	Soil type	θr(cm^3/cm^3)	θs(cm^3/cm^3)	α(cm^{-1})	n	Ks(cm/day)	R^2	SSQ
0–30	Clay	0.1808	0.4874	0.0524	1.1440	4.8	0.997	0.00023
30–60	Clay	0.1817	0.4962	0.0498	1.1440	4.8	0.996	0.00032

Where θr-Residual soil water content, θs-Saturated soil water content, α-Shape parameters, n-pore size distribution parameter, Ks-Saturated hydraulic conductivity, R^2-Coefficient of determination and SSQ-sum square of error.

3.2 Sensitivity Analysis of Model Parameters

Sensitivity analysis was performed to analyze the influence of each parameter variations on the model outputs and then to select the most sensitive settings (Chang et al. 2007). For this study Local sensitivity analysis (LSA) using a one-at-a-time (OAT) approach was used to understand the effect of each parameter to the model output since this approach allows a clear identification of single parameter effects. From the result, saturated soil water content, saturated hydraulic conductivity, and pore size distribution parameters were the most critical hydraulic parameters that affect model output (Fig. 2).

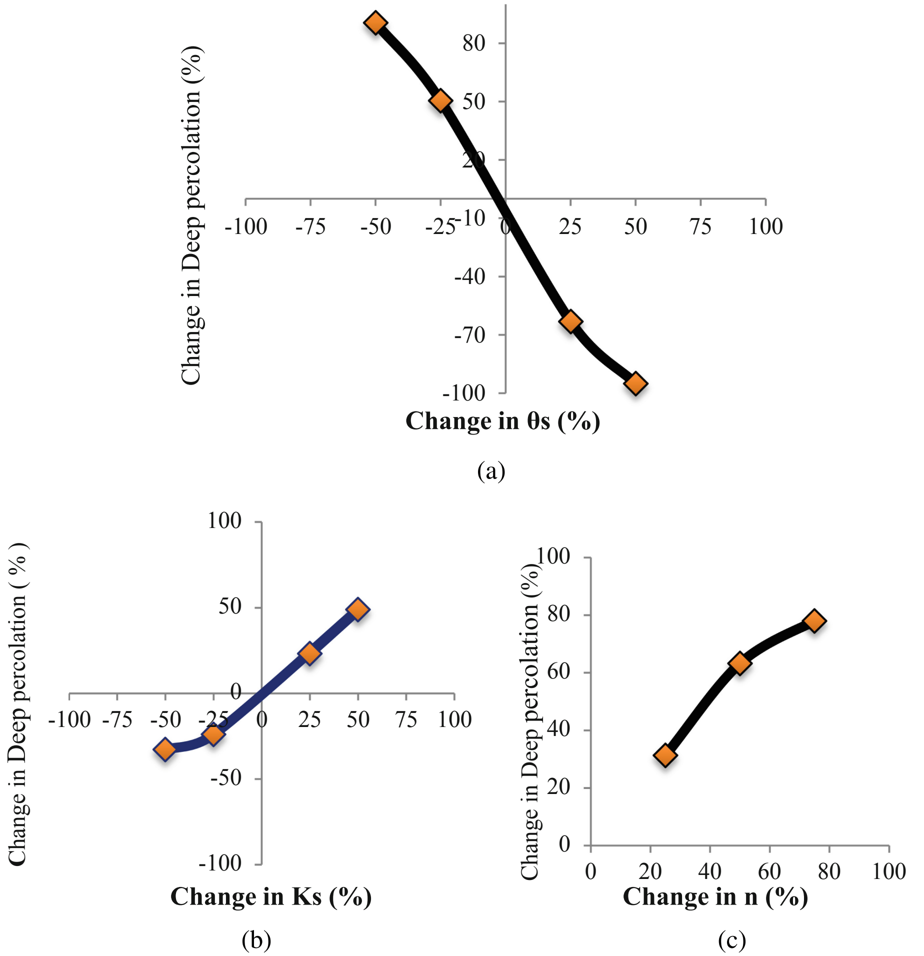

Fig. 2. Sensitivity analysis of saturated water content (θs) (A), saturated hydraulic conductivity (Ks) (B), and pore size distribution parameter (C).

3.3 Hydrus-1D Model Validation

For evaluating the accuracy of model, predicted soil water content from the observation node (at 10 cm soil depth) by Hydrus-1D compared with the observed SWC for all experimental plots (Figs. 3a, b and 4). Also, the model validated by graphical technique which provides a visual comparison of measured and simulated soil water content. The result showed that the model underestimates soil water in CA experimental plots averagely by 0.025 cm^3cm^{-3} during the first simulation period. Hydrus-1D model does not have parameters especially consider for CA in addition to soil hydraulic parameters and initial condition. Due to this reason, Hydrus-1D underestimates daily soil water content in CA plots. The observed and simulated soil water content matched well and showed reasonably similar trends for both CT and CA plots.

Comparison of observed and simulated soil water content at different times during crop growth in 2017/2018 and 2018 showed a good correlation. A good correlation was indicated by high R^2 (0.64–0.77) and low RMSE (0.021–0.063), ME (0.0013–0.040) values. The R^2, RMSE and ME between observed and simulated soil water content indicated that the model performed well in simulating soil water dynamics.

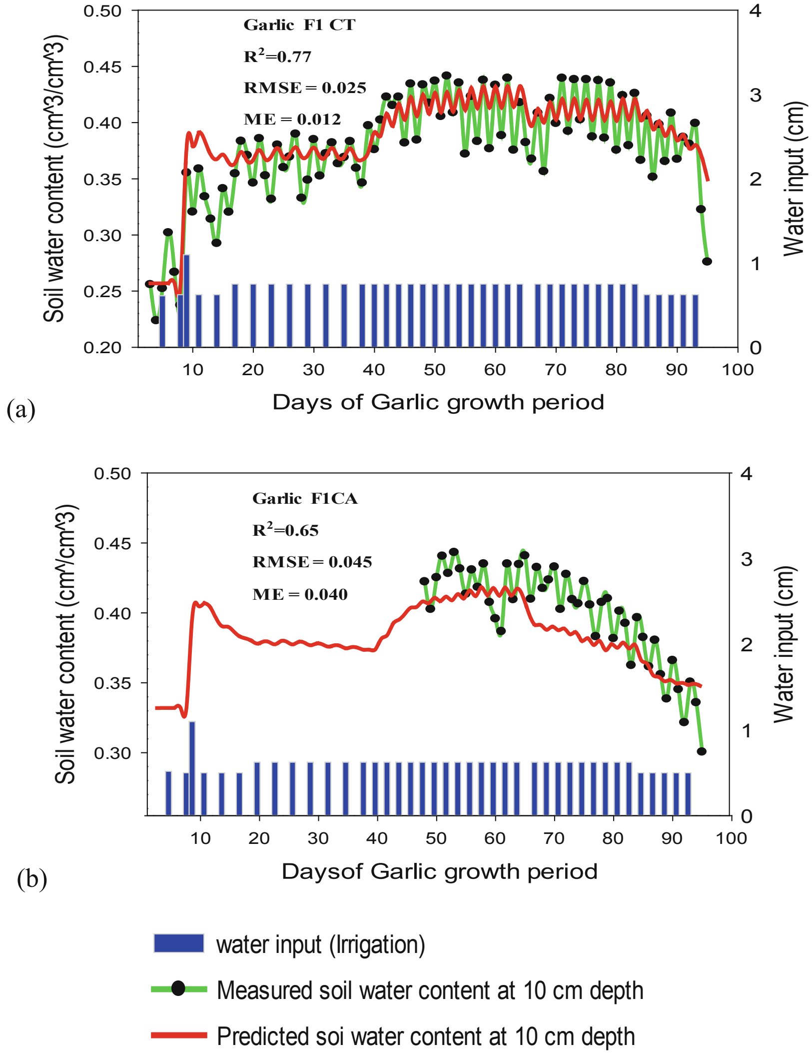

Fig. 3. Comparison of observed and simulated soil water content for CT and CA

During 2017/2018 simulation period, more fluctuations of soil water content in CT plot (Fig. 3a) than in the CA plot (Fig. 3b) were due to more irrigation water applications in CT compared to CA plot. Compared to growth stage, the soil system stored higher water content from the end of development to the beginning of late stage due to high irrigation applications. The result clearly showed that soil water content was gradually increase starting from the end of the development stage (immediately when irrigation interval is small) in CT and CA experimental plots. The model validation result clearly showed Hydrus-1D can simulate soil water dynamics in CA and CT experimental plots. However, the model underestimates soil water content in CA experimental plots, and the correlation coefficients were smaller compared to CT plots, even measured and simulated values had similar trend. There were discrepancies between the observed and predicted soil water content during most days of plant growth season, especially in CA plots, and the observed soil water contents were greater compared to predicted values. No soil hydraulic parameters were estimated for CA plots, and measurement errors at the field condition inevitably led to the difference between observed and simulated soil water content. Hydrus-1D does not have parameters consider only for CA, which may also cause for mismatch of observed and simulated water contents.

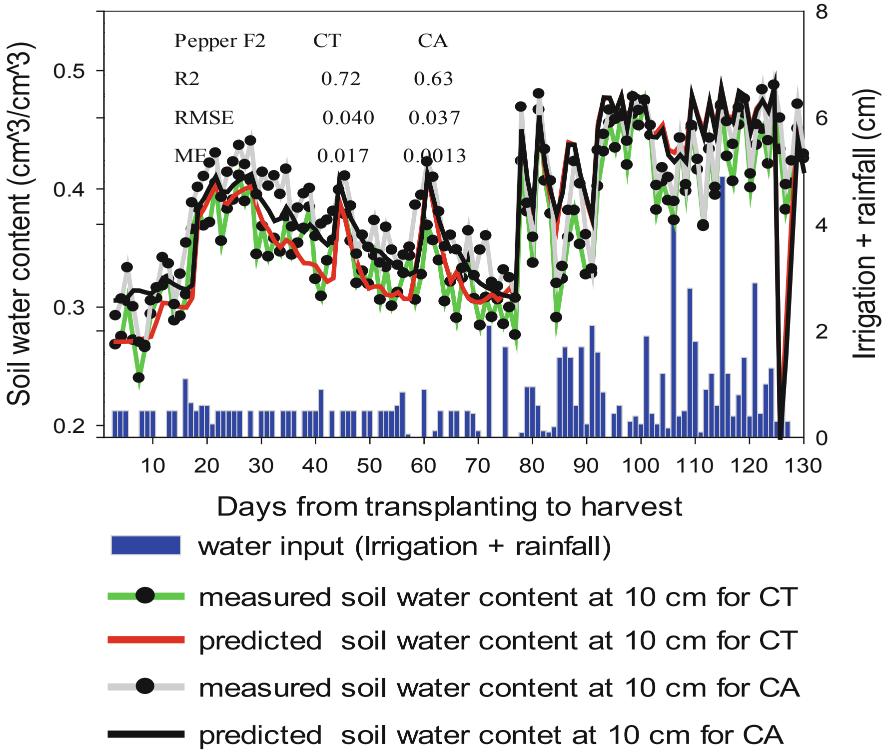

Fig. 4. Comparison of observed and simulated soil water content for CT and CA

Hydrus-1D also could simulate soil water dynamics (SWD) successfully during pepper growth season. Change in the soil water content between observed and simulated values matched well during this season. Daily Soil water content also responded positively to irrigation and rainfall events. Due to frequent rainfall events, the soil system store higher water content from 80–125 days after transplanting of pepper (DAT). Even though an equal amount of water was applied, both observed and predicted soil water content in CA was higher than in CT plots, especially at the early stage (Table 2).

Table 2. Average daily soil water content for experimental plots during simulation period

	Average observed daily soil water content ($cm^3.cm^{-3}$)		Average simulated daily soil water content ($cm^3.cm^{-3}$)	
	Garlic		Pepper	
Plot code	CT	CA	CT	CA
F1	0.376	0.400	0.392	0.398
F2	0.374	0.389	0.386	0.395
F3	0.371	0.384	0.425	0.432
F4	0.331	0.349		
F5	0.384	0.401		

3.4 Irrigation Water Applied

During 2017/2018 simulation period, crop growth was fully through irrigation applications. The average seasonal irrigation depths used were 278.86 mm and 241.68 mm for CT and CA plots respectively throughout the garlic growth season. During the second experimental period, average cumulative water input (irrigation plus rainfall) was 773.03 mm similarly for CT and CA plots. A decrease or increase of irrigation depth applied to the fields directly impacts the amount of water stored in the soil system (Figs. 3a, b and 4). Means that higher water input gives higher water content result in the soil system and vice versa. Also, smaller irrigation applications could not significantly affect and vary the simulated daily soil water content of Hydus-1D. There was a shortage of water for irrigation due to the decreasing of ground water potential staring from pepper transplanting to the coming of rainfall. The rain was onset around the beginning of pepper development stage even though the amount was minimal. However, the rain was occurred with sufficient amount during the mid-stage of pepper.

3.5 Effects of Conservation Agriculture on Soil Water

During 2017/2018 simulation period, the result demonstrated that CA plots stored more water in the soil system compared with CT plots; even irrigation applications in the former treatments were less. Similarly, daily soil water contents at the top 10 cm soil depth for CA plots were higher than CT plots during 2018 period. However, unlike the first equal amount of irrigation water was applied to the soil system for both tillage systems up to the beginning of rainfall during experimental pepper period. This clearly indicated that CA has the potential to conserve soil moisture due to the effect of mulch cover on the soil surface producing less evaporation and delay the drying of soil moisture. These results are consistent with those of others (Han et al. 2015, Thierfelder and Wall 2009, Ward et al. 2006).

Soil water in CA plots was higher throughout the whole growth period of garlic. Similarly, at the beginning of second experimental period just after transplanting – the mid stage of pepper measured and simulated soil water for CA were greater. However, during some days of plant growth, especially after pepper mid stage soil water difference between two treatments (CA and CT) was insignificant. This was probably due to the size of garlic leaf canopy was smaller, and its variation throughout its growth season was also lower. Therefore under garlic experiment, the top surfaces of CT plots were exposed to sunlight because of little leaf area coverage compared to CA plots, which has mulch cover. However, during second experimental period as pepper matured, plants expand their leaf canopy and shading the soil surface starting to mid-growth stage so that the top surfaces of CT plots were protected from direct interaction with solar radiation by large leaf canopy of pepper (compared to garlic) the same as CA which protected by mulch.

Based on the t-test equal variance statistical analysis result of observed soil water content for CA and CT of 2017/2018 simulation period have a significance difference with 95% confidence interval t cri (1.98) was less than t stat (2.82), therefore reject the non-rejection region of the probability distribution function. Means that the difference detected was statistically significant, as shown in Table 3.

Table 3. T-Test: Two-sample assuming equal variances for measured SWC of 2017/2018

Statistics	CA	CT
Mean	0.38	0.36
Variance	0.0014	0.0011
t Stat	2.82	
$P(T <= t)$ one-tail	0.0028	
t Critical one-tail	1.66	
$P(T <= t)$ two-tail	0.0055	
t Critical two-tail	1.98	

During 2018 simulation period, t-test equal variance statistical analysis result of average simulated SWC using Hydrus-1D in CA and CT experimental plots clearly indicated that the difference was significant statistically with t cri (1.97) was much less than t stat (2.65), reject non rejection region (Table 4).

3.6 Transpiration and Evaporation

Hydrus-1D model simulate daily plant transpiration and soil evaporation for two simulation periods. The simulation result showed that during the beginning of crop growth evaporation was higher since the plant was small with low soil coverage. Then evaporation was reduced with time for all experimental plots when plants mature, expanding their leaf canopy and shading the soil surface completely. The simulated transpiration was smaller at the early stage and continuously increases following plant growth. During

Table 4. T-Test: Two-sample assuming equal variances for simulated SWC of 2018

Statistics	CA	CT
Mean	0.38	0.37
Variance	0.00064	0.00087
t Stat	2.65	
P(T < = t) one-tail	0.00455	
t Critical one-tail	1.65	
P(T < = t) two-tail	0.0091	
t Critical two-tail	1.97	

2017/2018 the actual transpiration was first little then increases gradually and reaches an absolute peak value. Then the amount was reduced rapidly at the end stage of the plant following to absence of irrigation. The evaporation result for CT was more significant as compared to CA throughout the season. Therefore, CA has the potential to reduce water evaporation by interfering solar radiation falling on the soil surface and act as a barrier between the soil surface and atmospheric air above.

Actual root water uptake (mm/day) for CA showed more water uptake by roots compared with CT even though more irrigation water applied in the CT treatments. The actual transpiration result was an average of 93.5% and 88.8% of water input for CA and CT, respectively during the first simulation period. During pepper average cumulative transpiration resulted in CA plots (365.65 mm) were higher compared to those in CT plots (353.67 mm) even both treatments had equal water inputs. The results indicated that plants in CA plots were used water through their root system effectively compared to those in the CT experimental plots. Compared with simulation periods, the actual transpiration and soil evaporation resulted during 2017/2018 was lower than during 2018 period.

Also, the percentage of average seasonal evaporation result from CT plots was higher (7.69%) compared to those from CA plots (1.15%) during garlic growth period. Likewise, during experimental pepper period average seasonal evaporation greater for CT plots (5.83%) than CA plots (1.09%). The reason was presumably mulch cover on the soil surface of CA has the potential to reflect an incident solar radiation falling on the topsoil surface and act as a barrier between the soil surface and atmospheric air above. However, the top surface of conventionally tillage plots was open and exposed to solar radiation. Due to this reason, more water was evaporated from CT plots. Therefore, CA has the potential to reduce water evaporation by interfering solar radiation falling on the soil surface.

The simulated actual transpiration and potential transpiration was almost equal throughout most of the plant growth period (Fig. 5) during 2017/2018 period. This indicated that garlic crop was not under stress. However, during pepper growth season, actual root water uptake results were smaller compared to potential transpiration (Fig. 5) in most days throughout the growth period. Therefore pepper crops were under stress due to insufficient irrigation application during the experiment compared to garlic crops.

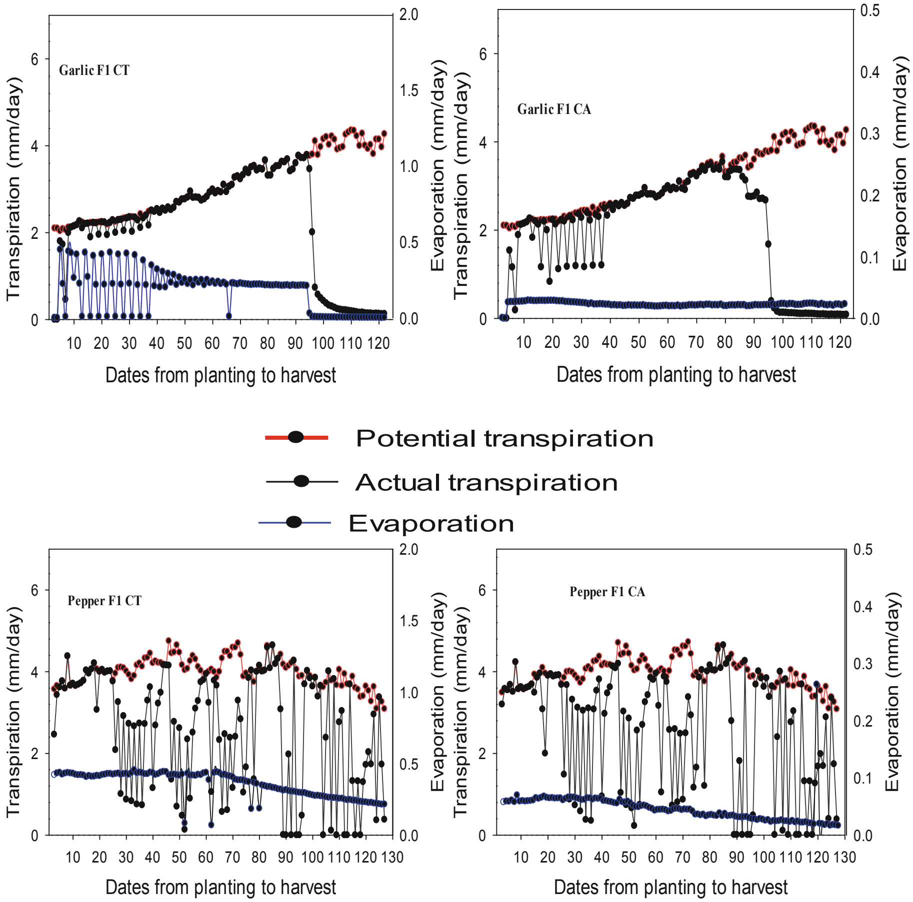

Fig. 5. Simulated potential transpiration, actual transpiration and soil evaporation throughout crops growth periods

3.7 Evapotranspiration (ET) Estimation

The maximum and minimum daily Potential evapotranspiration was approximately 6.088 mm/day and 2.742 mm/day respectively throughout garlic experimental period. The simulation result shown that excess water generated as surface runoff from experimental plots was insignificant (zero). The result was similar to the observed value during the field monitoring period i.e. Excess water was not generated as surface runoff from experimental plots during irrigation.

Reflecting global crop growth, simulated actual ET (sum of transpiration and evaporation) was initially small during seed germination stage of garlic. Actual evapotranspiration then gradually increased and reached its maximum value between 50 and 95 days almost similarly for all experimental plots. Cumulative actual evapotranspiration for CT plots was higher than CA plots due to higher evaporation from CT. The seasonal actual evapotranspiration results vary from 228.87–288.49 mm and 184.18–244.54 mm respectively in CT and CA plots throughout the season. During the late stages of garlic, actual daily evapotranspiration gradually declined and near to zero immediately starting 104 days of simulation because absence of irrigation caused water stress in the plant root zone.

During pepper, the maximum and minimum daily Potential evapotranspiration was approximately 6.033 mm/day and 1.096 mm/day, respectively. Actual ET results during garlic growth season were lower compared to those in pepper growth season due to higher water consumption of pepper. The seasonal simulated actual transpiration values for CA plots were more significant than CT plots; even the trend was similar. However, evapotranspiration for CT was greater than CA because of more evaporation from the former plot. The minimum and maximum cumulative AET results throughout pepper growth season were 363.85 mm and 422.13 mm respectively for CT plots. Under CA plots, the minimum of 344.00 mm and maximum of 391.03 mm seasonal actual evapotranspiration was resulted.

3.8 Deep Percolation Estimation

The simulated daily deep percolation value for each experimental plot by Hydrus-1D was plotted as a function of plant growth period (Fig. 6). Deep percolation closely corresponded with irrigation and rainfall events. During garlic and most of pepper growth stages when water input was predominantly through irrigation, the deep percolation was very insignificant for all experimental plots. Due to intensive rainfall (compared to irrigation applied before rain coming) relatively higher percolation was mainly observed during the later growth stages of pepper. This indicated that water management system used during the experiment was sound.

During 2017/2018 simulation period, the percentage of average seasonal deep percolation from CT and CA were 3.15% and 0.38% of water input respectively. Cumulative percolation was 29.95% and 34.51% for CT and CA respectively during 2018 (pepper) period. The result indicated that water percolation from CA plots was higher than CT plots. Overall, even though total water input for the CA was substantially lower than CT during garlic growth period cumulative deep percolation from CA was slightly higher than CT plots. Similarly, cumulative percolation result of CA was higher than CT pots during 2018 when seasonal water input was equal for both treatments.

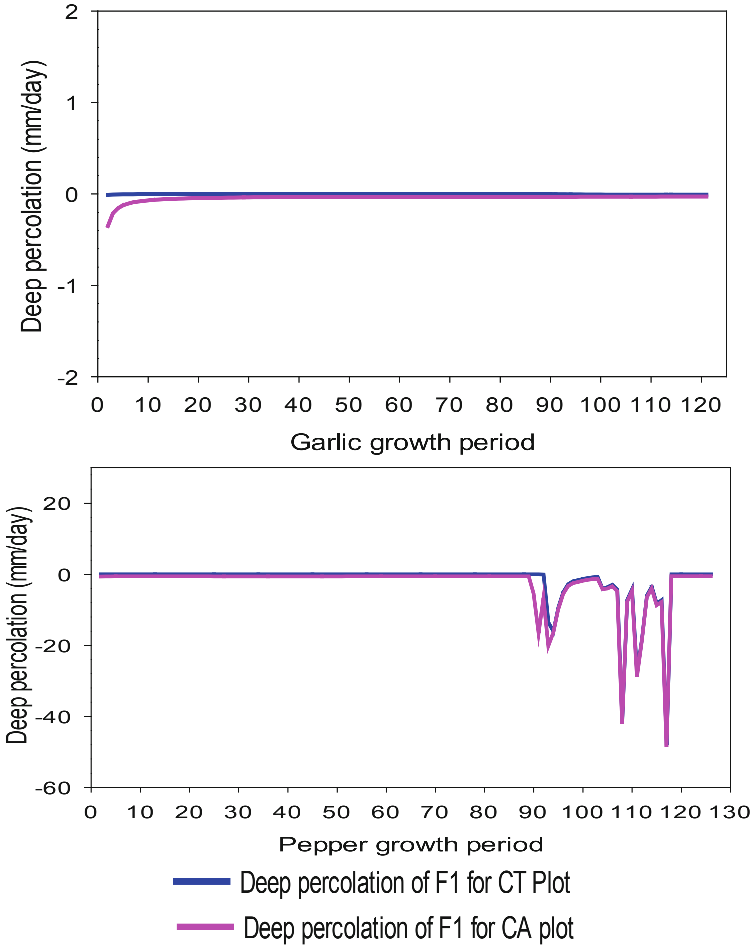

Fig. 6. Simulated deep percolation throughout the simulation periods

4 Conclusions

The result of this study showed Hydrus-1D could simulate root zone soil water dynamics in the CT and CA experimental plots. Soil water dynamics computed by the model fit well with the observed value at the top surface 10 cm soil depth. The daily soil water content stored in CA plots was higher compared with CT plots. Generally, more actual transpiration was observed in CA plots than CT due to high evaporation loss of later. The seasonal deep percolation from CA treatments was higher compared to those from CT treatments. However, evaporation loss for CT was more significant. The actual evapotranspiration was affected by water management substantially increase and decrease with irrigation/rainfall events. From the analysis of soil water dynamics during cop development period conclude that CA can increase infiltration and store more water in the soil system by reducing water loss through evaporation. Generally, CA practice used less water and had higher actual root water uptake; and recommended for farmers irrigation practice in the study area.

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