Modeling phosphorus distribution under different fertigation strategies in onion (*Allium cepa* L.) crop

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Abstract: The understanding of soil and nutrient dynamics under drip fertigation is relevant for crop production as well as water and nutrient management. The aim of this study was to generate information about the distribution of phosphorus (P) under different fertigation strategies for onion production on sandy clay loam soil during 2007-2008 to 2008-2009. The study involved field experiment, laboratory analysis and modeling of P distribution. The phosphorus distribution data in the field were collected, analyzed and used to calibrate and validate the solute transport model HYDRUS-2D for sandy clay loam soil. The performance of HYDRUS-2D was evaluated by comparing its simulated values with the observed values of soil moisture and nutrient concentration. The coefficient of determination (R^2), root mean square error (RMSE) and mean absolute error (MAE) were used as model performance indicators. The range of R^2 between 0.72-0.99 for water as well as nutrient distribution indicates good correlation between the observed and simulated values. The MAE and RMSE values for water and nutrient distribution were in between 0.0009 to 0.0039 which indicated the accuracy of the model. From these results, it can be concluded that the model is performing well for predicting the P concentration in the soil as well as the soil moisture distribution for onion crop grown under sandy clay loam. The model was also validated for water and phosphorus distribution with the observed values at the end of the crop season and found to be performing well. The HYDRUS-2D model may be used to carry out simulations for different soil types and with different fertigation and irrigation strategies for developing guidelines.

Keywords: HYDRUS-2D, Fertigation strategy, Phosphorus distribution, Onion

INTRODUCTION

Drip irrigation is often preferred over other irrigation methods because of the former's high water-application efficiency on account of reduced losses, surface evaporation and deep percolation. Improved water use efficiency under drip irrigation by reducing percolation and evaporation losses, provides environmentally safer fertilizer application through irrigation water (Mmolawa and Or, 2000). In countries where the cost of water is very low, such as India, the adoption of drip irrigation has initially been very slow. Recently however, drip irrigation combined with fertigation has been found to benefit farmers because of the very high efficiency of fertilizer use for such irrigation schemes. There is an ample scope for improving the efficiency of fertilizer use through fertigation, if the movement and reactions of fertilizers in the soil are well understood. Fertigation enables the application of soluble fertilizers and other chemicals along with irrigation water, uniformly and more efficiently (Patel and Rajput, 2000; Narda and Chawla, 2002). The dynamics of the water within the soil volume

surrounding the emitter represents a prerequisite to design irrigation systems as well as to manage water and nutrients (Akbar *et al.*, 1996; Zur, 1996). Few computer simulation models have the capability to analyze water flow and nutrient transport in multiple spatial dimensions, with the exception of HYDRUS-2D (Simunek *et al.*, 1999; Cote *et al.*, 2003) and FUSSIM2 (Heinen, 2001).HYDRUS-2D (Simunek *et al.*, 2006) has been used extensively for evaluating short term nitrogen fertigation strategies and the effects of soil hydraulic properties, soil layering, dripper discharge rates, irrigation frequency, and timing of nutrient applications on wetting patterns and solute distribution (Ajdary *et al.,* 2007; Patel and Rajput, 2008; Hopmans and Bristow, 2002; Doltra and Muñoz, 2010). Gardenas *etal.* (2005) analyzed four different micro irrigation systems in combination with five different fertigation strategies for various soil types, clearly demonstrating the effects of root distribution and fertigation strategy on the uniformity of water and nutrients around drip lines and their effects on water drainage and associated nitrate leaching by using the HYDRUS-2D.

The soil wetting and solute transport in trickle irrigation

was analyzed by using HYDRUS-2D model (Cote *et al.*, 2003). Many studies were conducted for water and nitrate distribution under drip fertigation (Ajdary *et al.*, 2007; Rajput and Patel, 2006, Wang *et al.*, 2014) but the information available on phosphorus distribution under drip fertigation is very limited. The nitrogen is more efficiently used when applied with phosphorus, potassium and sulfur. Most of the modeling studies dealing with similar topics are focused on simulations of water flow and nitrate leaching under drip irrigation system, but not the phosphorus distribution, so there is a gap in the understanding how the phosphorus is distributed with drip fertigation.

Keeping in view of the rationale, the present study was conducted to calibrate and validate the HYDRUS-2D for the phosphorus distribution from the onion field under inline drip fertigation system where fertigation was applied through inline drip irrigation system.

MATERIALS AND METHODS

Location of experimental field: The experiments were conducted in the field of Water Technology Centre, Indian Agricultural Research Institute, New Delhi, India, in 2007-2008 and 2008-2009 to calibrate and validate the HYDRUS-2D for the phosphorus distribution from the onion field under inline drip fertigation. The soil of the experimental site was sandy clay loam and low in organic matter (0.25%) with neutral pH (7.1). These soils have 87.45 kg/ha available N, 25 kg/ha assimilable P, 175kg/ha exchangeable K and 45kg/ha sulfur. The depth wise field capacity was varied from 20.91 per cent at 0-15cm with gradual increase to 28.86 % (15-30cm), 26.33%(30-45cm) and 28.33%(45-60 cm) and permanent wilting pointfor similar depth intervals as 6.25 to 6.22 % and then to 9.86 and 9.94 %, respectively. The crop calendar indicating date of sowing to date of harvesting is given in Table 1 and corresponding weather details for both the years are presented in Fig. 1. The weather was cool during the initial stages and warm to hot during the later stages. Rainfall during the two cropping seasons was 176 mm and 28 mm, respectively. The mean daily evaporation ranged from 2.9 to 5.6 mm and from 3.5 and 6.6 mm in the respective cropping seasoni.e. *rabi* season of 2007-2008 and 2008-2009. The actual mean maximum temperature ranged from 19.5°C to 36.5°C and 20.5°C to 39.0°Cin the years 2007-2008 and 2008-2009, respectively. The variations in mean minimum temperature from January to May were 5.5°C to 23.5°C and 7.2°C to 24.1°C respectively, for the years under consideration.

Treatment and Layout: Two months old seedlings of onion *Pusa Madhavi* were transplanted in *rabi season* i.e. in the second week of January during 2008 and 2009 with 15 cm spacing between rows and 10 cm between plants. The experiment was laid out in a split plot design having two main treatments (I_1 and I_2) as main plot and four fertigation treatments (F_1, F_2, F_3, F_4) as subplot keeping the plot size for the each replication as 2.4 m X 5 m.The detailed treatments are given in Table 2.

Irrigation/fertigation scheduling and crop management practices: The inline drip irrigation system with 4 litres per hour (lph) discharge emitter was used under this study. The emitter to emitter distance was kept as 50 cm and lateral to lateral distance was kept as 60 cm.The growing period of onion was 135 days in both the years of the study from transplanting to harvesting (Table 1). Before transplanting, 25 t/ha of farm yard manure (FYM) was applied to the field. The chemical fertilizers used in the experiment were urea, ortho-phosphoric acid, potassium chloride and magnesium sulphate as a source of N, P, K and S, respectively**.** The level of fertilizers adopted in the present study was 120 kg N ha^{-1}, 50 kg P ha^{-1}, 70 kg K ha^{-1} and 50 kg S ha^{-1} and it was divided in 12 equal

Table 1. Cultivation operation for two seasons.

Operation	Year	
	2007-2008	**2008-2009**
Nursery	Nov.10, 2007	Nov. 10, 2008
Transplanting date	Jan. 09, 2008	Jan. 09, 2009
Crop Settling	Jan. 09-24, 2008	Jan. 09-24, 2009
Vegetative development	Jan. 25-Feb. 28, 2008	Jan. 25-Feb. 28, 2009
Bulbification or Bulb formation stage	Feb. 29-April 18, 2008	March 01-April 19, 2009
Bulb Maturity stage	April 19-May 23, 2008	April 20-May 24, 2009
Last irrigation	May 11, 2008	May 12, 2009
Harvest	May 23, 2008	May 24, 2009
Length of growing season (From date of transplanting to Harvesting) (days)	135	135

doses. The fertilizers were injected at eight day interval through the inline drippers which was started 15 days after transplanting and stopped 30 days prior to the end of crop period. The time of application of fertigation injection was different in all four fertigation treatments i.e. fertigation during first half of irrigation duration (F_1), fertigation throughout irrigation duration (F_2), fertigation during second half of irrigation duration (F_3) and fertigation during middle half of irrigation duration (F_4). Determination of crop water requirement is the primary duty in any irrigation planning. For this, the reference evapotranspiration (ETo) was estimated using the FAO Penman-Monteith equation (Allen *et al.*, 1998) employing previous five year meteorological data. The phenological cycle of onion was divided into four stages from transplanting to harvesting which are considered to be the most relevant from the point of view of their response to irrigation, namely, crop settling (1st-15 days), vegetative development(2nd-35 days), bulbification or bulb formation (3rd-50 days) and bulb maturity stage (4th-35 days) with a crop coefficients (Kc) as 0.7 for the 1st, 0.90 for the 2nd, 1.05 for the 3rd and 0.75 for the 4th growth, respectively, given by Allen *et al.* (1998). The total duration of the crop season was 135 days. The crop water requirements were calculated by multiplying the ETo values with crop coefficients at that particular stage. The crop water requirement and irrigation requirement were calculated by using the ET_c for both the seasons.

Table 2. Treatment details.

Treatment	Elaboration
I	Irrigation
F	Fertigation
I_1	Two day irrigation interval
I_2	Four day irrigation interval
F_1	First half fertigation
F_2	Throughout fertigation
F_3	Second half fertigation
F_4	Middle half fertigation
I_1F_1	2 day irrigation interval with fertigation during first half of irrigation duration
I_1F_2	2 day irrigation interval with fertigation during throughout irrigation duration
I_1F_3	2 day irrigation interval with fertigation during second half of irrigation duration
I_1F_4	2 day irrigation interval with fertigation during middle half of irrigation duration
I_2F_1	4 day irrigation interval with fertigation during first half of irrigation duration
I_2F_2	4 day irrigation interval with fertigation during throughout irrigation duration
I_2F_3	4 day irrigation interval with fertigation during second half of irrigation duration
I_2F_4	4 day irrigation interval with fertigation during middle half of irrigation duration

Table 3. Root water uptake parameter of Feddes model.

Factors	Onion	
	Early growth	**Bulb formation stage**
P_o	- 10 cm	- 10 cm
P_{opt}	- 25 cm	- 25 cm
P_2H	- 450 cm	- 550 cm
P_2L	- 550 cm	- 650 cm
P_3	- 8000 cm	- 8000 cm
R_2H	0.021	0.021
R_2L	0.0042	0.0042

Sampling and analysis: Soil samples were collected from different depths *viz.* 0-15 cm, 15-30 cm, 30-45 cm and 45-60 cm and also it was taken at emitter, 15 cm away from emitter and 22.5 cm away from emitter and after different time interval (spatial and temporal). In the treatment of two day irrigation interval, soil samples were collected before fertigation, 4 h after fertigation, 24h, 48 h, 52 h and 72 h after fertigation and in the treatment of four day irrigation interval, the samples were collected periodically (Before fertigation, 4h, 24 h, 48 h, 72 h, 96 h, 100 h and 120 h after fertigation). The tube auger was used for collecting the soil samples from the field and analysed for moisture content and P concentration using standard procedures.

Water and nutrient transport modelling: In the present study, HYDRUS-2D was selected because it can simulate the effect of the following:
Soil hydraulic properties on water and nutrient movement
Discharge rate on the water and nutrient distribution
Time dependent flux boundary on water and nutrient distribution
Timing of water and nutrient application on the resultant distribution of water and nutrient distribution within the root zone

Description of hydrus-2d: The modeling of phosphorus leaching from the onion field under drip fertigation was carried out using the computer simulation model, HYDRUS-2D. It simulates three-dimensional axially symmetric water flow; solute transport and root water and nutrient uptake based on finite-element numerical solutions of the flow equations. The model can deal with prescribed head and flux boundaries, controlled by atmospheric conditions, as well as free drainage boundary conditions. The governing flow and transport equations are solved numerically using Galerkin-type linear finite element schemes. The current version 2.0 of HYDRUS includes a Marquardt-Levenberg parameter optimization algorithm for inverse estimation of soil hydraulic and/or solute transport and reaction parameters from measured transient or steady state flow and/or transport data. A detail description of model and related theory is presented in the report documents version 2.0 of HYDRUS (Simunek *et al.*, 1999).

System geometry: The simulations were done for a soil profile upto a depth of Z = 60 cm and radius r = 30 cm, with a drip emitter placed at the surface. The flux radius was taken equal to the wetted radius with corresponding emitter in the centre. Surface area for irrigation without causing ponding was determined from the flux radius and subsequently flux per unit area, resulting from emitter was estimated. Fig. 2 shows the conceptual diagram of simulated area and imposed boundary conditions. No flux was allowed through the lateral boundaries. Bottom boundary was considered as free drainage boundary. Surface boundary was considered as variable flux boundary (up to the radius of 25 cm) and atmospheric boundary for remaining 5 cm radius. The system was conceptually divided into four layers*viz.* 0-15 cm, 15-30 cm, 30-45 cm and 45-60 cm depending on the variability of the soil's physical properties such as texture of soil, hydraulic conductivity, moisture percentage at saturation and residual moisture content in the soil.

Initial and boundary conditions: Initial distribution of the water content in different soil layers within the flow domain was kept as observed in the experimental field. A sample figure showing the initial water content is shown in Fig. 3.

For the purpose of investigating the influence of drip emitter discharge, soil hydraulic properties and frequency of water input on wetting patterns, a time dependent flux boundary condition at the surface in a radius of 25 cm from emitter position was used. This was done to take into account the irrigation and no irrigation periods and temporal changes in duration of irrigation in the growing period. In the present case, water table was situated far below the domain of interest and therefore free drainage boundary condition at the base of soil profile was considered. On the sides of the soil profile, it was assumed that no flux of water took place and hence no flux boundary condition was chosen, as specified in HYDRUS-2D for impermeable boundaries where the flux is zero perpendicular to the boundary.

Input parameters:

Soil hydraulic properties: The soil properties considered are water retention θ(h) and hydraulic conductivity K (h) functions. In this study, Van Genuchten (1980) analytical model available in HYDRUS-2D was used for the soil hydraulic properties. The model was calibrated for the soil hydraulic properties obtained from field experiment.

Solute transport properties: A range of values of the longitudinal and transverse dispersivities was selected from literature and approximate values were selected after calibration process.

Input for root water uptake: Two root water uptake model of Feddes (1978) and S-shaped model are available in the HYDRUS-2D. The root water uptake model is selected to simulate the root water uptake of

onion crop at each point in the root zone according to soil pressure head conditions. P_{0-} the pressure head of which the plant begins to extract water whereas P_{0pt} - the pressure head at which plants begin to extract water at maximum possible rate (i.e. potential transpiration rate given in the time variable boundary condition). For a potential transpiration rate of r2H, P2H is the pressure head at which the plant no longer extracts water at maximum possible rate Root water uptakes ceases at P3 which is usually permanent wilting point. Plant parameters for onion crop at early growth stage and at bulb formation stage are given in Table 3.

Distribution of roots in the root zone in relative term with onion plant is shown in Fig. 4.

Calibration and validation: The model is calibrated for residual water content (θ_r), saturated water content (θ_s), Alpha (α) and n. The parameters were selected from the run when predicted and observed values are close enough. The model was calibrated for water and nutrient distribution. For nutrient distribution, nutrient transport parameters were taken from literature. After calibration, model was validated with the long term observed data to examine its predictability.

Calibration of the model was done using the values of water content and phosphorus concentration at various points along the line and at different depths as mentioned above, selected in the root zone with respect to the emitter, observed at 4, 24, 48, 52, 72, 100 and 120 hours after fertigation. To check the performance of HYDRUS-2D model, three performance indicators namely, coefficient of determination (R^2), Root mean square error(RMSE) and mean absolute error (MAE) were used (Willmott, 1981). Root mean square error (RMSE) and mean absolute error (MAE) were calculated using equations as given below. A coefficient of determination of 1.0 represents a perfect prediction while negative and value zero represents a prediction no better than the random variation in the observed data, negative values indicate increasingly poorer predictions (Nash and Sutcliffe, 1970)

$$MAE = N^{-1} \sum_{i=1}^{N} |P_i - O_i|$$

-------------------- i

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

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i = 1, 2, 3…………n

where, P_i = Predicted values, O_i = Observed values N = Total number of observations; A criterion adopted by Willmott (1981) was considered in evaluating different developed simulation models, the evaluation criteria consisted of:

i) Lower the mean absolute error, model predictions are good with better accuracy

ii) Smaller RMSE value, the better the performance of

a) 2007-2008

b) 2008-2009
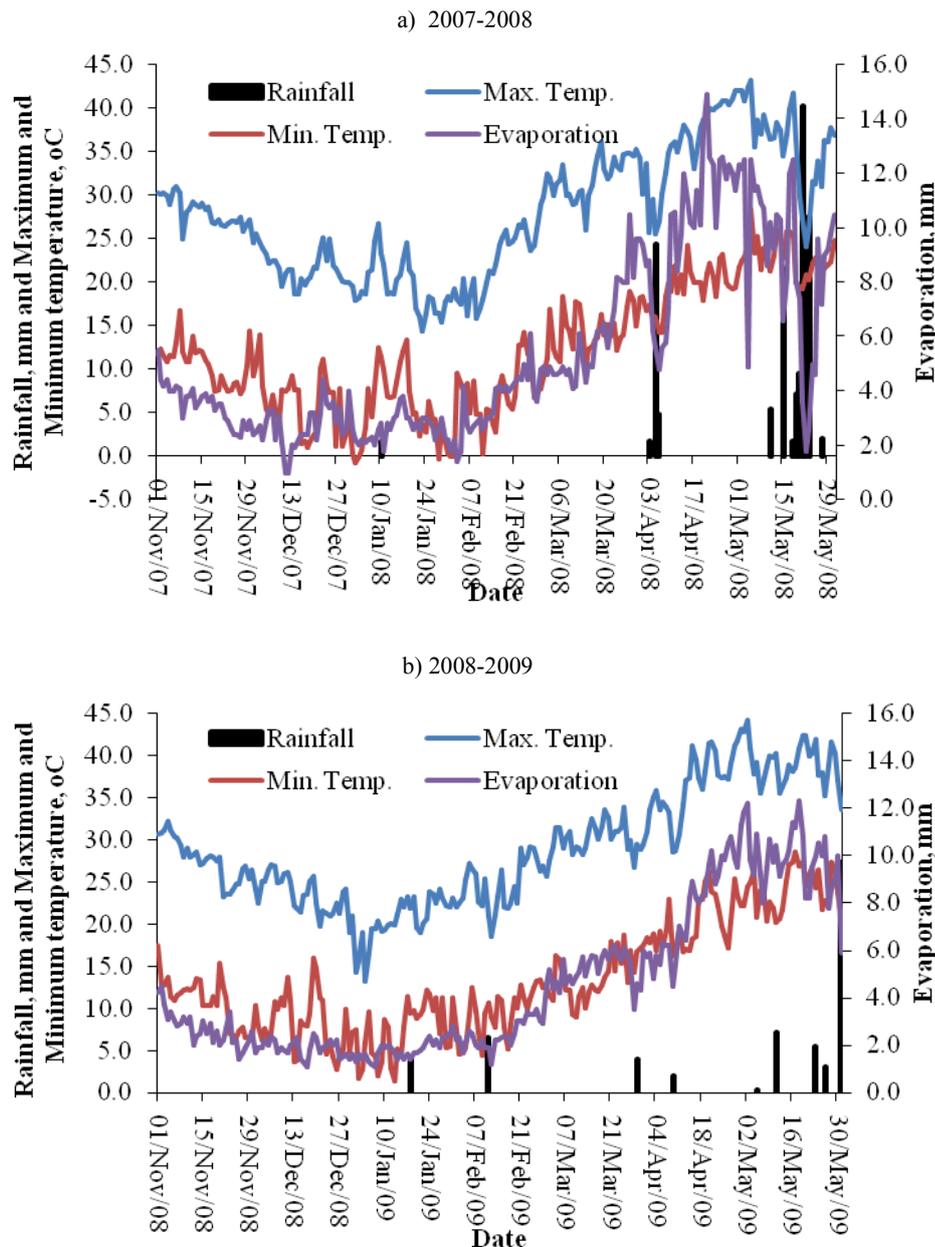
Fig. 1. *Meteorological data during experimentation a) 2007-08 and b) 2008-09.*

model

RESULTS AND DISCUSSION

Spatial and temporal distribution of water in the soil: Spatial distribution of water is described with the data collected in the mid crop season. To find out, the temporal variation in the water after irrigation, soil samples were taken before irrigation, 4, 24, 48, 52 and 72 h after irrigation for I_1 and for I_2, samples were collected before irrigation, 4, 24, 48, 72, 96, 100 and 120 h after irrigation.

Initial moisture content in the soil before irrigation varied from 17 to 22% in various soil layers. In all the

treatments, water applied through drip irrigation was more than required rate. This more application of water was necessary for the proper establishment of the crop. After the establishment of the onion, irrigation was applied according to calculated amount per treatment. Average water distribution pattern under irrigation treatments, I_1 and I_2, are shown in Fig. 5 and 6.

The soil water content under I_1 was relatively higher in upper profiles and near the emitters. Water content in all soil layers decreased as the distance from emitter increased in the horizontal direction. Similar results were reported by Mishra (2001), Rajput and Patel
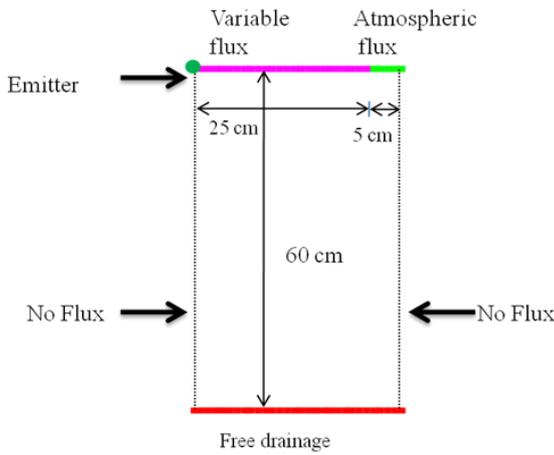
Fig. 2. *Conceptual diagram of simulated area.*
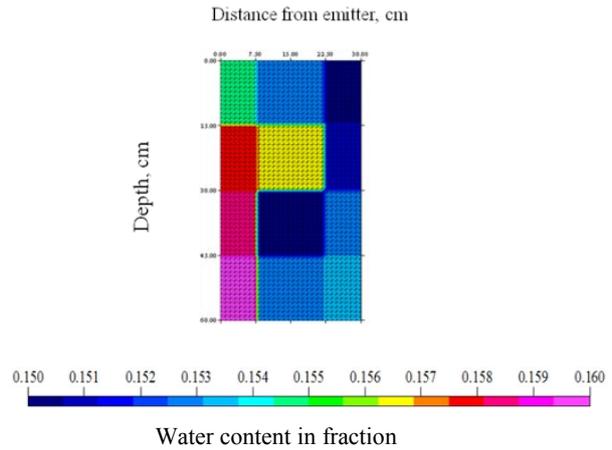
Fig. 3. *Initial conditions of water content in Soil.*
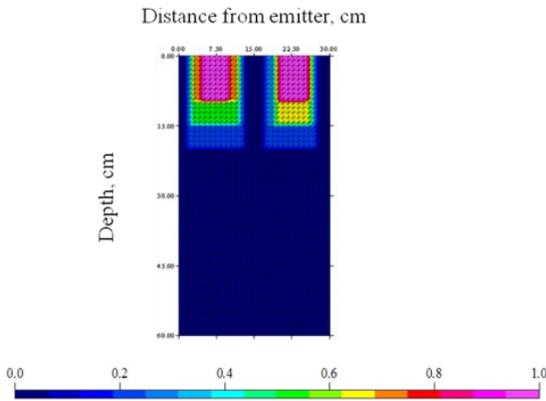
Fig. 4. *Relative root distribution of Onion in Soil.*

(2006). The similar trend was observed under I_2. But compared to I_1, more soil water content was observed in lower soil layers under I_2. This may be because of more quantity of irrigation water applied during single irrigation duration.

The analysis of Fig. 5 (a) revealed that simulated and observed water contents under I_1 follow a similar trend without much difference. The values of simulated and observed soil water content after 24 h varied from 23-

26 % and 19-22%, respectively. The soil water content increases 4 h after the next irrigation and simulated values followed the similar trend. Fig. 5 (b and c) showed the horizontal as well as vertical water content variation. Similar trend was observed 15 cm away from emitter and 22.5 cm away from emitter. In simulated and observed water content values, lowest moisture content was near the field capacity. A similar analysis was done for I_2 irrigation treatment and is depicted in Fig. 6. Compared to I_1, more moisture content was observed at upper as well as lower layers at the emitter. Simulated values also showed the similar trend. The water content values are decreasing from emitter to away from emitter (Fig. 6). This indicates that the model is able to simulate the soil water content as there was not much difference between the observed and simulated values.

The coefficient of determination (R^2), mean absolute error (MAE) and root mean square error (RMSE) were determined as model performance parameters for I_1 and I_2, which are given in Table 4 and 5. The R^2 between the observed and simulated values varied from 0.65 to 0.99. The MAE and RMSE were also estimated to examine the predictability of the model. MAE and RMSE values varied from 0.018 to 0.030.
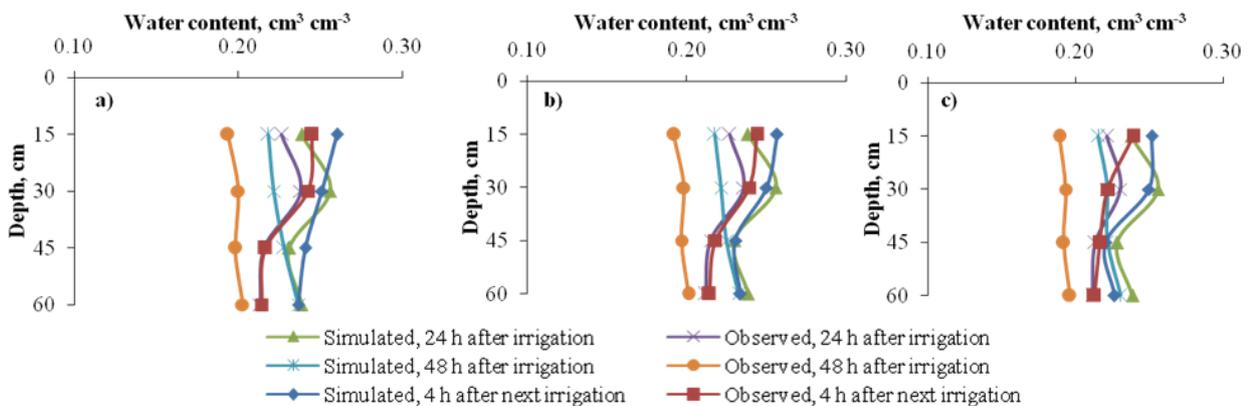
Fig. 5. *Simulated and observed water content in I_1 (a) at emitter (b) at 15 cm from emitter (c) at 22.5 cm from emitter.*
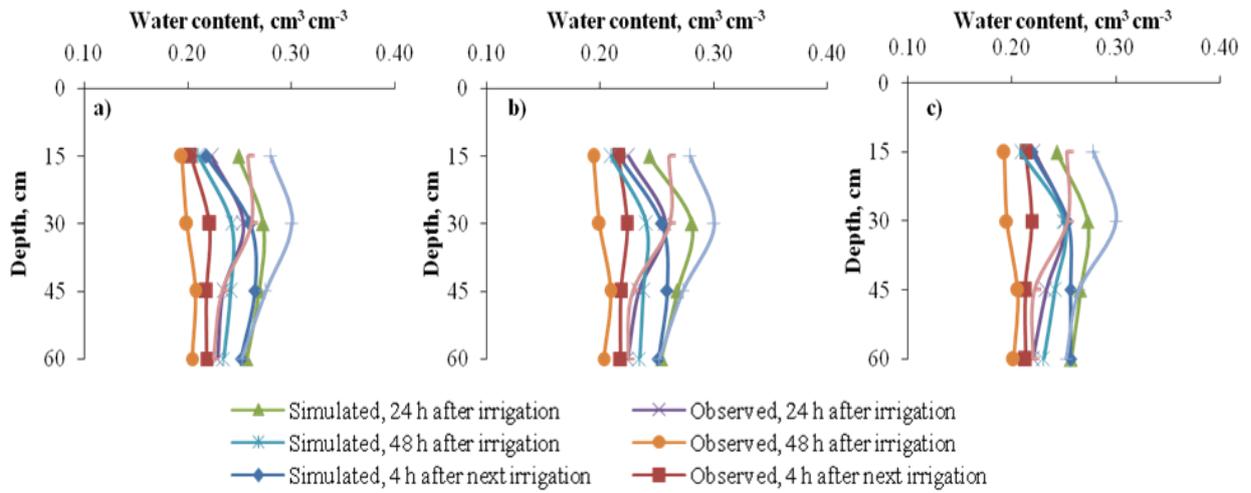
Fig. 6. *Simulated and observed water content in I_2 (a) at emitter (b) at 15 cm from emitter (c) at 22.5 cm from emitter.*
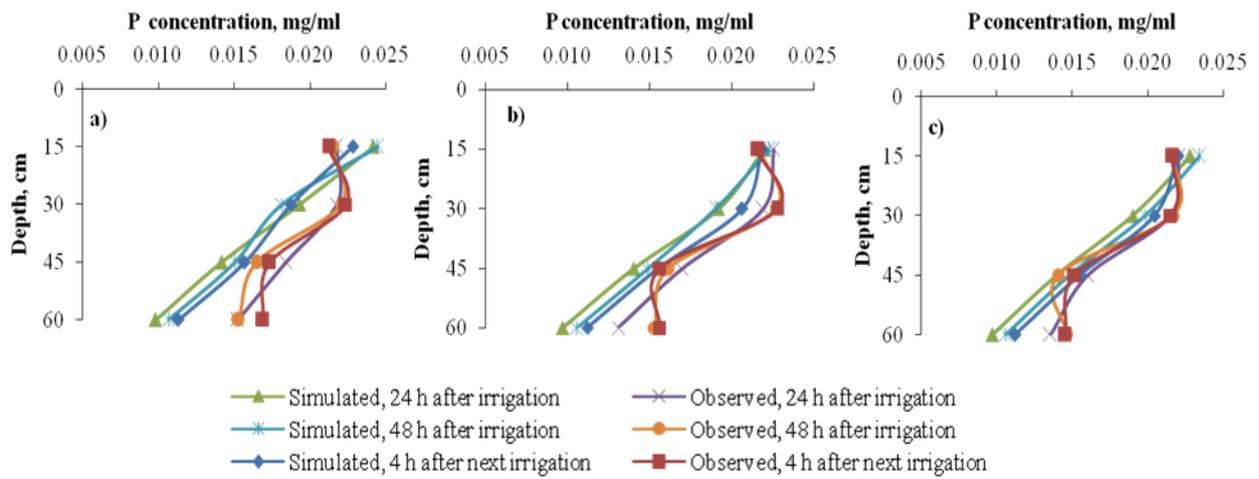
Fig. 7. *Simulated and observed P concentration in I_1 (a) at emitter (b) at 15 cm from emitter (c) at 22.5 cm from emitter.*
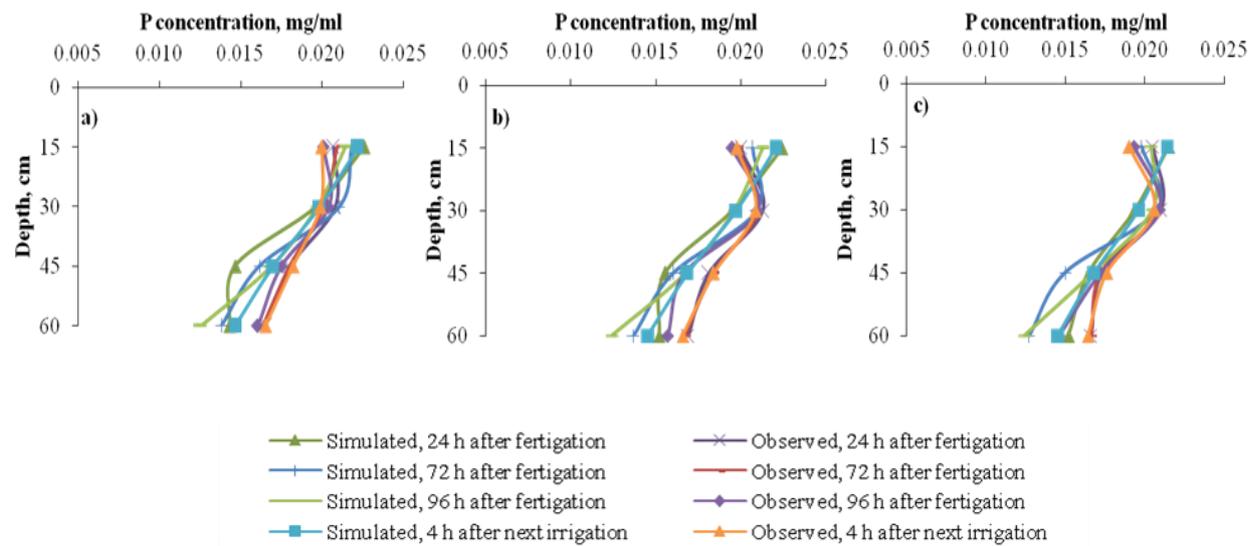
Fig. 8. *Simulated and observed P concentration in I_2 (a) at emitter (b) at 15 cm from emitter (c) at 22.5 cm from emitter.*

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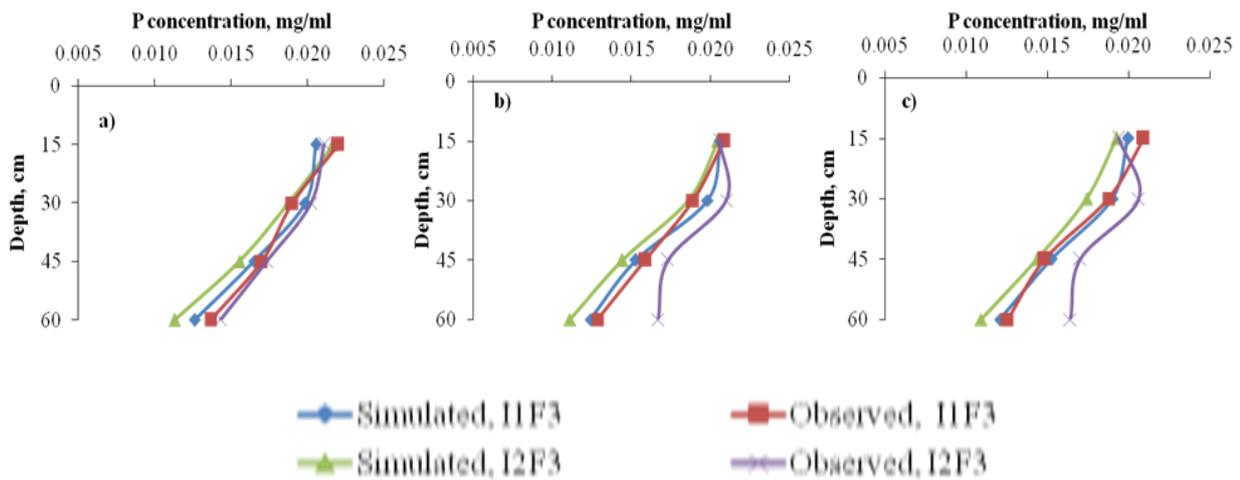
Fig. 9. *Validation of P distribution (a) at emitter (b) at 15 cm from emitter (c) at 22.5 cm from emitter.*
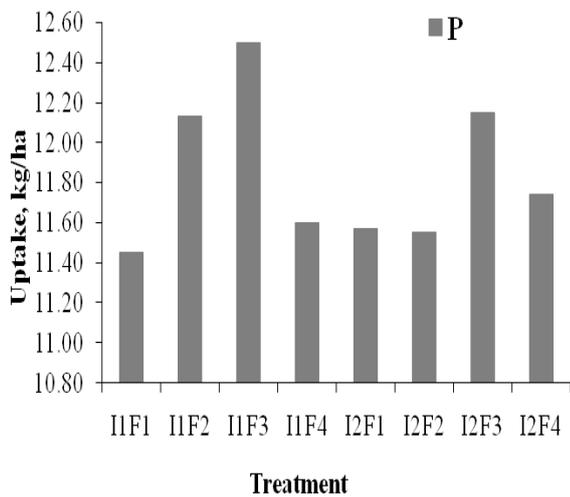
Fig. 10. *Uptake of phosphorus by onion plant under different treatments.*

This indicated that HYDRUS-2D can be used to simulate water distribution with very good accuracy. These finding were in line of the results of Skaggs *et al.* (2004). For I_2, coefficient of determination values varied from 0.65 to 0.88. The MAE and RMSE values varied from 0.029 to 0.039 which was more than the values of MAE and RMSE under I_1. The higher R^2 values revealed the better correlation between the observed and simulated values for I_1 and I_2. It means that HYDRUS-2D can be used to simulate water distribution with better accuracy in I_1 than I_2.

Spatial and temporal distribution of phosphorus in the soil: Spatial distribution of nutrients has been described using the data collected during the crop season. The different fertigation strategies described in methodology were followed during fertigation. From the yield data of the onion, F_3 strategy was found to be better than other strategies. So, F_3 fertigation strategy was selected for describing the nutrient distribution and intensive sampling was done in F_3 in 2009 as compared to 2008. To find out the temporal variation in the nutrient distribution, soil samples were taken before fertigation, 4, 24, 48, 52 and 72 h after fertigation for I_1 and for I_2, samples were collected before fertigation, 4, 24, 48, 72, 96, 100 and 120 h after fertigation.

Phosphorus distribution: The phosphorus concentration under F_3 was higher in upper profiles but in F_1, F_2 and F_4, P concentration was more at deeper layers (Figs. 7 and 8). Phosphorus is highly immobile but its mobility and availability increases with the moisture content (Ben-Gal and Dudley, 2003; Fanish and Muthukrishnan, 2013). Continuous wetting helps to move the phosphorus at deeper layers. Fertigation during second half of irrigation duration (F_3) helps to keep more P concentration at upper layers which can be available in the active root zone of the onion.

The model was used to predict the P concentration under F_3 treatment. Figs. 7 and 8 showed the observed and simulated P concentration at various depths and at various time intervals after the fertigation duration. Results indicated that simulated and observed P concentration followed a similar trend. The observed P concentration decreased with elapsed time and with application of irrigation water. In case of P concentration, simulated values were less than observed values which means that model is under predicting the P movement. The simulated and observed P concentrations at the emitter after 24 h of the fertigation were 0.0242 and 0.0217 mg/ml in the first layer and it was 0.0240 and 0.0215 mg/ml in the same layer in 48 h after fertigation. Simulated and observed P concentration decreased away from the emitter. Similar trend was observed for all the layers. After next irrigation, P

concentration showed decreasing trend in the upper layers while the concentration in lower layers was increased. A similar trend was observed under four day irrigation interval (I_2) and presented in Fig. 8. The more P concentration was observed in lower layers under I_2 due to the more amount of irrigation during the single irrigation event. That helps to travel P at lower layers.

To examine the predictability of the model on seasonal basis, simulations were carried out to predict the P distribution at the end of the crop season i.e. 135 days (Fig. 9). The coefficient of determination R^2, mean absolute error (MAE) and root mean square error (RMSE) were determined to find out the closeness between observed and simulated values and the accuracy of the model under I_1 and I_2. Those are presented in Table 4 and 5. The higher (0.72 to 0.99) values of R^2 indicated that simulated and observed values of P movement are highly correlated. MAE and RMSE values for P concentration varied from 0.0009 to 0.0039. The lower values of MAE and RMSE indicating the high accuracy and effectiveness of the HYDRUS-2D model for simulating P movement. The performance parameters revealed that the HYDRUS-2D may be used for the simulation of P distribution under drip fertigation.The similarresults of HYDRUS-2Dwere reported by Li *et al.* (2005) and Ajdary *et al.* (2007).

Nutrient uptake by the plant: The onion plant samples collected at the harvest were analysed in the laboratory to determine P uptake by the plant. Irrespective of the irrigation interval, the highest plant uptake of P (12.50 kg/ha) was observed in F_3. F_3 retained most of the nutrients in the upper profile making them easily available for the plant. The combined effect of fertigation and irrigation strategies showed in Fig. 10 which revealed that the highest P uptake was found under I_1F_3. The similar results were reported by EL-Desuki *et al.*, 2006; Jha *et al.*, 2000. The statistical analysis indicated that there was non-significant difference between the uptake of nutrients under different fertigation strategies. It can therefore be assumed that fertigation strategy did not have any impact on the uptake of the nutrients by plant.

Conclusion

Higher concentrations of P were observed at upper layers under the fertigation during the second half of irrigation duration. HYDRUS-2D model was used for the prediction of P concentration in different fertigation strategies and the results revealed that observed values were satisfactorily predicted. Calibration and validation results showed that HYDRUS-2D can be used for simulation of water and P distribution and leaching from the onion field (Cote *et al.*, 2003; Hanson *et al.*, 2006). The R^2, MAE and RMSE values indicated show better matching between observed and

simulated results. The R^2values ranged from 0.72 to 0.99 which indicated that observed and predicted values were highly correlated. The MAE and RMSE for water and nutrient distribution ranged between 0.0009 to 0.0039. The lower values of MAE and RMSE showed the accuracy and effectiveness of the HYDRUS-2D model. Results revealed that P uptake by plant was maximum in case of I_1F_3 treatment but the differences among the other treatments were non-significant. From the water and nutrient distribution information and under different treatments, it can be concluded that the HYDRUS-2D model can be used for the simulation of the water and nutrient distribution under different fertigation and irrigation scenarios. This will help to reduce the cost and time of performing the experiment on each soil type and for every discharge rate of the emitter.

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