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ORGINAL ARTICLE

# Modeling Water and Nutrient Dynamics in Response to Conservation Agriculture Practices under Smallholder Farms in the Ethiopian Highlands

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**ABSTRACT**

*The Agricultural Policy/Environmental eXtender (APEX) model have been developed to assess a wide variety of agricultural water resource and other environmental problems at a field or multi-subarea spatial scales, which further depicts its importance in decisions at plot scale farming. The model was established to evaluate the effect of conservation agriculture (CA) practices on water and nutrient loads of runoff and sediment under small on-farm experimental plots. Transferred flow model parameters from a watershed to experimental plots were used to simulate runoff with runoff and nutrient parameter adjustments under conservation agriculture and conventional tillage practices. The APEX model performed well in terms of performance measures in simulating the CA and the conventional tillage (CT) scenarios for different response variables under irrigated and supplementary irrigated vegetable production systems. It showed a decreased simulated ET by 15%, simulated average runoff by about 70%, simulated nitrogen in the runoff by 23%, and simulated phosphorus loads in the runoff by 54% under CA compared with the CT treatment while it showed increased average root zone soil water (20%), and increased average percolation (59%). The reason for the different responses of the simulated variables between CA and CT practices was obviously due to the combined use of grass mulch cover and no-tillage practices under CA treatment. APEX simulations indicated the contribution of such practices leading to the reductions in ET and runoff, which was the main reason for higher (14–27%) water-saving observed during the dry irrigation phases of various vegetable production under CA treatment. In this regard, APEX can be used as a tool to assess the impact of CA on hydrology and nutrient loads.*

Keywords. APEX, root zone soil water, conservation agriculture, nutrients, runoff



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1. INTRODUCTION

Water and nutrients are the critical inputs for rain-fed and irrigated crop production systems, although the degree of contribution varies both spatially and temporally. The dynamics of water and nutrients should always be monitored in response to different farming and management practices to manage these resources for better economic and environmental returns. However, field research used to conduct measurements across all possible locations, topography, farming, and cropping practices are often costly and even time-consuming (Chung et al. 1999). In filling such gaps, modeling techniques have been increasingly used in agriculture to evaluate the response of unmeasured variables to different farming and irrigation practices. However, the choice of an appropriate model for a specific purpose continued as a critical challenge for researchers. Recent advances in process-based models have been used to evaluate the effects of different agricultural practices at various spatial and temporal scales (Antle et al. 2017, Marin et al. 2014, Rauff and Bello 2015). However, verifying a model with adequate observed datasets for a particular region is necessary since models developed considering specific site conditions may not perform well in the other regions (Müller et al. 2017, Rivington and Koo 2010). Despite detailed field data required for verification (Iizumi et al. 2014, Ray et al. 2012), generally, process-based models such as the crop growth model (Di Paola et al. 2016), and carbon cycling model (Stockmann et al. 2013) are potentially accepted and commonly used to assess the response of water, nutrient and crop variables (growth and yield) to different irrigation, farming, and management practices at watershed, farm, or plot scale levels (Gassman et al. 2009).

Agricultural Policy Environmental eXtender (APEX) model is among few efficient process-based models used to evaluate the effect of agricultural practices at various farm levels to draw the best management practices (Clarke et al. 2017, Gassman et al. 2009, Moriasi et al. 2012, Tuppad et al. 2010b, Zhang et al. 2016). The model functions on long-term continuous time scales (daily, monthly, and annual). Unlike other models, APEX is a biophysical model that integrates different components including EPIC - Environmental Policy Integrated Climate model (Williams et al. 2008), CREAMS - daily runoff hydrology sub-model of the Chemicals, Runoff, and Erosion from Agricultural Management Systems model (Knisel 1980), GLEAMS - Groundwater Loading Effects of Agricultural Management Systems model (Leonard et al. 1987), Century model - the carbon cycling model (Parton et al. 1994), and ALMANAC - the Agricultural Land Management Alternatives with Numerical Assessment Criteria model (Kiniry et al. 2005).

APEX has been recently used to simulate runoff and sediment (Francesconi et al. 2014a, Wang et al. 2008), percolation (Kumar et al. 2011b, Wang et al. 2008), crop growth and yield (Talebizadeh et al. 2018), water quality (Sharifi et al. 2019), carbon cycling (Wang et al. 2008), and pesticides fates (Plotkin et al. 2013). It is also an important model to evaluate the effectiveness of a new practice when compared with the existing practices (control), which is then used to develop best management scenarios on the use and management of soil nutrients (Cavero et al. 2012, Francesconi et al. 2014b, Tuppad et al. 2010a), tillage practices (Francesconi et al. 2014b), and irrigation practices (Cavero et al. 2012).

Most of the above studies (Kumar et al. 2011a, Wang et al. 2008) indicate the power of the APEX model at a watershed scale and in most cases used for rain-fed practices under cereal production conditions. Although recent studies have demonstrated the good performance of APEX approaches for modeling watershed-scale flow and sediment hydrological variables (Assefa et al. 2018, Golmohammadi et al. 2014, Sharifi et al. 2019), its applicability in the evaluation of pairwise differences between conservation agriculture (CA) and conventional tillage (CT) practices is limited. Therefore, the objective of this study was to evaluate the applicability of the APEX model for simulating runoff, water dynamics, nutrient dynamics, and crop yield under conservation agriculture (CA) and conventional tillage (CT) practices at the plot scale. Specifically, the study assessed the model's performance in simulating runoff, nutrients, and crop yield, and evaluated the effects of CA and CT on water dynamics (root-zone soil water, evapotranspiration, and deep percolation) and nutrient dynamics (total carbon pool, nitrogen mineralization, and organic phosphorus).

**2. Materials and Methods**

*2.1 Site description*

The study site is found in Dengeshita watershed, Upper Abay Basin, Ethiopia. Experimental plots were established near 11.32° N latitude, 36.85 ° E longitude, and at an altitude of 2042 m above mean sea level (Figure 1). The mean annual rainfall of 24 years (1995-2019) in the nearby town (Dangila) meteorological station is 1400 mm with more than 80% occurring from mid-June to September. The mean annual minimum and maximum temperature are in the range of 5-12 °C and 18-29°C. Before the establishment of this experiment in 2016, most of the selected on-farm plots were used as cultivated lands mainly growing maize under the rain-fed phase (May to August). There was no irrigated crop production in the area and over the selected on-farm plots. The average slope of the plots are in the range of 2% to 5%. The dominant top (60 cm) soil was loam soil texture and slightly acidic with a pH of 6.0 as described by Belay et al. (2020).

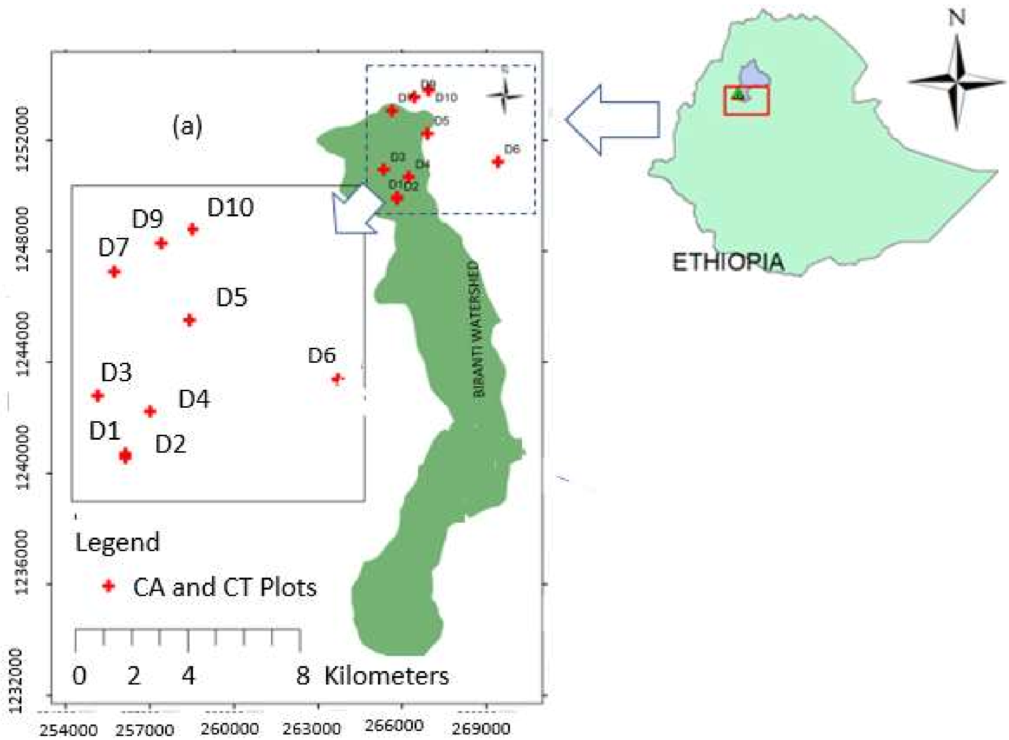
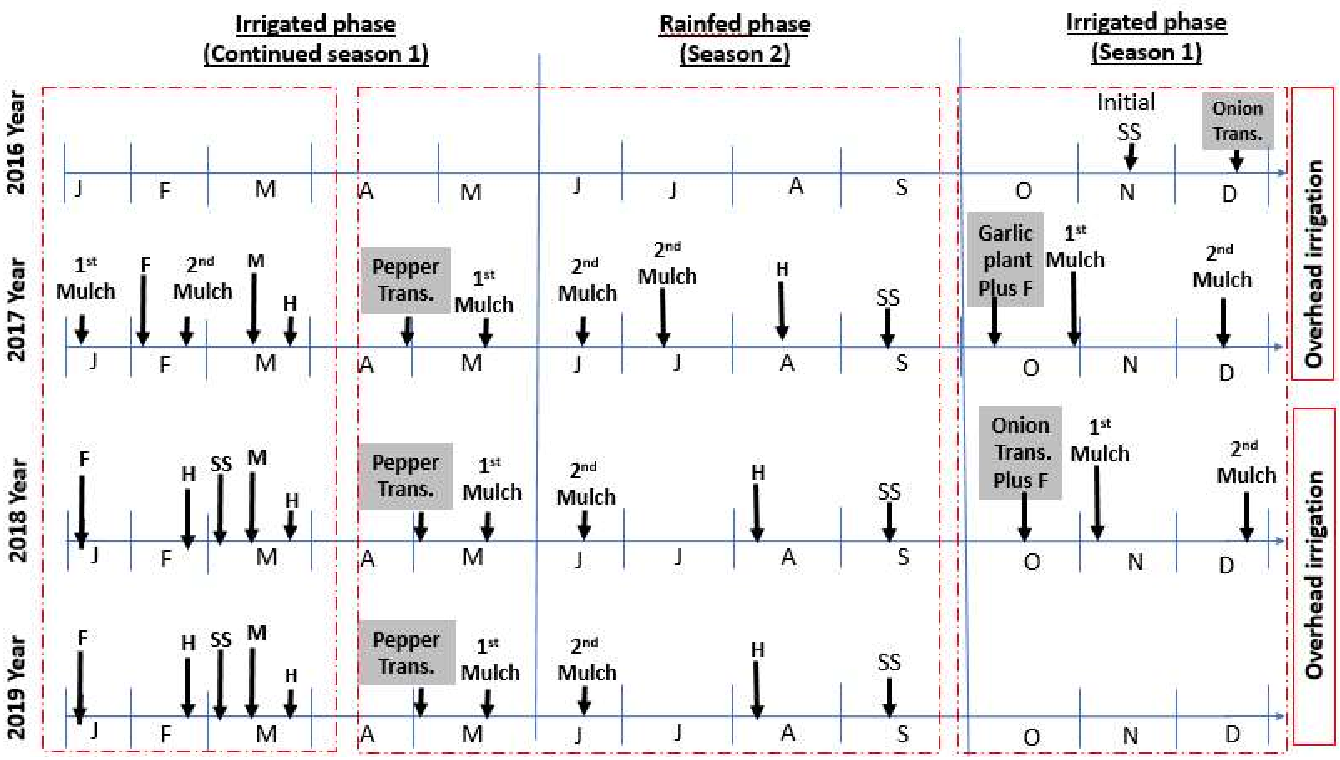



Figure 1 Location map of the experimental site

**2.2 Experimental periods**

This experiment was conducted continuously for three years (2016-2019) under irrigated (season 1) and rainfed (season 2) phases (Figure 2). Garlic and onion were grown in the 1st season (season 1) through irrigation whereas pepper was grown in the 2nd season with supplemental irrigation (start with irrigation and harvest with rain) as shown in Figure 2. The overhead irrigation method was used in both seasons for 2016 and 2017/2018 years and was converted to a drip system in 2018 and 2019 (Figure 2). Experimental activities such as transplanting, application of mulch, manure (M) and fertilizer (F), vegetable harvest (H) and soil sampling (SS), and crop rotations for both seasons are shown in Figure 2.




*Note: SS=Soil sampling, H = harvest; M= manure application; Trans.= transplanting, letters from J to D stands for Months ( January to December).*

Figure 2: A schematic diagram showing experimental years (2016 to 2019 years, cropping seasons , type of irrigation method with major farming activities.

### 2.3 Experimental design and layout

A total of 8 experimental plots were established on an area of 100 $m^2$ in size, where 50 $m^2$ was randomly assigned for CA and the rest for CT practice (Figure 3) under a paired 't' design. All other crop management practices were equally treated. CA practice here refers to minimum soil disturbance (no-till) and application of local grass as mulch, while CT refers to the existing farmers' practice (i.e. 4 to 6 tillage frequencies with 15 to 20 cm tillage depth using animal or hand tools) without mulch.

Farmers used a modified pulley system (Figure 4a) to lift water from shallow groundwater wells from 2016 to 2018 years and were replaced by solar Majipump technology in 2018 (Figure 4b).

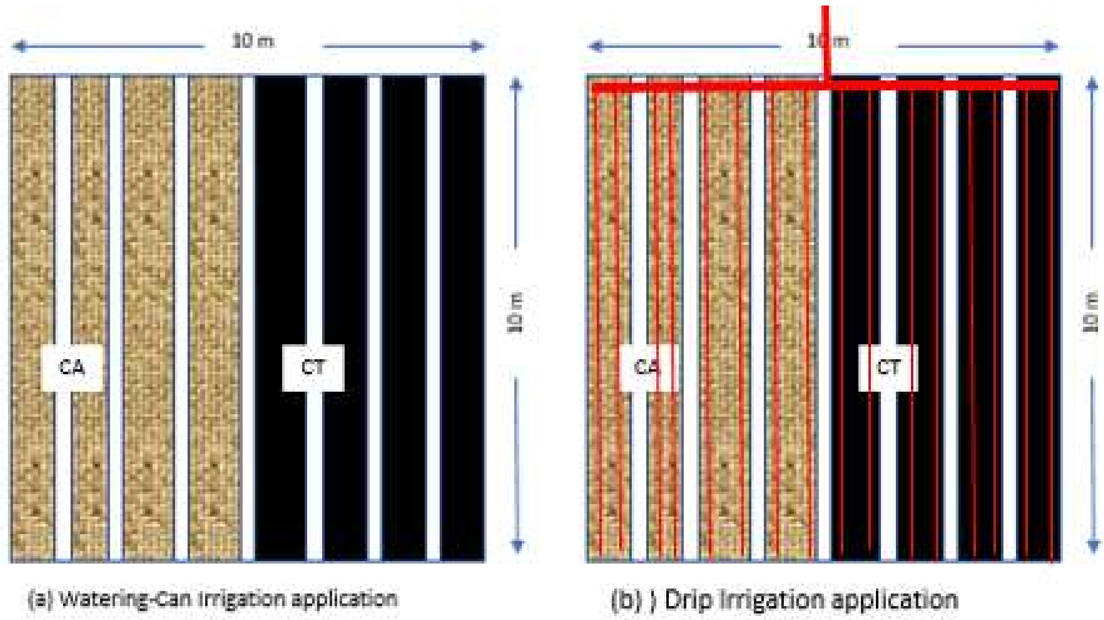



Figure 3: Experimental design and layout for overhead in 2016 and 2017/2018 years (a), and drip system in 2018 and 2019 (b) as indicated in Figure 2

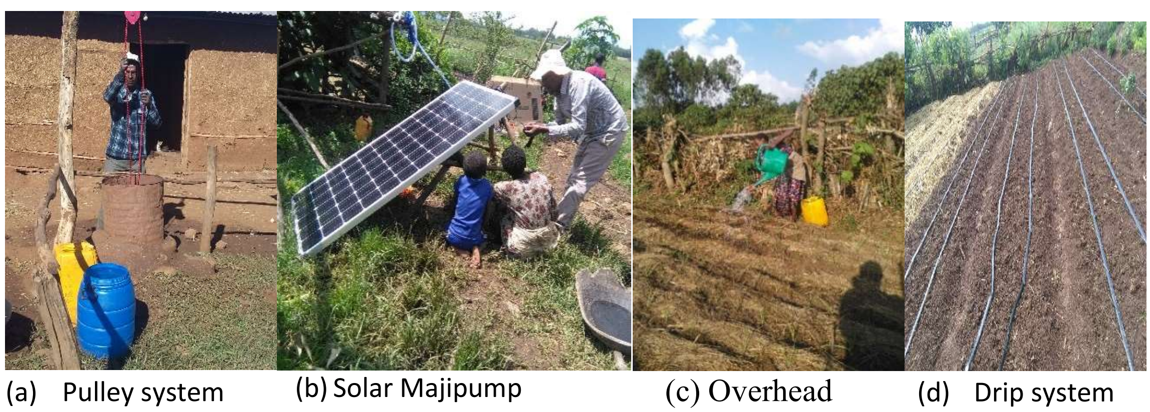



Figure 4: Water lifting and irrigation technologies used during the experimental period (2016-2019), modified pulley water lifting system (a), solar-driven Majipump water lifting system (b), overhead water application system using watering-can (c), and drip irrigation system (d).

**2.4 Agronomic practices**

Agronomic practices such as tillage, planting, harvesting, mulching, fertilizer and chemical application were monitored during the 3 years' experiment (2017-2019) for both irrigated and rainfed production (Figure 2). UREA fertilizer (46-0-0; N-P-K) was uniformly applied to each plot at the rate of 200 kg $ha^{-1}$. Local seed-free (to prevent weed infestation) and dried grass (85% organic matter, 0.18% total nitrogen, and 17 ppm available phosphorus) was applied at the rate of 2 t $ha^{-1}$ as mulch for CA plots at the beginning and mid of each cropping season (i.e. about 8 t $ha^{-1}yr^{-1}$). Cattle manure (compost: 42% organic matter, 2.1% total nitrogen, and 82 ppm available phosphorus) has been applied at the rate of 5 t $ha^{-1}$ uniformly for both CA and CT management after the harvest of the 1st crop. Onion and garlic harvests were made from February to March in the dry phase while pepper was harvested from July to

August (i.e. 4 to 6 harvests were made for pepper). The vegetable yield was then weighed from each plot during every harvest separately for CA and CT management.

### 2.5. Climate data

Climate data used for the model was collected from Dangila weather station (15 km from the site) for 2013 –2019 years. Data from 2013 to 2015 was used for the APEX model warm-up period of the simulation while data from 2016-2019 was used for purpose of calibration and validation processes (simulation) of water and nutrient dynamics. The climate data used include rainfall, temperature (maximum and minimum), relative humidity, actual sunshine hours, and wind speed. The monthly rainfall of Dangila metrological station is shown in Figure 5.

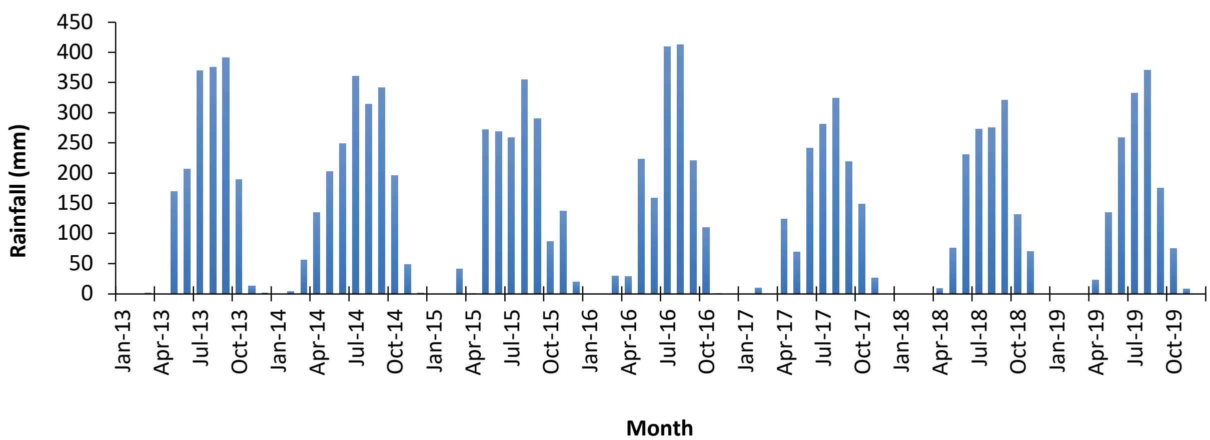



Figure 5: Monthly rainfall (2013-2019) of the nearby meteorological station used for modeling

### 2.4. Runoff, soil moisture, and nutrient measurement

*Runoff*

Runoff was measured using runoff collectors of a geomembrane sealed trench of size 0.5 m by 0.4 m by 1 m (200 L in capacity), installed at the lower end of treatment beds. One trench was used for a treatment where the runoff drains from 4 beds into the trench. It was recorded during every storm at daytime, and runoff collected during the nighttime was recorded in the morning. Each time after measurement, the trench was cleaned from incoming sediments (Belay et al. 2020). For dry drip and overhead irrigation periods, the return flow or excess water (runoff) was zero. The amount of percolated water (leachate) was monitored every 10 days using a wetting front detector (WFD) installed 40 cm below the soil surface (Belay et al.,(2020). The runoff data was used to calibrate the APEX model for hydrology.

*Sampling runoff and leachate*

During the wet period, from collected runoff, a water sample of 50 mL (20 mL for $NO_3$-N, 10 mL for $PO_4$-P) was collected for determining the concentration of nutrients (i.e., $NO_3$-N and $PO_4$-P) where about 10 sampling dates are randomly selected throughout the pepper growing period. Available phosphorus and $NO_3$-N concentrations were determined using the Palintest photometer 7500 tests. The nitrate-nitrogen and available phosphorus loads were calculated by multiplying the drainage volumes for each period with the corresponding measured $NO_3$-N and $PO_4$-P concentrations.

*Soil moisture*

Soil moisture at the top 20 cm depth was monitored using time domain reflectometry (TDR) probes (TDR 200 Spectrum Technology Inc.). The TDR was not installed type. Rather, two agricultural extension agents were trained to measure the soil moisture each time by inserting a pair of 20 cm length TDR rods into the soil. TDR measurement was conducted before an irrigation event for each treatment. A detail of the process was explained by Belay et al (2020). The soil moisture data was used to compare with the model root zone soil moisture.

### 2.5. Soil Characteristics

Soil samples were collected at the beginning of the experiment (2016), and after 3 years (2019) for testing bulk density, pH (H2O, 1:2.5), electrical conductivity, cation exchange capacity, available potassium, available phosphorus, total nitrogen, organic matter, organic carbon, field capacity, permanent wilting point, and soil texture. Sampling was made at two soil depths: the top 0-30 cm, and 30-60 cm. About 1 kg of the composite soil sample was prepared for further soil laboratory analysis. A cylinder, drop-hammer core sampler with a 5 cm height (h) and 5 cm diameter (d) was driven into the soil with blows from a drop hammer to determine bulk density. The cylinder containing an undisturbed soil core was then removed and trimmed to the end, and volume was calculated. The weight of the soil core was then determined after drying in an oven at 105°C for about 24 hours (O'Kelly 2004). Average soil characteristics data of experimental plots are shown in Table 1.

Table 1: Average soil characteristics of experimental plots determined in a soil laboratory. "√" Mark indicates that soil variable was used as an input in the APEX model for each treatment.

| Soil characteristics | Initial (2016) Test results | | CA (2019) Test results | | CT (2019) Test results | | Remark |
|---|---|---|---|---|---|---|---|
| | 0-30 | 30-60 | 0-30 | 30-60 | 0-30 | 30-60 | |
| Organic carbon - OC, g $Kg^{-1}$ | 2.3 | 2.2 | 4.5 | 4.0 | 4.0 | 3.7 | √ |
| Total nitrogen-TN, g $Kg^{-1}$ | 0.17 | 0.17 | 0.36 | 0.26 | 0.31 | 0.24 | |
| Electric conductivity-EC, dS/m | 0.13 | 0.09 | 0.39 | 0.37 | 0.36 | 0.31 | |
| Cation exchange capacity-CEC, cmol $kg^{-1}$ | 24.0 | 25.0 | 38.0 | 41.0 | 37.0 | 39.0 | √ |
| pH (H2O, 1:2.5) | 6.0 | 5.9 | 5.5 | 5.4 | 5.5 | 5.4 | √ |
| Available-phosphorus, mg $Kg^{-1}$ | 21.0 | 8.5 | 30.2 | 30.7 | 26.7 | 22.9 | √ |
| Available, potassium, mg $Kg^{-1}$ | 1111.0 | 792.0 | 143.0 | 25.0 | 33.0 | 29.0 | √ |
| Field capacity, $cm^3$ $cm^{-3}$ | 34.0 | 30.0 | 31.0 | 28.0 | 31.0 | 28.0 | √ |
| Permanent wilting point, $cm^3$ $cm^{-3}$ | 22.0 | 21.0 | 22.0 | 21.0 | 22.0 | 21.0 | √ |
| Bulk density, $g/cm^{-3}$ | 1.22 | 1.32 | 1.22 | 1.32 | 1.22 | 1.32 | √ |
| Sand, g $Kg^{-1}$ | 39.0 | 22.0 | 28.0 | 27.0 | 25.0 | 24.0 | √ |

### 2.6 The APEX Model

We used Soil Conservation Service Curve Number method (SCS-CN ) method in the APEX model as clearly described by Assefa et al. (2018). APEX simulates watershed or plot level processes primarily based on weather data, soil types and their characteristics, topography, vegetation, and management practices (Wang et al., 2014). The most common practices for use in APEX which were properly monitored each season in this study include tillage, planting, fertilizer, irrigation, and mulch application details (date, frequency, amount, type, and harvest). APEX input data were properly organized in the "APEX editor" macro environment to run the model using a calibrated executive application file in a similar way as Assefa et al. (2020) described. A fixed irrigation application rate of overhead and drip irrigation was provided in the APEX model. The most important management factors for the CA other than the control treatment were the use of grass mulch and no-tillage practices and were provided in the management files.

APEX model used atmospheric N inputs, fertilizer and manure N applications, crop N uptake, organic N transport on sediment; and nitrate-nitrogen ($NO_3$-N) losses in leaching, surface runoff, and other processes. Nitrate-nitrogen ($NO_3$-N) losses in runoff were used for calibrating the nutrient balance based on the observed data. Amounts of $NO_3$-N contained in the runoff were estimated as products of the volume of water and the average losses. The loading function considers sediment yield, organic N loss in the soil surface, and an enrichment ratio (Williams, 1995). ADDMULCH operation was in APEX version 1501 (in 2017 release) which was explained in detail by Assefa et al. (2018).

**2.7. APEX model calibration and validation at the seasonal time scale**

APEX model was calibrated for runoff and nutrients using the observed data of experimental plots under CA and CT systems with continuous vegetable production (2017 through 2019). Some hydrological parameters have been calibrated by Assefa et al. (2018) for the tilled system based on streamflow data at a watershed scale which was not calibrated according to plot level, and they transferred model parameters to the APEX plot level simulation at the experimental site by considering scale effect of parameters. Experimental plots were divided into four data sets for calibration, and four data sets for validation as we could not get the same crop every year for modeling crop yield as stated by Assefa et al. (2020). In a 3-year vegetable experiment, onion and garlic crops have been used in the first dry irrigation phase while green pepper was used in the second supplementary irrigation phase. For the dry irrigation phase, onion and garlic crops have been validated using APEX by Assefa et al. (2020). In this study, we focused on modeling pepper yield using the three seasons observed yield data of the on-farm plots, which were not calibrated for the site.

In this study, some of the parameters (Table 2) were modified using observed runoff and soil moisture data for both tilled (CT) and conservation agriculture (CA) at the plot level. We then used the fitted values of the most sensitive calibrated parameters for the site. The most sensitive parameters (parameter: fitted value), according to Assefa et al. (2018), used in this study include Hargreaves potential evapotranspiration (PET) equation exponent (PARM-34: 0.6), runoff CN residue adjustment parameter (PARM-15:0.25), runoff volume adjustment factor (PARM-92:0.6), runoff CN initial abstraction (PARM-20:0.191), soil water lower limit (PARM-5:0.4), and soil evaporation coefficient (PARM-12:1.512), in the order of decreasing influence (Assefa et al. 2018). Besides, we also used PARM-23, PARM-49 and PARM-61 for calibration purposes. For nutrient dynamics studies, only Param 14 (Nitrate leaching ratio) was more sensitive and was adjusted using the observed data of nitrogen and phosphorus in runoff. In all cases, we used the manual calibration technique. All other values were managed in the same way as used by Assefa et al. (2018). After calibration and validation, the unmeasured water and nutrient balance components were compared between CA and CT practices.

**2.8. Model performance statistical measures**

We used commonly used statistical measures to evaluate APEX model performance in the adjustment of some parameters in runoff and nutrient components. These include Nash – Sutcliffe efficiency (NSE), and Coefficient of determination ($r^2$) according to Moriasi et al. (2007) and Wang et al. (2012).

**3. Results**

*3.1 Calibration of APEX for hydrology and nutrients*

*Runoff*

APEX calibrations of runoff during the crop growth period were improved through the adjustment of runoff parameters (Table 2) until the simulated runoff agreed with the observed runoff. The most sensitive parameters, in the order of importance, are shown in Table 2 with great modification for some as compared with the parameters set by Assefa et al. (2018).

Table 2 Water balance sensitive parameters, parameter value range, default value, and adjusted/calibrated values for water balance.

| parameters | Parameter range | Assefa et al. (2018) | Calibrated values for CA | Calibrated values for CT |
|---|---|---|---|---|
| Param 12 | 1.5-2.5 | 1.5 | 1.5 | 2 |
| Param 17 | 0-0.5 | 0.5 | 0.45 | 0.4 |
| Param 20 | 0.05-0.4 | 0.191 | 0.191 | 0.2 |
| Param 23 | 0.0023-0.0032 | 0.0032 | 0.0032 | 0.0032 |

| | | | | |
|---|---|---|---|---|
| Param 49 | 0.1-15 | 0.3 | 6* | 10* |
| Param 61 | 0.05-0.95 | 0.2 | 0.95 | 0.95 |

** Parameter value valid for pepper crop.*

The APEX model simulation results of all the above (Table 3) parameter values across the crop growth period exhibited a very good performance with $r^2$=0.99 for CA and $r^2$ = 0.96 for CT, and with NSE =0.97 for CA and with NSE=0.91 for CT during calibration (Figure 6). The model results during validation across crop growth period also exhibited a very good performance with $r^2$=0.94 for CA and $r^2$ = 0.91 for CT and with NSE =0.77 for CA and with NSE=0.57 for CT (Figure 6). The simulated runoff was greater than the observed runoff for both calibration and validation. An average simulated runoff reduction of 70% was achieved under CA compared with the CT during calibration while it showed a runoff reduction under CA of about 65% during validation compared with the CT. The average observed runoff showed about 35-45% lower under CA compared with the CT. Observed and simulated runoff during the three dry seasons was approximately zero as shown in Figure 6.

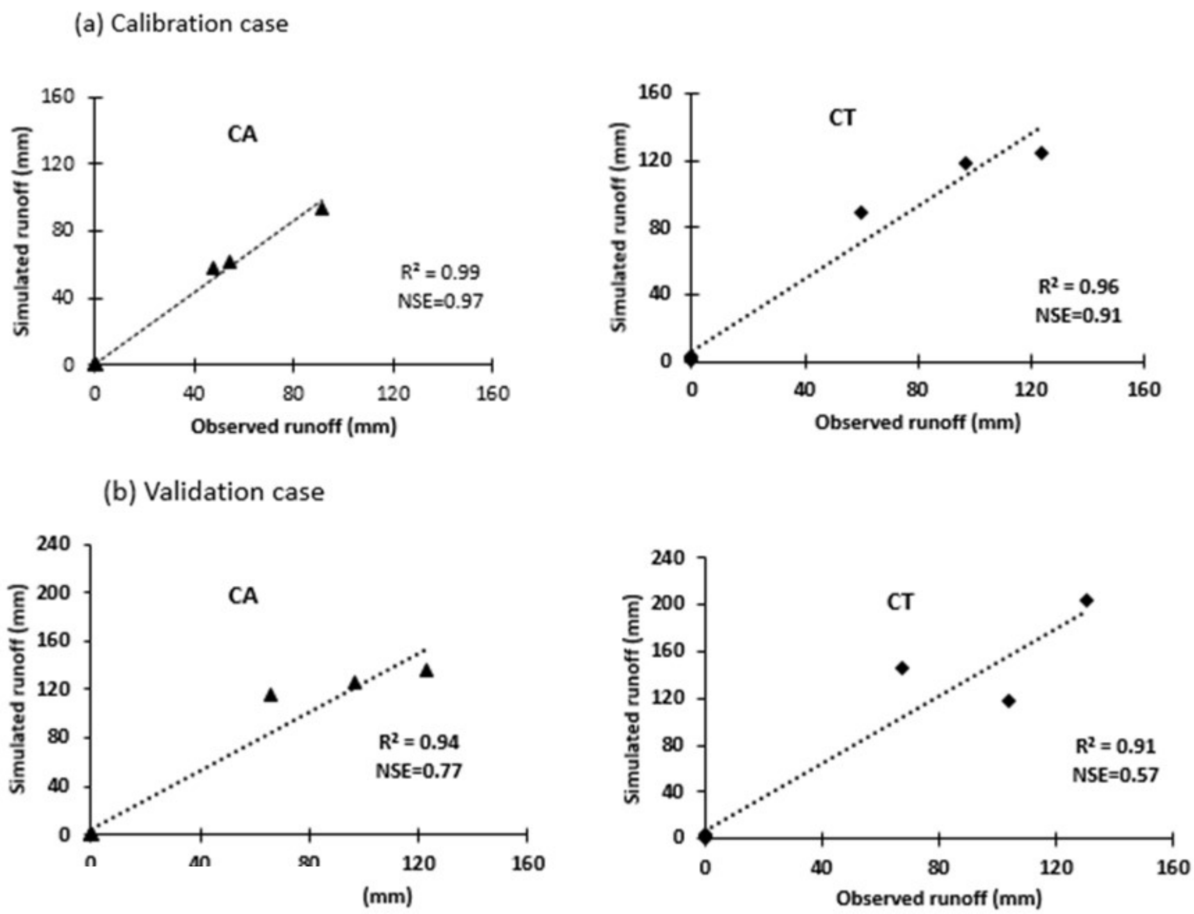



Figure 6: Average observed versus simulated runoff for treatments in the crop periods (1st cycle-October to February (dry), and 2nd cycle –March to August-(rain)) and the results of model performance measures; coefficient of determination ($r^2$) and Nash-Sutcliffe efficiency (NSE). The dry period runoff results (three seasons) were approximately zero for both simulated and observed cases.

*Nutrient*

APEX model simulation of nitrogen load in runoff (QN) for CA treatment was in close agreement with observed values with $r^2$=0.87, NSE= 0.35 and under calibration case and with $r^2$=0.82, NSE=0.58 under validation case (Figure 7). Similarly, APEX simulation of QN for CT gave a good performance with $r^2$=0.93, NSE= 0.63 under calibration case and with $r^2$=0.81, NSE=0.57 under validation case (Figure 7). APEX model performance using NSE measure showed poor performance under CA treatment compared with CT treatment. APEX performance was satisfactory based on the two ($r^2$ and NSE) model performance measures for both CA and CT treatments except for calibration case in CA (NSE=0.55). QN in this phase was nil since there was no or little runoff in dry phases of the drip irrigation system. However, CA practices showed reduced QN values for both the observed and simulated cases when compared with the CT.

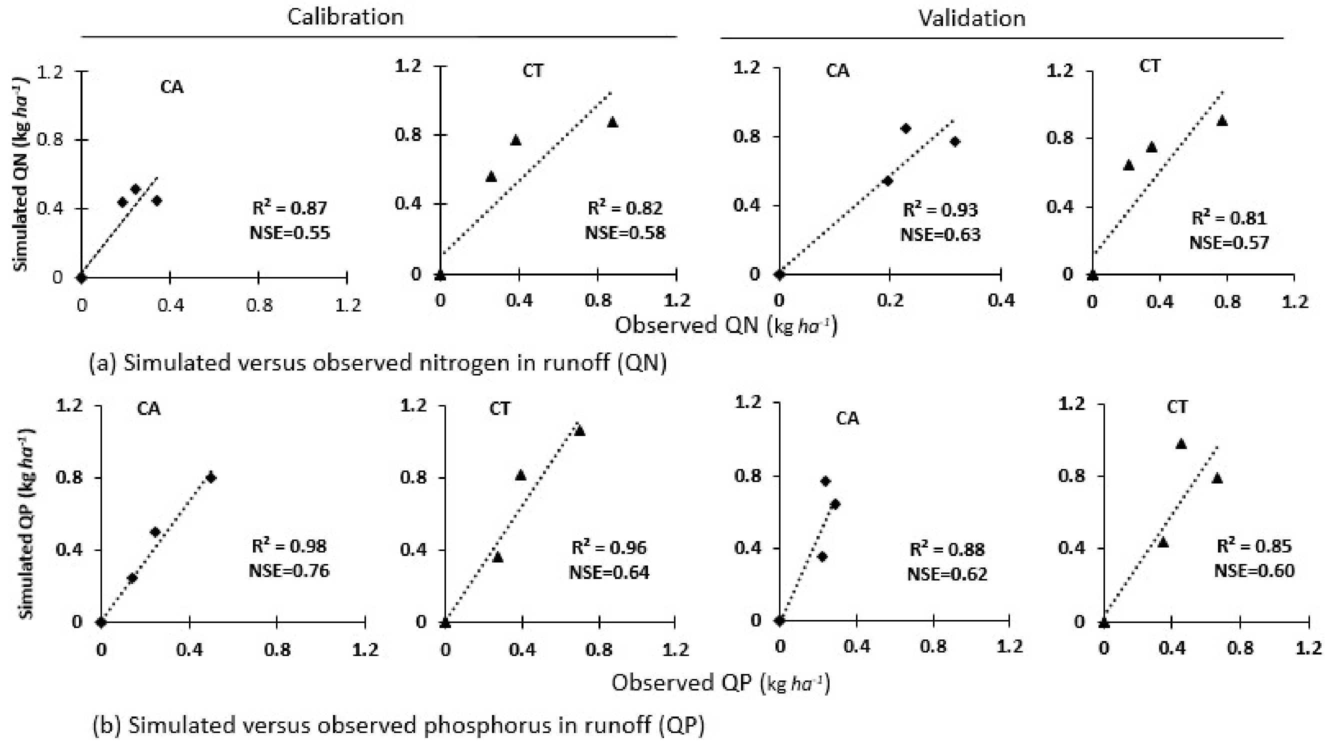



Figure 7: Average observed and simulated nitrogen in runoff (a) and phosphorus in runoff (b) under calibration and validation cases for CA and CT treatments for the crop periods and the model performance measure values; coefficient of determination ($r^2$), and Nash-Sutcliffe efficiency (NSE).

Similarly, APEX model simulation of phosphorus load in runoff (QP) for CA treatment was in close agreement with observed values with $r^2$=0.98, NSE= 0.76 under calibration case and with $r^2$=0.88, NSE=0.62 under validation case (Figure 7). Similarly, APEX simulation of QP for CT showed good performance with $r^2$=0.96, NSE= 0.64 under calibration case and with $r^2$=0.85, NSE=0.60 under validation case (Figure 7). APEX model performance using NSE measure showed poor performance under CT treatment compared with CA treatment. APEX performance was a very good result in terms of $r^2$ and NSE for both CA and CT under calibration and validation cases. Similarly, since there was no or little runoff in dry phases of the drip irrigation system, QP in this phase was nil. However, CA practices showed reduced QP values for both the observed and simulated cases when compared with the CT.

*Crop Yield*

Onion and garlic crops have been simulated and validated by Assefa et al. (2020), however, in a 3-year vegetable experiment, green pepper was used in the second supplementary irrigation phase which was not validated by Assefa et al. (2020). After runoff and nutrient calibration, the crop parameters such as biomass-energy ratio (WA=33), harvest index (HI=0.6), optimal plant growth (TOP=25), optimum base temperature (TBS=11.5) and maximum potential leaf area index (DMLA=6) have been modified for pepper to simulate the yield at the plot level. Accordingly, the simulated and observed pepper yield of the three years were compared between treatments (Figure 8). It shows that the simulated yield followed similar patterns of variation with the observed pepper yield (Figure 8).

Pepper yield from overhead irrigation (2017) was the lowest than the yield obtained from drip irrigation systems (2018 and 2019). Moreover, the APEX model showed significantly increased simulated yield under CA as compared to the CT management (Figure 8).

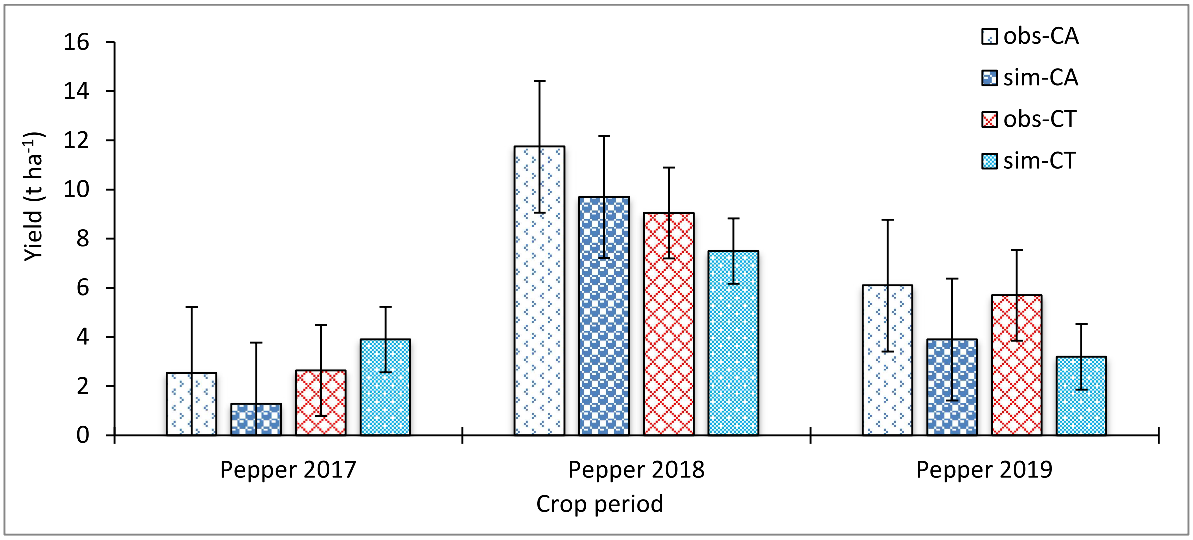



Figure 8: Average observed (Obs.) versus simulated (Sim.) pepper yield, pepper yield (observed and simulated) in three experiential years (2017-2019) under conservation agriculture and conventional tillage treatments.

**3.2 Impacts of CA practices on unmeasured water and nutrient dynamics**

*(a) Evapotranspiration, percolation, and soil water results of the APEX model*

After calibration and validation of the APEX model using observed runoff (Figure 6), the water balance components such as evapotranspiration (ET) (Figure 9a), root zone soil water (RZSW), and percolation (PRK) (Figure 9b) were investigated to observe the impact of CA practices when compared with CT practice. It showed that the CA treatment would allow a reduction of ET by about 10-33 % during the dry and rainy periods compared with the CT, except for the rainy period of 2019 which showed an increased ET (by 15 % ) in the CA (Table 3).

Table 3: Simulated evapotranspiration (ET), percolation (PRK), and root zone soil water (RZSW) for the CA and CT treatments in the cropping periods (full and supplementary irrigation or dry and rain periods).

| Variables | Treatments | Crop periods* | | | | | |
|---|---|---|---|---|---|---|---|
| | | 2016/2017 (Season 1) | 2017 (Season 2) | 2017/2018 (Season 1) | 2018 (Season 2) | 2018/2019 (Season 1) | 2019 (Season 2) |
| ET | CA | 373.00 | 388.00 | 229.00 | 693.00 | 265.00 | 632.00 |
| | CT | 411.00 | 500.10 | 304.30 | 696.00 | 353.50 | 537.00 |
| | % difference | 10.19 | 28.89 | 32.88 | 0.43 | 33.40 | **-15.03** |
| PRK | CA | 16.00 | 256.00 | 63.40 | 268.00 | 162.58 | 128.00 |
| | CT | 11.60 | 167.40 | 59.00 | 148.00 | 72.00 | 85.00 |
| | % difference | 37.93 | 53.10 | 7.46 | 81.08 | 125.81 | 50.59 |
| RZSW | CA | 97.00 | 85.00 | 79.50 | 85.00 | 82.00 | 52.00 |
| | CT | 78.60 | 72.50 | 75.40 | 83.40 | 64.00 | 35.00 |
| | % difference | 23.41 | 17.24 | 5.44 | 1.92 | 28.13 | 48.57 |

*Note: Season 1 implies crop periods from October to February (onion or garlic cropping periods) while season 2 implies crop periods from March to August (Pepper cropping period).

Similarly, the APEX model showed an increased root zone soil water (RZSW) in the range of 2-49% (average 21%) in the CA when compared with CT treatment over dry and rain periods under various cropping periods (Table 3). The variation in RZSW between treatments shown by the APEX model was the highest (>75%) during the no-soil water stress period (after irrigation and during wet periods) and was the lowest (<10 %) during the soil waterstressed period after the 1st irrigation cycle stopped (Figure 8b). In Figure 8b, the portion of the figure within the dashed box shows the simulated RZSW during dry and supplementary irrigated phases (variation was highest between CA and CT) while the dashed circle portion of the figure show RZSW when irrigation was stopped, and until the second planting period where the variation was lowest (Figure 8).

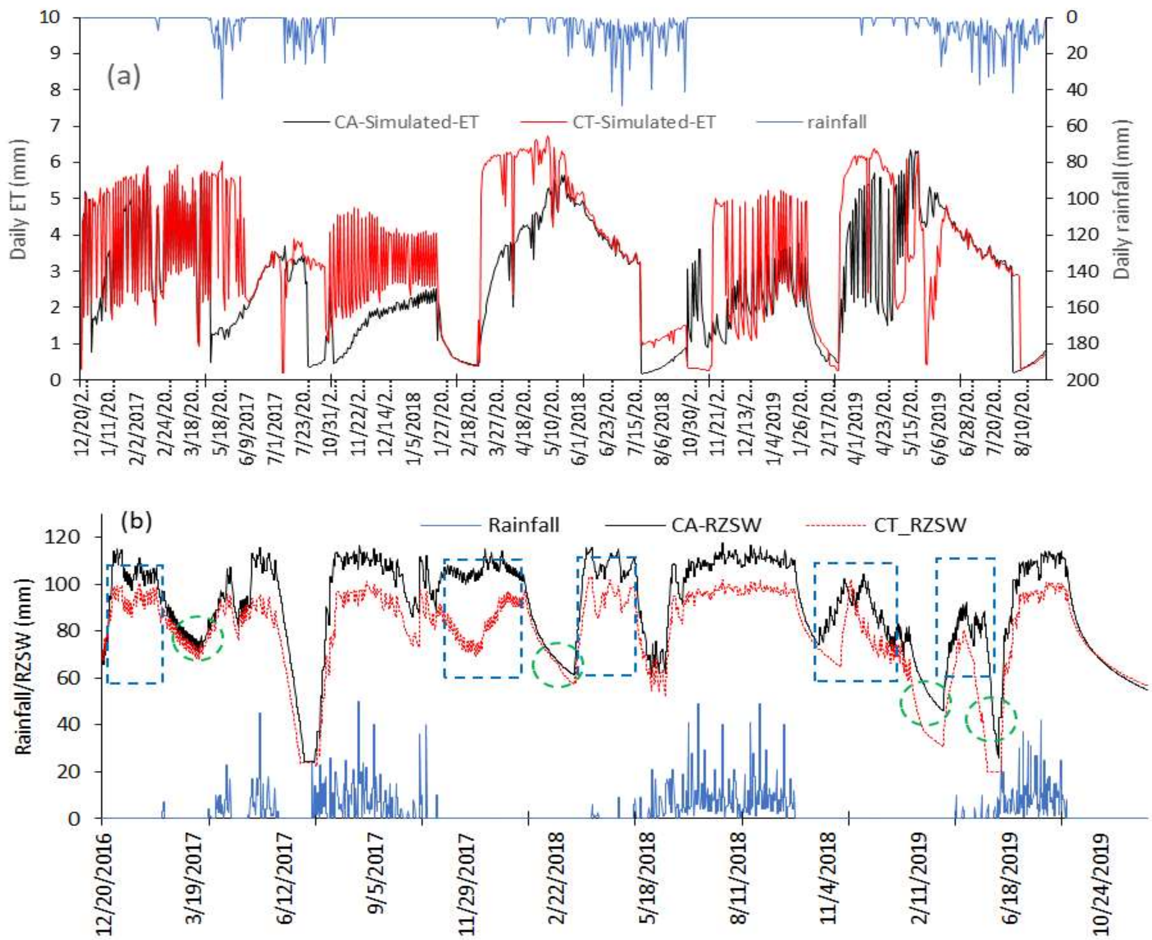



Figure 9: Simulated ET (a) and root zone soil water (RZSW) (b) values for conservation agriculture (CA) and conventional tillage (CT) practices for the three years (6 irrigation cycles).

On the other hand, the response of percolation (PRK) past the root zone (20 cm) to grass mulch and no-tillage (CA) practices under both dry and supplementary irrigation phases was also well simulated by APEX showing about 8-126% higher percolation in the CA compared with CT (Table 3). The variation in PRK between treatments was maximum during the dry period irrigation phase and minimum during rainy periods of the experiment in the site. PRK depends on the soil water available in the upper soil layer (20 cm), greater soil water under CA may induce further percolation process to occur within the soil when compared to the CT treatment.

*(b) Impacts of CA on soil quality.*

Among many output options of the APEX model, crop residue, total carbon pool, net total N mineralization, and fresh organic phosphorus have been simulated across soil depths of interval approximately 1 cm (Figure 10). All soil organic components showed significantly higher loads (in kg ha$^{-1}$) under CA treatment compared with the CT for all soil depths (Figure 10). Simulated crop residue was significantly ($p<0.05$) higher for both treatments at 1 cm depth and lower after 35 cm soil depth which was higher under CA compared with the CT treatment (Figure 10a). The total carbon pool was highest near the plow depth between 14 -30 cm and lowest at 3 cm depth below the soil surface, however, it was higher under CA compared with the CT for all depths (Figure 10b). Similarly, Net N-mineralized was highest at the plow depth (14-21 cm) in the case of CA and was increasing with depth for CT treatment, however, greater values were simulated under CA for all depth (Figure 10c). Unlike the above components, simulated fresh organic phosphorus (FOP) showed higher values for the top 7 cm soil depths for both treatments however, greater simulated values were observed under CA compared with the CT (almost zero under the lower depths) (Figure 10d).

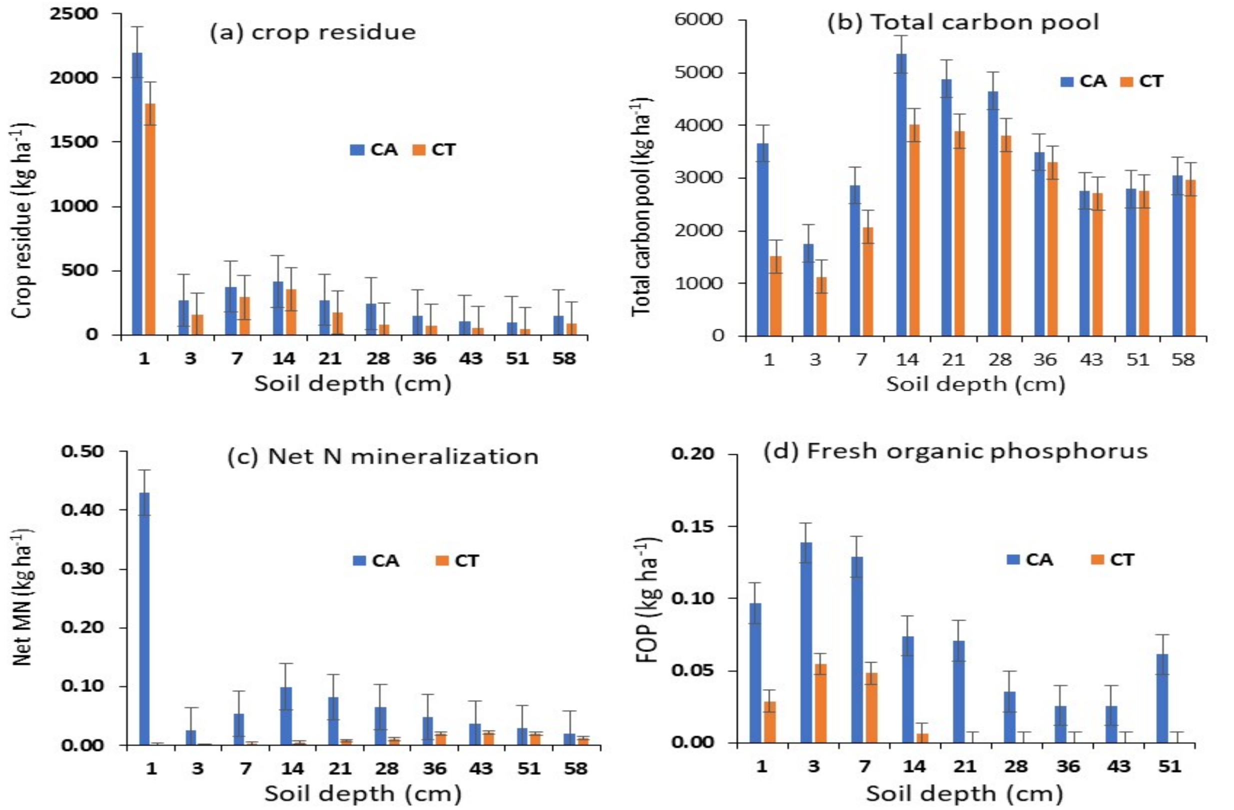



Figure 10: Simulated changes in soil crop residue left on the ground (a), total carbon pool (b), total Net N mineralized (c), and fresh organic phosphorus (d) against CA and CT treatments simulated after the end of the experiment (2019).

# 3 Discussion

## 3.1 Water dynamics

*Runoff and Evapotranspiration*

The agreement between measured and modeled runoff obtained in this work was similar in performance at watershed scale reported by Assefa et al (2018). In this study, APEX reasonably performed to simulate surface runoff in the crop growth period under CA and CT practices at the plot scale, though its performance was lower for CT (Figure 6). Surface mulch under CA encouraged infiltration and decreased runoff due to curve number reduction compared with CT(Williams et al. 2008). The reduction in observed runoff (4 -56%) and an increase of percolated water (20-50%) in the CA reported by Belay et al. (2020) showed an impact to increased water saving particularly during the dry irrigation phases by improving soil water storage. Besides, the use of mulch reduces runoff by absorbing the energy of raindrops and then by delaying the runoff and enhances percolated water (PRK) as reported by Mohammad and Adam (2010).

On the other hand, the APEX model has performed well in simulating ET particularly during dry phases (Table 3 and Figure 11) which is in agreement with the reduction of the evaporation of water from the soil reported by Diaz et al. (2005). Simulated ET was slightly ($p>0.05$) higher (10%) than the observed ET for CA while it showed significantly ($p<0.05$) higher (20%) observed ET than the simulated ET under CT of the two years (Figure 11). However, variations in simulated ET under pepper were insignificant between CA and CT during rainfed, though it showed lower values of simulated ET for CT in 2019 as compared with 2018 (Figure 11). Greater reductions in ET under CA were probably due to the cooling effect (reduction in soil temperature) during dry periods as a result of surface mulch cover (Schonbeck and Evanylo 1998). The greater (14-33%) reduction in ET under CA during the dry irrigation phases of various vegetable production (Table 3) could also imply an improved water-saving (14–27%) as reported in different studies (Assefa et al. 2020, Assefa et al. 2018, Belay et al. 2020, Belay et al. 2019). Overhead irrigation system in season 2 which was conducted only in 2017 was nil as compared with the contribution of rain (95%) and therefore, had little impact to affect runoff.

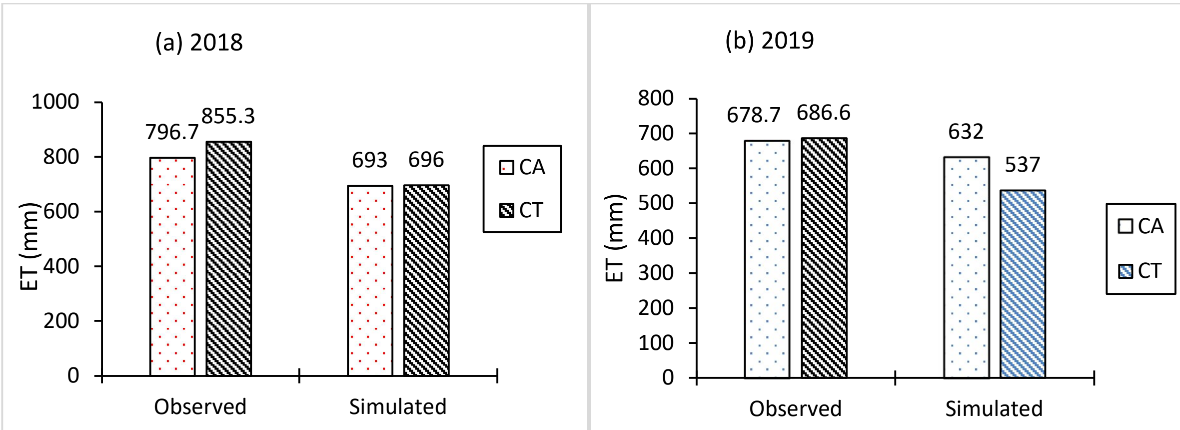



Figure 11: Comparison of ET pepper crop under CA and CT treatments using measured data and simulated values for 3 supplementary irrigated seasons (season 2) as described by Belay et al. (2020).

*Percolation (PRK) and root zone soil water (RZSW)*

On the other hand, the observed percolated water for both treatments which was captured from only the vertical component of subsurface water was clearly explained by Belay et al. (2020). However, the result could not be compared with the simulated PRK that included all subsurface internal flows (vertical, horizontal and groundwater storage components) in the soil. The percolated water amount reported by Belay et al. (2020) was about 8-10 % of simulated PRK under CA and CT practices indicated in this study. However, the variation in simulated PRK between treatments was attributed to the use of no-tillage used to encourage less disturbance of soil pore networks and increases porosity (Kabir 2005).

In addition to this, the response of simulated RZSW to grass mulch and no-tillage practices under both dry and supplementary irrigation phases was also efficiently modeled by APEX showing a significant ($p<0.05$) difference between treatments under various cropping seasons (Table 3). Simulated RZSW was lower when irrigation was stopped and continued until the second planting period (Figure 8). This showed that APEX depicted changes in RZSW and could be used to build different farming scenarios. Similar simulated results have been reported by Assefa et al. (2018) and Golmohammadi et al. (2014). Soil moisture and temperature are the most influential factors (Carbonell-Bojollo et al. 2019, Lal 2004) to affect crop growth and microorganism activity (organic matter decomposition). Indeed, soil moisture is a key factor in the activity of soil biota that breaks down OM to plant-available form (Carbonell-Bojollo et al. 2019). In such cases, CA could have more importance in regions with limited rainfall and high evaporation rates (Hobbs et al. 2008).

In this study, observed root zone soil water in the upper soil layer (20 cm) in selected 4 crop periods was plotted with the simulated value of RZSW (20 cm soil depth) to observe the impact of CA practice compared with the CT (Figure 11). Though the simulated soil water was much higher compared with the observed, both the observed and simulated RZSW in CA was significantly ($p<0.05$) higher compared with the CT, particularly during dry phases (Figure 11a and c).

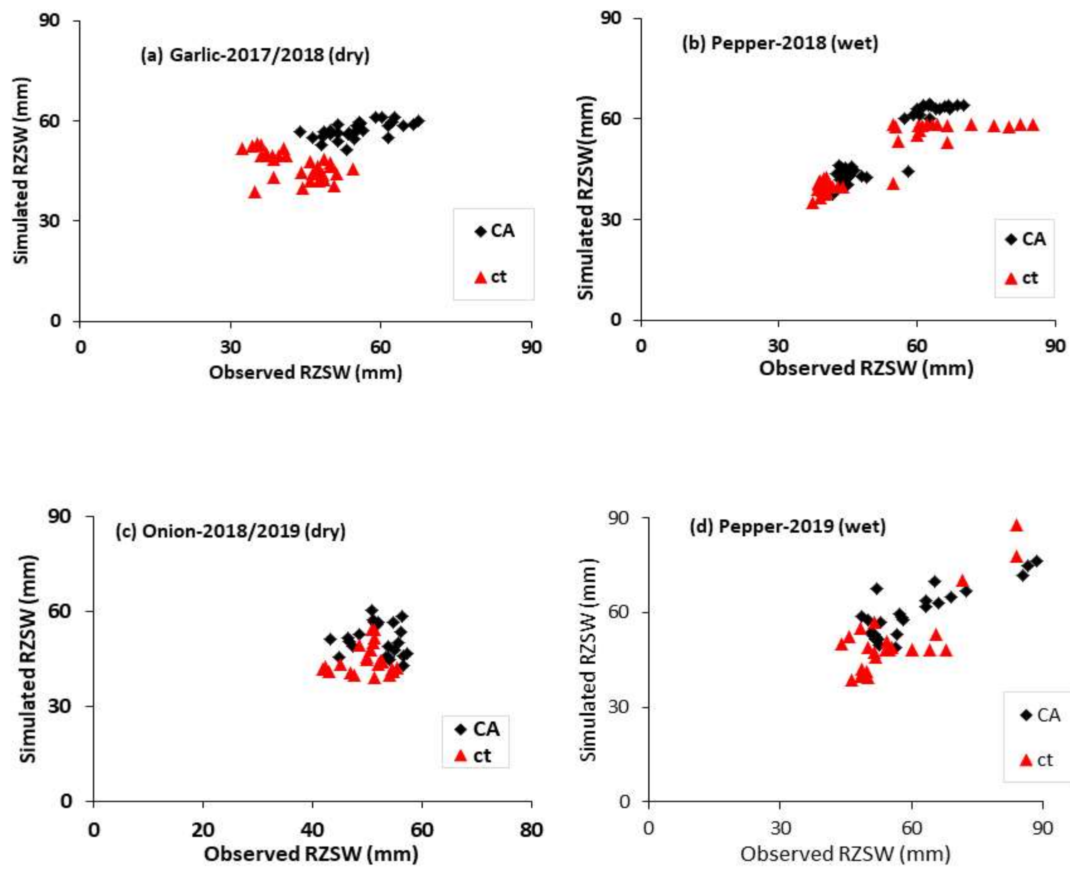



Figure 11: Comparison of the RZSW under CA and CT treatments using measured data (20 cm soil depth) and simulated values (20 cm depth) for selected 4 irrigation periods. Observed RZSW was the average of calibrated TDR readings for the upper 20 cm soil layer measured before irrigation. Garlic and Onion (a and c) were selected for the dry phase while pepper (b and d) were selected for the supplementary phase.

### *3.2 Nutrient Dynamics*

We found APEX model has performed well to simulate QN for both treatments with lower NSE value under CA treatment compared with CT which indicated simulated QN was greater than the observed QN since APEX has also predicted increased simulated crop residue (Figure 11a)., total carbon pool (Figure 8b) and Net N-mineralized (Figure 11c) due to the added mulch under CA treatment which was not practical for the observed case. However, CA practices showed reduced QN values for both the observed and simulated cases when compared with the CT. The N-loss is also similar to those found by Cavero et al. (2012) in the Mediterranean region at the watershed level.

Similarly, the APEX model simulation of phosphorus load in runoff (QP) in both treatments was in close agreement with observed values under calibration and validation conditions (Figure 7). CA practices showed reduced QP values for both the observed and simulated cases when compared with the CT while APEX simulated increased fresh organic phosphorus (Figure 11d) under CA treatment compared with CT treatment at different soil depths. The result was also in line with Borah et al. (2006) and Chaplot et al. (2004). Moreover, APEX was proved to be an effective tool to assess CA practice as the best practice for reducing N and P loads in the runoff because of its barrier effects to reduce sediment-laden nutrients from surface runoff. The average simulated QP reduction under CA could be associated with reductions in a runoff, as QP calculation in APEX considers the volume of runoff (Wang et al. 2008). Lower N losses were found in efficient drip irrigation systems with typical low return flow (no-runoff), and higher losses in inefficient surface irrigation systems with typical high excess unused irrigation water (Assefa et al. 2020, Belay et al. 2020, Klocke et al. 1999, Spalding et al. 2001).

In connection with simulated crop residue, an increase in net N mineralization (Figure 11c) with the microbial decomposition of organic N from manure, organic matter, and mulches/crop residues (Cambardella et al. 2003) has also released soluble inorganic nutrients in plant-available form. Temperature and soil moisture could play a greater role in this process (Diacono and Montemurro 2011). In this regard, mineralized N under CA was highest near the optimum root depth (14-21 cm) where most of the microorganisms exist and then decreased with depth. It means that nutrients in the organic matter must undergo mineralization before they can be used by plants. The total carbon pool was highest near the plow depth between 14 -30 cm and lowest at 3 cm depth below the soil surface, however, it was higher under CA compared with the CT for all depths due to similar reasons (Figure 11b). We also tried to compare the observed total soil organic carbon (TOC) and total nitrogen (TN) at the end of the e xperiment (2019) with the simulated one for both treatments (Figure 12).

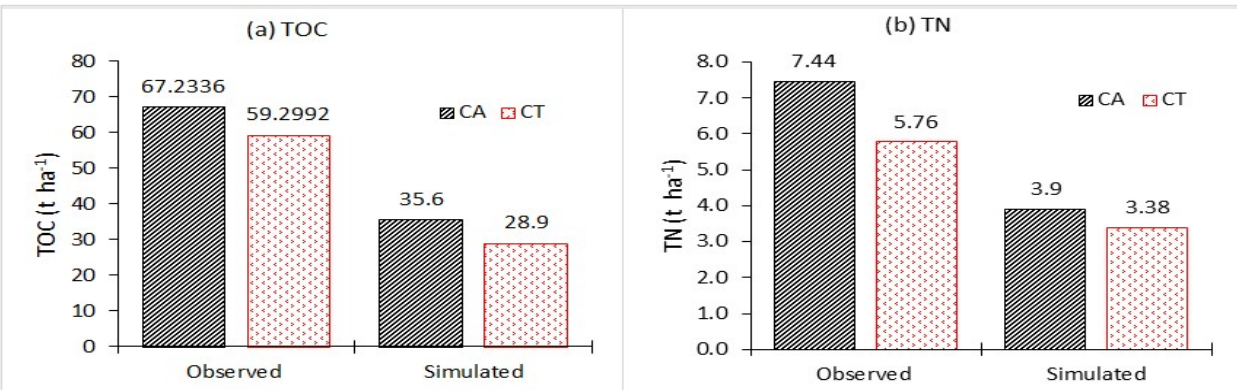



Figure 12: Comparison of observed and simulated total organic carbon (TOC) and total nitrogen (TN) under CA and CT treatment.

The simulated TOC was about 1.9 and 1.7 times lower than the observed respectively for CT and CT treatments (Figure 12a) while simulated TN was about 1.9 and 2.05 times lower than the observed respectively for CA and CT (Figure 12b). Both observed and simulated TOC and TN were slightly greater under CA treatment compared with the CT due to an increased crop residue and mulch and the associated increase of TOC and TN from such input (Figure 10c) by microbial decomposition of organic N from manure, organic matter, and mulches/crop residues (Cambardella et al. 2003). The lower simulated values may be attributed to the higher simulated nitrogen in runoff compared with the observed as depicted in Figure 7a.

### *3.3 Yield and crop biomass*

Simulated pepper yield followed similar patterns with the observed yield, and the variation between treatments followed the same pattern (Figure 8). Pepper yield from overhead irrigation (2017) was the lowest than the yield obtained from drip irrigation systems (2018 and 2019) which were probably attributed to leaf blight associated with the application of impure well water over the whole aboveground plant parts (Xie et al. 1999). In addition to this, the contribution of irrigation in 2017 (5%) was less than the contribution of irrigation in 2018 (46%) as compared to the rain which again indicated that the reduction in yield might be due to waterlogging effect (Belay et al. 2020). Besides, transplanting of pepper about 2 months before a rainy season can improve the yield since the rain season coincides with flowering and fruit development stages Jameiz et al., (2000). Moreover, the APEX model showed significantly increased yield under CA as compared to the CT management (Figure 8) which also showed significantly higher simulated crop biomass under CA treatment compared with the CT (Figure 10a).

## 5. Conclusion

In conclusion, The APEX model reasonably captured the differences in hydrological responses between conservation agriculture (CA) and conventional tillage (CT) under the experimental conditions. APEX simulations show decreased evapotranspiration, runoff, nitrogen, and phosphorus loads in runoff while it also showed an increment in root zone soil water and percolation under CA compared with the CT treatment. The reason for the different responses of simulated variables under CA and CT practices was obviously due to the combined use of grass mulch cover and no-tillage practices under CA treatment. Observed data for runoff and soil water content indicated similar trends in variation among treatments. Thus, APEX simulations can be used to effectively select the best management vegetable production scenarios compared to the existing practices. The model can therefore be used for assessing the effectiveness of various vegetable production scenarios and water uses to inform the farmer. The improvement of irrigation water saving and the decrease in the runoff for the vegetable crops allow us to conclude that mulch cover with no-tillage practices can be used as an effective farming practice in alleviating water shortage issues experienced in water shortage areas. Model simulations indicated lower evapotranspiration, runoff, and nitrogen and phosphorus losses in runoff, together with higher root-zone soil water and deep percolation under CA than under CT. These differences were primarily associated with the combined effects of no-tillage and grass mulch used in the CA treatment. The observed runoff and soil water content generally showed trends consistent with the simulated results, although discrepancies between observed and simulated values remained for some variables.

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**Reference**

Antle, J.M., Basso, B., Conant, R.T., Godfray, H.C.J., Jones, J.W., Herrero, M., Howitt, R.E., Keating, B.A., Munoz-Carpena, R. and Rosenzweig, C.J.A.s. (2017) Towards a new generation of agricultural system data, models and knowledge products: Design and improvement. Agricultural Systems 155, 255-268.

Assefa, T., Jha, M., Reyes, M., Worqlul, A., Doro, L., Tilahun, S.J.J.o.S. and Conservation, W. (2020) Conservation agriculture with drip irrigation: Effects on soil quality and crop yield in sub-Saharan Africa. Journal of Soil and Water Conservation 75(2), 209-217.

Assefa, T., Jha, M., Reyes, M. and Worqlul, A.W.J.S. (2018) Modeling the impacts of conservation agriculture with a drip irrigation system on the hydrology and water management in sub-Saharan Africa. Sustainability 10(12), 4763.

Belay, S.A., Assefa, T.T., Prasad, P., Schmitter, P., Worqlul, A.W., Steenhuis, T.S., Reyes, M.R. and Tilahun, S.A.J.S. (2020) The Response of Water and Nutrient Dynamics and of Crop Yield to Conservation Agriculture in the Ethiopian Highlands. Sustainability 12(15), 5989.

Belay, S.A., Schmitter, P., Worqlul, A.W., Steenhuis, T.S., Reyes, M.R. and Tilahun, S.A.J.W. (2019) Conservation Agriculture Saves Irrigation Water in the Dry Monsoon Phase in the Ethiopian Highlands. 11(10), 2103.

Borah, D., Yagow, G., Saleh, A., Barnes, P., Rosenthal, W., Krug, E. and Hauck, L.J.T.o.t.A. (2006) Sediment and nutrient modeling for TMDL development and implementation. 49(4), 967-986.

Cambardella, C.A., Richard, T.L. and Russell, A.J.E.J.o.S.B. (2003) Compost mineralization in soil as a function of composting process conditions. 39(3), 117-127.

Carbonell-Bojollo, R., Veroz-Gonzalez, O., Ordoñez-Fernandez, R., Moreno-Garcia, M., Basch, G., Kassam, A., Repullo-Ruiberriz de Torres, M.A. and Gonzalez-Sanchez, E.J.J.S. (2019) The Effect of Conservation Agriculture and Environmental Factors on CO2 Emissions in a Rainfed Crop Rotation. 11(14), 3955.

Cavero, J., Barros, R., Sellam, F., Topcu, S., Isidoro, D., Hartani, T., Lounis, A., Ibrikci, H., Cetin, M. and Williams, J.J.A.w.m. (2012) APEX simulation of best irrigation and N management strategies for off-site N pollution control in three Mediterranean irrigated watersheds. 103, 88-99.

Chaplot, V., Saleh, A., Jaynes, D., Arnold, J.J.W., Air, and Pollution, S. (2004) Predicting water, sediment and NO 3-N loads under scenarios of land-use and management practices in a flat watershed. 154(1-4), 271-293.

Chung, S., Gassman, P.W., Kramer, L., Williams, J.R. and Gu, R.J.J.o.E.Q. (1999) Validation of EPIC for two watersheds in southwest Iowa. Journal of Environmental Quality 28(3), 971-979.

Clarke, N., Bizimana, J.-C., Dile, Y., Worqlul, A., Osorio, J., Herbst, B., Richardson, J.W., Srinivasan, R., Gerik, T.J. and Williams, J.J.A.w.m. (2017) Evaluation of new farming technologies in Ethiopia using the Integrated Decision Support System (IDSS). Agricultural water management 180, 267-279.

Di Paola, A., Valentini, R., Santini, M.J.J.o.t.S.o.F. and Agriculture (2016) An overview of available crop growth and yield models for studies and assessments in agriculture. Journal of the Science of Food and Agriculture 96(3), 709-714.

Diacono, M. and Montemurro, F. (2011) Sustainable agriculture volume 2, pp. 761-786, Springer.

Diaz, F., Jimenez, C. and Tejedor, M.J.A.w.m. (2005) Influence of the thickness and grain size of tephra mulch on soil water evaporation. 74(1), 47-55.

Francesconi, W., Smith, D.R., Heathman, G.C., Wang, X. and Williams, C.O.J.T.o.t.A. (2014a) Monitoring and APEX modeling of no-till and reduced-till in tile-drained agricultural landscapes for water quality. Transactions of the ASABE 57(3), 777-789.

Francesconi, W., Smith, D.R., Heathman, G.C., Wang, X. and Williams, C.O.J.T.o.t.A. (2014b) Monitoring and APEX modeling of no-till and reduced-till in tile-drained agricultural landscapes for water quality. 57(3), 777-789.

Gassman, P.W., Williams, J.R., Wang, X., Saleh, A., Osei, E., Hauck, L.M., Izaurralde, R.C. and Flowers, J. (2009) The Agricultural Policy Environmental Extender (APEX) model: An emerging tool for landscape and watershed environmental analyses.

Golmohammadi, G., Prasher, S., Madani, A. and Rudra, R.J.H. (2014) Evaluating three hydrological distributed watershed models: MIKE-SHE, APEX, SWAT. 1(1), 20-39.

Hobbs, P.R., Sayre, K. and Gupta, R.J.P.T.o.t.R.S.B.B.S. (2008) The role of conservation agriculture in sustainable agriculture. 363(1491), 543-555.

Iizumi, T., Yokozawa, M., Sakurai, G., Travasso, M.I., Romanenkov, V., Oettli, P., Newby, T., Ishigooka, Y., Furuya, J.J.G.e. and biogeography (2014) Historical changes in global yields: major cereal and legume crops from 1982 to 2006. Global ecology and biogeography 23(3), 346-357.

Kabir, Z.J.C.J.o.P.S. (2005) Tillage or no-tillage: impact on mycorrhizae. 85(1), 23-29.

Kiniry, J., Cassida, K., Hussey, M., Muir, J., Ocumpaugh, W., Read, J., Reed, R., Sanderson, M., Venuto, B., Williams, J.J.B. and Bioenergy (2005) Switchgrass simulation by the ALMANAC model at diverse sites in the southern US. Biomass and Bioenergy 29(6), 419-425.

Klocke, N., Watts, D.G., Schneekloth, J., Davison, D.R., Todd, R. and Parkhurst, A.M.J.T.o.t.A. (1999) Nitrate leaching in irrigated corn and soybean in a semi-arid climate. 42(6), 1621.

Knisel, W.G. (1980) CREAMS: A field scale model for chemicals, runoff, and erosion from agricultural management systems, Department of Agriculture, Science and Education Administration.

Kumar, S., Udawatta, R.P., Anderson, S.H. and Mudgal, A.J.A.s. (2011a) APEX model simulation of runoff and sediment losses for grazed pasture watersheds with agroforestry buffers. 83(1), 51-62.

Kumar, S., Udawatta, R.P., Anderson, S.H. and Mudgal, A.J.A.s. (2011b) APEX model simulation of runoff and sediment losses for grazed pasture watersheds with agroforestry buffers. Agroforestry systems 83(1), 51-62.

Lal, R.J.G. (2004) Soil carbon sequestration to mitigate climate change. 123(1-2), 1-22.
Leonard, R., Knisel, W. and Still, D.J.T.o.t.A. (1987) GLEAMS: Groundwater loading effects of agricultural management systems. Transactions of the ASAE 30(5), 1403-1418.
Marin, F.R., Ribeiro, R.V., Marchiori, P.E.J.T. and Physiology, E.P. (2014) How can crop modeling and plant physiology help to understand the plant responses to climate change? A case study with sugarcane. Theoretical and Experimental Plant Physiology 26(1), 49-63.
Mohammad, A.G. and Adam, M.A.J.C. (2010) The impact of vegetative cover type on runoff and soil erosion under different land uses. 81(2), 97-103.
Moriasi, D., Wilson, B., Douglas-Mankin, K., Arnold, J. and Gowda, P.J.T.o.t.A. (2012) Hydrologic and water quality models: Use, calibration, and validation. Transactions of the ASABE 55(4), 1241-1247.
Moriasi, D.N., Arnold, J.G., Van Liew, M.W., Bingner, R.L., Harmel, R.D. and Veith, T.L.J.T.o.t.A. (2007) Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the ASABE 50(3), 885-900.
Müller, C., Elliott, J., Chryssanthacopoulos, J., Arneth, A., Balkovic, J., Ciais, P., Deryng, D., Folberth, C., Glotter, M. and Hoek, S.J.G.M.D. (2017) Global gridded crop model evaluation: benchmarking, skills, deficiencies and implications. Geoscientific Model Development 10(4), 1403-1422.
O'Kelly, B.C.J.D.T. (2004) Accurate determination of moisture content of organic soils using the oven drying method. Drying Technology 22(7), 1767-1776.
Parton, W.J., Ojima, D.S., Cole, C.V. and Schimel, D.S.J.Q.m.o.s.f.p. (1994) A general model for soil organic matter dynamics: sensitivity to litter chemistry, texture and management. Quantitative modeling of soil forming processes, 39, 147-167.
Plotkin, S., Wang, X., Potter, T., Bosch, D., Williams, J., Hesketh, E. and Bagdon, J.J.T.o.t.A. (2013) APEX calibration and validation of water and herbicide transport under US Southern Atlantic Coastal Plain conditions. 56(1), 43-60.
Rauff, K.O. and Bello, R.J.A.S. (2015) A review of crop growth simulation models as tools for agricultural meteorology. Agricultural Sciences 6(09), 1098.
Ray, D.K., Ramankutty, N., Mueller, N.D., West, P.C. and Foley, J.A.J.N.c. (2012) Recent patterns of crop yield growth and stagnation. Nature communications 3(1), 1-7.
Rivington, M. and Koo, J. (2010) Report on the meta-analysis of crop modelling for climate change and food security survey.
Schonbeck, M.W. and Evanylo, G.K.J.J.o.S.A. (1998) Effects of mulches on soil properties and tomato production I. Soil temperature, soil moisture and marketable yield. 13(1), 55-81.
Sharifi, A., Lee, S., McCarty, G.W., Lang, M.W., Jeong, J., Sadeghi, A.M. and Rabenhorst, M.C.J.W. (2019) Enhancement of Agricultural Policy/Environment eXtender (APEX) Model to Assess Effectiveness of WetlandWater Quality Functions. 11(3), 606.
Spalding, R.F., Watts, D.G., Schepers, J.S., Burbach, M.E., Exner, M.E., Poreda, R.J. and Martin, G.E.J.J.o.E.Q. (2001) Controlling nitrate leaching in irrigated agriculture. 30(4), 1184-1194.
Stockmann, U., Adams, M.A., Crawford, J.W., Field, D.J., Henakaarchchi, N., Jenkins, M., Minasny, B., McBratney, A.B., De Courcelles, V.d.R., Singh, K.J.A., Ecosystems and Environment (2013) The knowns, known unknowns and unknowns of sequestration of soil organic carbon. Agriculture, ecosystems & environment 164, 80-99.
Talebizadeh, M., Moriasi, D., Gowda, P., Steiner, J.L., Tadesse, H.K., Nelson, A.M. and Starks, P.J.A.w.m. (2018) Simultaneous calibration of evapotranspiration and crop yield in agronomic system modeling using the APEX model. Agricultural water management 208, 299-306.
Tuppad, P., Santhi, C., Wang, X., Williams, J., Srinivasan, R. and Gowda, P.J.A.e.i.a. (2010a) Simulation of conservation practices using the APEX model. 26(5), 779-794.
Tuppad, P., Santhi, C., Wang, X., Williams, J., Srinivasan, R. and Gowda, P.J.A.e.i.a. (2010b) Simulation of conservation practices using the APEX model. Applied engineering in agriculture 26(5), 779-794.

Wang, X., Gassman, P., Williams, J., Potter, S., Kemanian, A.R.J.S. and Research, T. (2008) Modeling the impacts of soil management practices on runoff, sediment yield, maize productivity, and soil organic carbon using APEX. 101(1-2), 78-88.

Wang, X., Williams, J., Gassman, P., Baffaut, C., Izaurralde, R., Jeong, J. and Kiniry, J.J.T.o.t.A. (2012) EPIC and APEX: Model use, calibration, and validation. 55(4), 1447-1462.

Williams, J., Izaurralde, R. and Steglich, E.J.T.D., Version (2008) Agricultural policy/environmental extender model. Theoretical Documentation 604, 2008-2017.

Xie, J., Cardenas, E.S., Sammis, T.W., Wall, M.M., Lindsey, D.L. and Murray, L.W.J.A.w.m. (1999) Effects of irrigation method on chile pepper yield and Phytophthora root rot incidence. 42(2), 127-142.

Zhang, B., Feng, G., Read, J.J., Kong, X., Ouyang, Y., Adeli, A. and Jenkins, J.N.J.A.W.M. (2016) Simulating soybean productivity under rainfed conditions for major soil types using APEX model in East Central Mississippi. Agricultural water management 177, 379-391.