Filipovic, Vilim; Romic, Davor; Romic, Marija; Borosic, Josip; Filipovic, Lana; Mallmann, Fabio Joel Kochem; Robinson, David A.. 2016. **Plastic mulch and nitrogen fertigation in growing vegetables modify soil temperature, water and nitrate dynamics: experimental results and a modeling study.** *Agricultural Water Management*, 176. 100-110. 10.1016/j.agwat.2016.04.020

Plastic mulch and nitrogen fertigation in growing vegetables modify soil temperature, water and nitrate dynamics: experimental results and a modeling study

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ABSTRACT

Plastic mulch in combination with drip irrigation present a common agricultural management technique practiced in commercial vegetable production. This management can result in various impacts on water and nutrient distribution and consequently affect nutrient dynamics in underlying soil. The aim of this work was to: (i) compare the effects of different mulching types (color) on soil temperature and (ii) crop growth; (iii) estimate the effect of plastic mulch cover (MULCH) on water and (iv) nitrate dynamics using HYDRUS-2D. The field experiment was designed in the Croatian coastal karst area on main plots with three levels of nitrogen fertilizer: 70, 140, and 210 kg ha^{-1}, which were all divided in five subplots considering mulch covering with different colors types (black, brown, silver, and white) and no covering (control). Monitoring of water and nitrate dynamics was ensured through lysimeters which ensured input data for HYDRUS-2D model. The experimental results showed that plastic mulch had a significant effect on soil temperature regime and crop yield. The dark color mulch (black, brown) caused higher soil temperature, which consequently enabled earlier plant development and higher yields. HYDRUS-2D simulated results showed good fitting to the field data in cumulative water and also nitrate outflow. Water flow simulations produced model efficiency of 0.84 for control (CONT) and 0.56 for MULCH systems, while nitrate simulations showed model efficiency ranging from 0.67 to 0.83 and from 0.70 to 0.93, respectively. Additional simulations exposed faster transport of nitrates below drip line in the CONT system, mostly because of the increased surface area subjected to precipitation/irrigation due the absence of soil cover. Numerical modeling revealed large influence of plastic mulch cover on water and nutrient distribution in soil. Study suggest that under this management practice the nitrogen amounts applied via fertigation can be lowered and optimized to reduce possible negative influence on environment.

Keywords: Plastic mulch cover; Vegetable cultivation; Soil temperature; Water flow; Nitrate dynamics; HYDRUS-2D.

1. INTRODUCTION

Growing global population, the consequent demand for food and increasing access to irrigation have resulted in agriculture being the main water consumer at the global scale. Commercial vegetables producers apply intensive management which involves high irrigation demands and input of agrochemicals. Plastic mulch application is a common agricultural practice due to variety of benefits to the crop, mostly vegetable biomass production. Plastic mulch can be used: (i) to modify soil temperature, which may promote faster growth early in the season and generally lead to earlier harvest, (ii) for effective weed control, (iii) to prevent nutrient losses by leaching, (iv) to prevent fruit contact with soil, and (v) to reduce soil water loss by decreasing evaporation from the soil surface (Fritz, 2002).

Various vegetables including bell pepper are commonly grown along the Mediterranean coast in raised soil beds (ridge) covered with plastic mulch. The use of impermeable plastic mulch in bell pepper cultivation affects water fluxes and may change crop water use and distribution compared to open-field conditions (Allen et al., 1998; Amayrehand and Al-Abed, 2005). It can also improve water use efficiency and decrease irrigation requirements by 10-20% by reducing soil evaporation (Deng et al., 2006), as it acts as a moisture barrier which diminishes the surface area of soil evaporation. Plastic mulch affects the microclimate around the crop by modifying the radiation budget (absorptivity vs. reflectivity) of the surface and by decreasing the soil water loss. Color affects the surface temperature of the mulch cover and consequently the underlying soil temperature.

Drip irrigation is usually placed underneath mulches for precise management of soil moisture and nutrients, which can reduce irrigation frequency and quantity, and may reduce the incidence of moisture-related physiological disorders. Combination of drip irrigation method with liquid fertilizer application provides an effective and cost-efficient way of water and nutrients addition to crops (Bar-Yosef, 1999) while minimizing leaching of nutrients from the root zone (Gärdenäs et al., 2005). However, different crop management techniques such as mulch covers can have various impacts on water and nutrient distribution in underlying soil and consequently affect nutrient leaching towards groundwater resources. Liquid fertilizers are usually applied together with irrigation water which makes them easily available for crops, but also for leaching to deeper soil layers.

Karst areas exhibit a challenge for the protection of groundwater resources, because high heterogeneity, high vulnerability and fast groundwater flow result in low natural attenuation of contamination (Bakalowicz, 2005). Due to geological and climatic conditions as well as anthropogenic influence, high leaching potential is present in such environment in which agrochemicals can easily reach groundwater or surface water resources (Romić et al., 2003a). Episodic rainfall events of high intensity can lead to rapid recharge, which has strong impact on discharge and contaminant transport to karst springs, particularly if the conduit system (*e.g.* soil porous system) is well developed (Butscher et al., 2011).

Numerical modeling is being quite popular lately for the assessment of different agrochemical leaching and water distribution under various initial and boundary conditions due to their rising accuracy and effectiveness. In the absence of large experimental data sets, we can explain water and nutrients dynamics in multi-dimensional space using mathematical solutions by performing numerical simulations. The HYDRUS code is widely used for modeling water and solutes dynamics in the (un)saturated zone in a one-, two or three-dimensional direction (Šimůnek et al., 2008). The HYDRUS allows for specification of water and nutrient uptake, transport of multiple solutes, which can be either independent or involved in sequential first order decay reactions, *e.g.* nitrification chain. The code has been largely used to simulate fertigation and/or nitrate leaching (Hanson et al., 2006; Filipović et al., 2013; Phogat et al., 2013). Rudisch et al. (2013) performed a modeling study using HYDRUS-2D to evaluate the effect of plastic mulched ridge (raised soil beds) cultivation on soil water dynamics under potato fields (*Solanm tuberosum* L.) on hillslopes in South Korea. The results indicated that plastic mulch reduced drainage up to 16% but on the other hand increased surface runoff up to 65%, which could lead to soil erosion and flood risk. Liu et al. (2013) simulated the temporal variations of soil water content in a drip irrigated cotton field under mulching. They used HYDRUS-2D to fit the observed soil water content indicating satisfying model accuracy.

Most of the modeling studies dealing with similar topics are focused on simulations of water flow and/or nutrients under plastic mulch or drip irrigation system, but not their combination, so there is a gap in the understanding how the plastic mulch in combination with drip irrigation affects soil moisture and nitrate distribution. The effect of plastic mulch on water and a consequent solute translocation are not well understood, in terms of their exact quantity and location in time below the vegetable planting rows. Therefore, the objectives of this study were: (i) to compare the effects of different mulching types (color) on soil temperature and (ii) consequently crop growth; (iii) to estimate the effect of plastic mulch cover on water and (iv) nitrate dynamics using HYDRUS-2D. The modeling study using 2D presentation is expected to allow better understanding of soil water dynamics and nitrate behavior in crops managed with plastic mulch and drip irrigation.

2. MATERIALS AND METHODS

2.1. Field experiment

The experimental site was located in the Croatian coastal area *i.e.* Vrana valley (43°57' N, 15°30' E), which is an area with intensive agricultural (mostly vegetable) crop production. Vrana basin is an ecologically highly sensitive area (in terms of leaching potential) located in a karst environment. Additionally, the applied agrochemicals can easily reach Vransko Lake located in the research area, the largest freshwater lake in Croatia protected as a Natural park, and induce water quality deterioration and eutrophication. Mean annual precipitation in that area is 910 mm, and mean monthly temperatures ranges from 7 °C (January) to 23 °C (July). The soil type is classified as Gleysol (WRB) with 30% clay, and pH value of 7.2 in its tilled layer.

Prior to field experiment installation the soil was ploughed till 40 cm depth and harrowed to provide necessary growing condition. Furthermore, experimental plots measuring 20 x 7.5 meters each were treated with herbicide following the agricultural practices used in local vegetable production. The experiment was designed according to the split-plot design in three repetitions with the main plots corresponding to three different N inputs, *i.e.* 70, 140, and 210 kg ha^{-1}. The main plots were divided in five subplots, four of them covered with different plastic mulch color types: black, brown, silver, and white, and the fifth of them, the control subplot, remained without plastic mulch.

Fertilizer levels were applied in combination with drip irrigation (7:5:9 NPK, liquid fertilizer, INA, Petrokemija - where N was in form of ammonium and nitrate). Irrigation was performed with a single line of drip irrigation tape with 30 cm spaced emitters (Netafim, Israel) that was placed in the center of each bed prepared for planting transplants. Installation of mulching materials and the drip irrigation system, as well as planting of transplants were all done using a tractor-drawn planter and film layer (Maas, MOD 140). Container-grown bell pepper (*Capsicum annuum* L. cv. Bianca F1) transplants were planted on 8–9 May. Prior to mulching, pesticides were sprayed at the field site in order to remove weeds and provide same growing conditions in all plots.

2.2. Field monitoring

Temperature probes were installed on all subplots near soil surface at 5 cm depth. Soil temperature was measured three times a day *i.e.* always at 7, 14 and 21 h, during the period from May 15^{th} till October 10^{th}. Due to initial data fluctuation and a necessary period for probe calibration, the first two weeks of measurements were excluded from the results. Therefore, the results presented correspond for the period between June 4^{th} and October 10^{th}.

Field lysimeters were installed into 9 subplots, *i.e.* all subplots covered with black and brown plastic mulch and in the three control subplots. For this procedure, a vertical trench was excavated to the depth of 2 m. A horizontal slot was unearthed from the trench at a depth of 90 cm, and a round stainless steel plate lysimeter (Ø 65 cm) was installed into that soil layer in order to not disturb the soil above the plate. PVC net in combination with geotextile (fleece) was installed together with a gravel layer on the lysimeter plate for preventing small particles to be washed with leachate and to conduct the flow. A tygon tube was installed onto the plate to conduct the sampled water toward a 10 L tank buried in the soil at the depth of 150 cm, which also provided a suction corresponding to -90 cm of pressure head.

Meteorological data were collected on Jankolovica weather station (located in the proximity of field site) which included daily rates of precipitation, air temperatures (maximum, minimum, and average), humidity, wind speed, and solar radiation. From collected data daily potential evapotranspiration rates were then calculated based on Penman–Monteith approach (Monteith, 1981). The crop coefficient (K_c) approach was used in which crop evapotranspiration is calculated by multiplying ET_o by K_c (Allen et al., 1998). Crop coefficient and the length of each phase (in days) were taken from Allen et al. (1998) for three different growing stages of bell pepper crop *i.e.* initial ($K_{c\text{-}ini}$ 0.7), mid-season ($K_{c\text{-}mid}$ 1.05), and late season ($K_{c\text{-}end}$ 0.95). Daily rates of precipitation, irrigation, evaporation, and bell pepper transpiration are presented on Fig. 1. Crop growth parameters and yield were measured during the growing season on all subplots. Plant height and number of flowers and fruits were determined on 20 plants per subplot. Bell pepper fruits were also collected as they reached maturity and yield was measured.

2.3. Laboratory analyses

Bulk soil samples were taken at the beginning of the field experiment in each plot with an auger in four layers of the profile: 0–40, 40–60, 60–92, and 92–120 cm depth, which correspond to different soil horizons. The main physical and chemical analyses were conducted for each soil layer. The particle size distribution was measured by the pipette method after disaggregation in sodium pyrophosphate (HRN ISO 11277:2004). Soil pH and organic matter were determined using a Mettler Toledo MPC 227 conductivity/pH meter in water (pH H_2O) (HRN ISO 10390:2005) and by sulfochromic oxidation (HRN ISO 14235:2004), respectively. Nitrate concentration was determined in the 1.0 M KCl soil extracts (HRN ISO 14256-2:2009) using the continuous flow auto–analyzer (San++ Continuous Flow Analyzer, Skalar). Soil physical and chemical data are presented in Table 1.

Undisturbed soil samples of 100 cm^3 volume were taken, at the same time and on the same locations of the bulk soils samples, for the determination of bulk density and soil hydraulic properties in each layer (*e.g.* soil water retention and hydraulic conductivity curves). The saturated hydraulic conductivity, K_s, was determined using the constant head method (Klute and Dirksen, 1986) in the first tilled layer (0–40 cm). The saturated water content, θ_s, was measured using the ISO 11274:1998, *i.e.* sandbox method. The points of the soil water retention curves were measured in all layers using a pressure plate apparatus (Dane and Hopmans, 2002) for applied pressures of 33, 625, and 1500 kPa.

Soil water samples were collected from all lysimeter tanks after each large precipitation and irrigation event during the whole experiment, transported to the laboratory, and stored at 4 °C before analysis. Nitrate concentrations were determined in these water samples using the continuous flow auto–analyzer (San++ Continuous Flow Analyzer, Skalar).

2.4. Modeling study

2.4.1. Coupled flow and solute transport equations

Numerical modeling of water flow and fertilizer movements was performed in two-dimensional domain using HYDRUS-2D software (Šimůnek et al., 2008). Water flow dynamics in a variably saturated medium is solved using a numerical solution for Richards' equation, which is defined as:

$$\frac{\partial \theta}{\partial t} = \nabla(K\,\nabla\,\mathrm{H}) - S_w \qquad (1)$$

where θ is the volumetric water content [$L^3\ L^{-3}$]; K is the unsaturated hydraulic conductivity [$L^3\ T^{-1}$]; H is the hydraulic head [L]; S_w is a sink term, accounting for plant uptake [$L^3\ L^{-3}\ T^{-1}$]; ∇ is the spatial gradient operator; and t is time [T]. The plant water stress is accounted for using the model suggested by Feddes et al. (1978), which is implemented in HYDRUS:

$$S_w(h) = \alpha(h) S_p \qquad (2)$$

where h is the soil water pressure head [L]; $\alpha(h)$ is the water stress response function, which varies between 0 and 1; and S_p is the potential root water uptake rate (1/d).

The analytical van Genuchten Mualem model (van Genuchten, 1980) describing the unsaturated soil hydraulic functions (*i.e.* soil water retention curve and unsaturated hydraulic conductivity) was used in the modeling study, which is defined as follows:

$$\theta(h) = \theta r + \frac{\theta s - \theta r}{(1 + |\alpha h|^{n})^{m}} \text{, for } h < 0 \quad (3)$$

$$\theta(h) = \theta s \text{, } for\ h \geq 0$$

$$K(h) = K_s S_e^{l}(1 - (1 - S_e^{\frac{1}{m}})^{m})^{2} \quad (4)$$

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} \quad (5)$$

$$m = 1 - \frac{1}{n};\ \ n>1 \quad (6)$$

where $\theta(h)$ and $K(h)$ are volumetric water contents [L^3 L^{-3}] and unsaturated hydraulic conductivities [L T^{-1}] at the soil water pressure heads of h (L), respectively; θ_r and θ_s denote residual and saturated soil water contents [L^3 L^{-3}], respectively; S_e is the effective saturation; K_s is the saturated hydraulic conductivity [L T^{-1}]; α is the inverse of air-entry value or bubbling pressure [L^{-1}]; n is the pore size distribution index; and l is the pore connectivity parameter. The pore connectivity parameter equaled to an average value for many soils was used for all soil layers (l=0.5) (Mualem, 1976).

For solute transport, ammonium and nitrate were considered and their transformations and transport were simulated. The partial differential equations governing non-equilibrium chemical transport of solutes involved in a sequential first-order decay chain during transient water flow in a variably saturated rigid porous medium are simplified as follows:

a) For ammonium:

$$\frac{\partial \theta c_1}{\partial t} + \rho \frac{\partial s_1}{\partial t} = \nabla(\theta D \nabla c_1) - \nabla(q c_1) - \mu_v \theta c_1 - \mu_n \theta c_1 - S_w c_1 \quad (7)$$

b) For nitrate:

$$\frac{\partial \theta c_2}{\partial t} = \nabla(\theta D \nabla c_2) - \nabla(q c_2) + \mu_n \theta c_1 - S_w c_2 \quad (8)$$

where c_i is the liquid phase concentration of the chemical species i (subscripts 1 and 2 represent ammonium and nitrate, respectively) [M L^{-3}]; D is the dispersion coefficient tensor [L^2 T^{-1}]; q is the volumetric flux density [L T^{-1}]; ρ is the bulk density of the soil [M L^{-3}]; s_1 is the adsorbed concentration of ammonium [M M^{-1}]; μ_v is the first-order reaction rate constant [T^{-1}] representing volatilization of ammonium to ammonia; and μ_n is the first-order reaction rate constant [T^{-1}] representing nitrification of ammonium to nitrate. The relationship between ammonium in solution (c_1) and adsorbed (s_1) is described as follows:

$$s_1 = K_d c_1 \quad (9)$$

where K_d is the distribution coefficient for ammonium [$L^3\ M^{-1}$].

2.4.2. Model parameterization

The model domain geometry was 200 x 200 cm with a 110 cm width and 10 cm high rise in the middle of surface, which represents the soil bed (ridge) for growing bell pepper (Fig. 2). The simulations were performed for two different management techniques, *i.e.* MULCH and CONT systems, using different boundary conditions at the top. The MULCH corresponds to the subplots with plastic mulch cover. The upper boundary conditions on the sides of these subplots were set as atmospheric conditions, while the raised seed bed had no flow conditions (plastic mulch), except for the small opening in the middle, corresponding to the bell pepper growing opening, which had irrigation conditions and crop transpiration applied (Fig. 2a). In MULCH system the precipitation amount was increased by a factor of 3.33 (Dusek et al., 2010) due to surface runoff from the plastic mulch which ends up in open field (30 cm width) at both sides. Note that MULCH field data was an average of two subplots, *i.e.* subplots covered with black and brown plastic mulch, since in the model it was not possible to distinguish between those two. The CONT system corresponds to the control subplots without plastic mulch cover, which had atmospheric conditions along the upper boundary, except for the small opening in the middle that received the irrigation and transpiration conditions as for the MULCH scenario (Fig. 2b). The lateral (both) and lysimeter boundary conditions were determined as no flux and as seepage face, respectively. The bottom boundary condition was set as variable groundwater fluctuations with the highest groundwater level reaching 180 cm below surface (ensured by the pumping station at Vrana Lake).

Three additional scenarios were performed for each of the two management systems corresponding to application of three doses of nitrogen. In these scenarios, liquid fertilizer was applied every 7 days, starting from May 28th and finishing on September 11th (16 applications), which accounted for total application of 70, 140 and 210 kg N ha^{-1}, depending on the plot. The scenarios for CONT system were named as $CONT_{70}$, $CONT_{140}$ and $CONT_{210}$, with the numbers representing the N doses applied with the irrigation. MULCH system names followed this same criterion, *i.e.* $MULCH_{70}$, $MULCH_{140}$ and $MULCH_{210}$. Rooting depth was set as 35 cm with maximum root density in both systems (considered to be the depth of main root mass).

Modeling study was performed from 1st of May till 31st of December, while the bell pepper transplants were planted on 9th May with the first fertigation input on the 28th of May. The simulation started earlier in order to approach a "pseudo-equilibrium conditions" before starting with the irrigation and fertilizer addition (Hanson et al., 2006) which ensured that the initial soil water regime was not a factor that influenced in the transport processes of applied nutrients (Gärdenäs et al., 2005). The initial condition for water content was set as a hydrostatic pressure head distribution with 20 cm at the bottom of soil profile (groundwater level at 180 cm below soil surface at the start of simulation). The initial ammonium concentrations were neglected while nitrate concentrations were set for entire domain based on soil measurements in first soil layer (0–40 cm). These values were transformed based on the molar mass in order to fit model input units *i.e.* mmol cm^{-3} (Ravikumar et al., 2011; Filipović et al., 2015). The initial nitrate concentrations ranged from 9.67 e^{-6} to 1.98 e^{-5} mmol cm^{-3} depending on the plot. For solute modeling parameters, the longitudinal dispersivity along the direction of flow was taken as 5 cm and the transverse dispersivity was taken as one order of magnitude less (Filipović et al., 2013). The bulk densities for soil layers were set according to Table 1. The first-order reaction term representing nitrification of ammonium to nitrate (μ_n), of 0.2 day^{-1} and distribution coefficient for ammonium (K_d) of 3.5 cm^3 g^{-1} were taken from Hanson et al., 2006. The first-order reaction term for volatilization of ammonium to ammonia (μ_v) was 0.0552 day^{-1} (Bolado-Rodriguez et al., 2005). Application of fertilizer (7:5:9 NPK liquid fertilizer), which was defined also in kg ha^{-1}, was in the same way transformed into concentration of nitrogen for both species (ammonium or nitrate) in the volumes of applied irrigation (mmol cm^{-3}). For the crop solute uptake (cRoot), a high value of 10 mmol cm^{-3} was selected aiming that all nitrogen species could be taken up passively without any constraints (Hanson et al., 2006), since the quantity of crop uptake was not the aim of this study.

2.4.3. Soil hydraulic properties estimation

Additional soil hydraulic properties needed (*i.e.* θ_r and K_s for deeper layers, and α and n for all layers) for solving van Genuchten-Mualem model were derived from the Rosetta model (Schaap et al., 2001) implemented in HYDRUS. The initial estimates of hydraulic properties were based on soil textural distribution, bulk density and water retention values at 33 and 1500 kPa. The hydraulic properties were determined for the four soil layers: 0–40, 40–60, 60–92 and 92–120 cm. All parameters of the 92–120 cm soil layer were considered to be valid till 200 cm depth in the modeling approach, because of its low influence on lysimeter and rhizosphere. Values of selected hydraulic parameters, *i.e.* α and K_s, of the four different soil layers were further fine-tuned using an inverse modelling technique (Hopmans et al., 2002). The calibration of the saturated hydraulic conductivity K_s and α parameter was done using selected values of experimental data from lysimeter outflow. Final values of soil hydraulic parameters utilized in the model are shown in Table 2.

2.5. Statistical analysis

Statistical analysis of experimental field results (soil temperature, crop growth and yield) was performed using the Statistical Analysis Software (SAS Institute, 2001). Analysis of variance was applied using One-way ANOVA or MIXED procedure, depending on the analyzed data. The significance of differences between the means was determined using a Tukey's Honestly Significant Difference test at $P<0.05$.

For the modeling results, in addition to graphical comparison of observed and simulated values, the model performance was evaluated using coefficient of determination (r^2), and the model efficiency coefficient (E) also known as Nash-Sutcliffe (1970) coefficient:

$$r^2 = \left(\frac{\sum_{i=1}^{n}(O_i-\bar{O})(S_i-\bar{S})}{\sqrt{\sum_{i=1}^{n}(O_i-\bar{O})}\sqrt{\sum_{i=1}^{n}(S_i-\bar{S})}} \right) \quad (10)$$

$$E = 1 - \frac{\sum_{i=1}^{n}(O_i-S_i)^2}{\sum_{i=1}^{n}(O_i-\bar{O})^2} \quad (11)$$

where O_i and S_i represents observed and simulated values, respectively; $\bar{O}$ and $\bar{S}$ represent average of observed and simulated values, respectively; and n is the number of observed/simulated points.

3. RESULTS AND DISCUSSION

3.1. Experimental results

3.1.1. Soil Temperature

The statistical comparison was performed for a period of 129 days, from June 4th (starting measurement of temperature probes) until October 10th (end of growing season). Bell pepper roots and plant canopy were already well-established on June 4th. Soil temperature regimes in subplots covered with plastic mulches were similar among the different color mulches, but were higher than in the control subplots, which showed the lowest values (average of 21.4 °C) during the research period (Table 3 and Fig. 3). Although the difference between the mulch covers were not significant (Table 3), the subplots with the black plastic cover showed the largest values during the season (average of 23.3 °C). The average soil temperatures were in order black>brown>white>silver as expected (Fig. 3), which is in agreement with studies performed under similar growing conditions (Romić et al., 2003a). Other studies also report the temperature increase in soil with mulching, *e.g.* Ibarra-Jiménez et al. (2011) in Mexico, and Ngouajio and Ernest (2005) in United States, which also showed the highest soil temperatures when covered with black colored plastic mulches.

3.1.2. Growth parameters

Different fertilization rates were applied in the experiment to test the effects on yield and vegetative growth of bell pepper. However, nitrogen fertigation did not have a significant effect on bell pepper yield (Table 4). This could be partly attributed to the fact that some N was leached below root zone due to the large irrigation events. Moreover, the main reason was the manure application on the year before in the whole experimental site which could have provided sufficient amounts of slow releasing nutrients needed for crop growth, minimizing the effect of the nitrogen addition.

On the other hand, plastic mulches significantly affected yield, but the statistical difference was found only between the control plot (without mulch) and brown and black plastic mulch, which both caused a significant increase of bell pepper yield. Still, there was no statistically significant difference between brown and black plastic mulch, nor between the control plot and white and silver plastic mulch. What is more, evaluating only the mulches (white, silver, brown, black) no statistically significant difference was verified. However, noticeable differences were seen when evaluating the growth parameters at the early stage *i.e.* on June 23rd when black and brown mulch covers provided larger plant height, following larger number of fruits and flowers (Table 4). This clearly indicates positive mulch effect on growth in the initial stage, which could lead to earlier harvest time. Similar results were presented in the study performed by Romić at al. 2003b on watermelon (*Citrus lanatus* L.). They indicated that mulching with polyethylene materials enabled an earlier harvest compared to the control treatment and paper mulching, which was due to more rapid initial crop growth.

3.2. Modeling study

3.2.1. Water flow

Water flow simulations were performed using HYDRUS-2D for specified initial and boundary conditions (described in 2.4.2 section). First, the model results were confronted with the observed data of cumulative water outflows from lysimeters at the two different management types, *i.e.* CONT and MULCH systems. The modeling of CONT system showed good agreement with the observed data (r^2=0.97, E=0.84) and followed the outflow pattern during the researched period (Fig. 4). The large outflows and their appearances during time were well captured by the model. Simulations of MULCH system resulted in lesser fitting to the observed data but still in well agreement, presenting satisfactory comparison coefficients, *i.e.* r^2=0.97 and E=0.56. The MULCH system simulations showed a more uniform cumulative water outflow curve due to smaller interaction area between irrigation and rainfall at the upper boundary considered in HYDRUS model, in which preferential flow was not considered (Fig. 4). However, in the field some structure variations and macropore presence could be expected, thus small discrepancies between the model and field derived data is expected. The measured data of CONT system showed larger amount of cumulative water outflow compared to the MULCH system *i.e.* 135.8 compared to 111.35 mm, respectively. This difference is the direct result of increased surface area in CONT system for precipitation on the raised bed and around bell pepper crop, which are located exactly above the lysimeter and therefore easily conduct the water to this point. This has certainly affected water and nutrient distribution in the upper soil layers.

Fig. 5 show the simulated distribution of pressure heads in CONT and MULCH systems. On a selected day (September 15th), there was a large precipitation event with 32.6 mm of rainfall and 21.7 mm of irrigation applied the day before (cumulative amount of 54.3 mm). Such large amount of water caused a decrease in pressure head and an increase in water content range, which also resulted in large differences between the two systems. The system with the plastic mulch showed drier conditions in the whole area of raised bed due to the absence of rainfall along upper boundary. Plastic cover decreased wetting area and reduced outflow in the MULCH system (47.8 compared to 51.0 mm for the CONT) on this selected date. There is a noticeable effect of the increased runoff occurring in the MULCH system, which raised the pressure head values below the open rows at the sides. Also, the lysimeter plate influenced the pressure head distribution above them in both cases. The drip irrigation distribution below drip line shows uniform wetting patterns in the absence of precipitation events (Skaggs et al., 2004), on the contrary they can be deformed by the precipitation events. Water content also showed (not shown) larger variation in the MULCH system due to uneven precipitation distribution following the pressure head behavior. Since the irrigation amounts applied were the same on both investigated systems (CONT and MULCH), both of them had enough water for optimal crop growth. Consequently, the additional amount of water in CONT system influenced nitrate leaching pattern and distribution towards deeper soil layers.

3.2.2. Nitrogen dynamics

After water flow was correctly described by the HYDRUS-2D model, we proceeded with nitrogen modeling at the two applied management practices *i.e.* CONT and MULCH systems, with three scenarios in each system *i.e.* 70, 140 and 210 kg N ha^{-1} (six scenarios). The fertilizer inputs are implemented in the model every seven days (weekly), in the form of ammonium and nitrate, together with the irrigation application (mmol cm^{-3}).

Nitrate concentrations in solution leached from the lysimeter reflect the behavior of water flow and depended mostly on large precipitation/irrigation events. Fig. 6 shows the values of observed and simulated cumulative nitrate concentrations in lysimeter outflow in the researched period for the CONT system. A good agreement between observed and model derived results was verified for the three CONT scenarios, shown by the model performance coefficients r^2=0.95 and E=0.67 for $CONT_{70}$, r^2=0.94 and E=0.81 for $CONT_{140}$, and r^2=0.93 and E=0.83 for $CONT_{210}$. Similar values for model performance coefficients were observed on the simulated results for the MULCH scenarios (r^2=0.93 and E=0.70 for $MULCH_{70}$, r^2=0.94 and E=0.87 for $MULCH_{140}$, and r^2=0.95 and E=0.93 for $MULCH_{210}$ – Fig. 7). The high level of agreement between the simulated and measured water and nitrate fluxes indicate a very good performance of HYDRUS model, as reported by several studies with the similar modeling approach (Skaggs et al., 2004, Phogat et al., 2013). In both systems, the highest nitrate concentrations in lysimeter outflow followed the input rate, and were in order 210 > 140 > 70 kg N ha^{-1}, as expected. Therefore, the leaching of nitrate was related to the fertilizer application rate, with the larger nitrate input providing larger nitrate outflow.

After the simulations of nitrate leaching towards the lysimeter and satisfactory fitting, a new set of simulations was conducted without the lysimeter in the modeling domain. The same initial concentrations (zero ammonium and nitrate) in the soil profile were maintained, in order to eliminate its direct effect on nitrate dynamics and to be able to compare two management systems in terms of nitrate translocation.

The snapshot of ammonium concentration presented in the Fig. 8 showed its distribution in the soil profile 105 days after the beginning of the simulation (on the day of the 12^{th} application of fertilizer, with 13.3 mm of irrigation). The contour of the solute pattern in both systems shows that most of the ammonium concentration remained in the near vicinity of drip line emitter, which was observed during the whole period of fertigation in all scenarios. Only a slight movement until approximately 10 cm depth could be noticed, which is reduced because of its sorption to the soil solid phase, its fast transformation to nitrate via nitrification process, and also due to root uptake (Hanson et al., 2006). Since ammonium ions are positively charged, they adsorb well to the negatively charged soil clay particles, and thus their leaching significantly reduces. Also, only matrix flow was considered in our simulations *i.e.* single porosity model, and there was no consideration of rapid preferential flow of ammonium, which may occur in the field during growing season.

In contrast to this ammonium transport pattern, continuous downward nitrate movement was observed during the whole simulated period as a result of the high amount of water input (irrigation/precipitation) and inability of soil to adsorb nitrate. On the Fig. 9 different snapshots in time are presented for the 210 kg N ha^{-1} application dose scenario in both CONT and MULCH systems (note different scales for each time – this was done for better presentation of nitrate dynamics). Only the scenario with the highest N input is shown, since the graphical presentation is the same for all three fertilization levels and the only difference is that the concentrations are reduced with the decrease on N dose application. The simulations show similar nitrate behavior in both systems, with nitrate concentration being the highest around drip line during the whole crop growing period, in which the fertigation were applied on a weekly basis. This can be seen up to the t=208, since the last fertigation was applied on 168^{th} day, after which redistribution phase began to take place. The contour of nitrate in the soil profile was similar in both systems, although there is a tendency in CONT system for more lateral and uneven distribution near the drip line, which was mainly due to the evapotranspiration and rainfall. Such an unequal fertilizer distribution can affect crop growth, while excess precipitation can foster nitrate leaching towards deeper soil layers. This can be noticed on the two last print times (t=208 and t=245) when the large precipitation event leached the most of the nitrate toward deeper layers. The CONT system showed larger accumulation of nitrate in the subsoil (~80 cm), while the highest concentration of nitrate in the MULCH system was still located near the drip line (~20 cm). This can also be seen from lysimeter outflow results, where we have measured a cumulative nitrate leaching of 0.0031 mmol cm^{-3} from the subplots with no mulch covering (control), compared to 0.0016 mmol cm^{-3} from the plastic mulch covered subplots.

In this study, we have applied equal amount of fertilizer in two systems. However, farmers can easily add less fertilizer in the mulched management system, since the nutrients will be longer present in the tilled soil layer and thus provide more available nutrients for crop uptake during the growing season.

Mass balance was calculated for all simulated scenarios, and the cumulative N contents (kg ha^{-1}) are presented in Table 5. Both CONT and MULCH systems showed increasing root uptake with increasing N dosage, since we presumed an unlimited passive crop uptake. Leaching was considered to be at lysimeter boundary (90 cm depth), while bottom flux of N was neglected because of the small values of nitrate reaching bottom of the profile during our simulation period (the bottom leaching would be certainly more pronounced if the simulations were extended in time).

Large differences were observed between CONT and MULCH system leaching, which are related to the increased infiltration and flow velocity (Gärdenäs et al., 2005). Accumulated N in soil profile (200 x 200 cm) presented in Table 5 is a sum of nitrogen from the applied fertilizer during the research period. In the CONT system, large differences are evident when comparing different dosage scenarios, while in MULCH system the differences were smaller due to the fact that most of the N was still remained in the upper soil layers, because of its less leaching. Root uptake values and its efficiency is reported to be around 50% when drip irrigation in combination with fertigation is applied (Hanson et al., 2006 – grape, Phogat et al., 2013 – orange tree). Lower efficiency was found for bell pepper due to shallow rooting since the bell pepper rooting depth is under 50 cm below soil surface, and is not able to uptake nutrients from deeper layers. Thus, the fertigation should be optimized in the way that: (i) more fertigation events (here we used weekly fertigation) with less fertilizer amount are applied, which would increase fertilizer efficiency (Gärdenäs et al., 2005, Ravikumar et al., 2011); and (ii) increase irrigation frequency, based on crop evapotranspiration values.

4. CONCLUSIONS

Different management practices used in a crop production can affect water distribution and soil water content, which may consequently influence nutrient dynamics and crop growth and yield. In this study, the effect of plastic mulching in combination with drip irrigation was evaluated on soil temperature and bell pepper growth parameters and yield using experimental field data. The data showed that plastic mulch had a significant effect on soil temperature regime and crop yield, with small differences between the different coloring mulches. The dark color mulch (black, brown) caused a higher soil temperature, which consequently enabled earlier crop development and higher yields. On the other hand, different N dosage (70, 140, and 210 kg ha^{-1}) did not cause differences in the same parameters. This is attributed to the fast transport of nutrients to the deeper soil layers (below root zone) due to high input of precipitation/irrigation, and more importantly to the animal manure application of the preceding year, which increased the initial nutrient content in the soil of the experimental site.

In addition, a modeling approach was confronted to lysimeter study in terms of water and nitrates dynamics. After optimization of soil hydraulic properties, simulations were carried using HYDRUS-2D for two selected management options *i.e.* CONT system – without plastic mulch cover, and MULCH system – plot covered with plastic mulch. The results of HYDRUS-2D modeling showed good fitting in both cumulative water and nitrate outflows to the observed field site data, with a high level of agreement. Water flow simulation produced model efficiency of 0.84 for CONT and 0.56 for MULCH systems, while nitrate simulations showed model efficiency range from 0.67 to 0.83 and from 0.70 to 0.93, respectively.

After successful model performance, the new set of simulations was initiated with all same initial conditions but without the lysimeter plate. The simulations revealed faster transport of nitrates below drip line in CONT system mostly because of the increased precipitation/irrigation at soil surface as a result of the absence of soil cover. Contrary, in the MULCH system most of the nitrates were still left in the upper soil layer at the end of simulation. Numerical modeling revealed a large influence of plastic mulch cover on water and nutrient distribution in soil, and suggested that in such conditions fertigation rates and frequency can be optimized in order to diminish the possibility of nitrate leaching towards groundwater resources.

REFERENCES

1. Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop Evapotranspiration: Guide-lines for Computing Crop Water Requirements. FAO Irrigation and Drainage Paper 56, Rome, Italy.
2. Amayreh, J., Al-Abed, N., 2005. Developing crop coefficients for field-grown tomato (*Lycopersicon esculentum* Mill.) under drip irrigation with black plastic mulch. Agric. Water Manage. 73 (3), 247–254.
3. Bakalowicz, M., 2005. Karst groundwater: A challenge for new resources. Hydrogeol. J. 13, 148–160, doi:10.1007/s10040-004-0402-9.
4. Bar-Yosef, B., 1999. Advances in fertigation. Adv. Agron. 65, 1–75.

5. Bolado-Rodriguez, S., Alonso-Gaite, A., Álvarez-Benedi, J., 2005. Characterization of nitrogen transformations, sorption and volatilization processes in urea fertilized soils. Vadose Zone J. 4:329–336.

6. Butscher, C., Auckenthaler, A., Scheidler, S., and Huggenberger, P., 2011. Validation of a numerical indicator of microbial contamination for karst springs. Ground Water. 49, 66–76.

7. Dane, J.H., Hopmans, J.W., 2002. Water retention and storage: laboratory. In: Methods of soil analysis. Part 4. Physical methods, Third Edition. SSSA, Madison, WI.

8. Deng, X., Shan, L., Zhang, H., Turner, N.C., 2006. Improving agricultural water use efficiency in arid and semiarid areas of China. Agric. Water Manage. 97 (8), 1102–1116.

9. Dusek, J., Ray, C., Alavi, G., Vogel, T., Sanda, M. 2010. Effect of plastic mulch on water flow and herbicide transport in soil cultivated with pineapple crop: A modeling stiudy. . Agric. Water Manage. 97, 1637-1645.

10. Feddes, R.A., Kowalik, P.J., Zaradny, H., 1978. Simulation of Field Water Use and Crop Yield. John Wiley and Sons, New York, NY.

11. Filipović V., Toor G.S., Ondrašek G., Kodešová R., 2015. Modeling water flow and nitrate–nitrogen transport on golf course under turfgrass. J. Soils Sediments. doi: 10.1007/s11368-014-0980-7

12. Filipović, V., Kodešová, R., Petošić, D., 2013. Experimental and mathematical modeling of water regime and nitrate dynamics on zero tension plate lysimeters in soil influenced by high groundwater table. Nutr. Cycl Agroecosys. 95:23–42.

13. Fritz, V.A., 2012. Plastic Mulches: Benefits, Types, and Sources. Minnesota High Tunnel Production Manual for Commercial Growers – Second Edition. Regents of the University of Minnesota. http://hightunnels.cfans.umn.edu/

14. Gärdenäs, A., Hopmans, J.W., Hanson, B.R., Šimůnek, J., 2005. Two dimensional modelling of nitrate leaching for different fertigation strategies under micro irrigation. Agric. Water Manage. 74, 219–242.

15. Hanson, B.R., Šimůnek, J., Hopmans, J.W., 2006. Evaluation of urea–ammonium–nitrate fertigation with drip irrigation using numerical modeling. Agric. Water. Manage. 86, 102–113.

16. Hopmans, J.W., Šimůnek, J., Romano, N., Durner, W., 2002. Simultaneous determination of water transmission and retention properties. Inverse methods. p. 963–1008. In: Dane, J.H., Topp, G.C., editors. Methods of soil analysis. Part 4. Physical methods. SSSA Book Ser. 5, Madison, WI, SSSA.

17. Ibarra-Jiménez, L., Lira-Saldivar, R.H., Valdez-Aguilar, L.A., Río, J.L.D., 2011. Colored plastic mulches affect soil temperature and tuber production of potato. Acta Agriculturae Scandinavica, Section B — Soil and Plant Science 61(4), 365–371.

18. Klute, A., Dirksen, C., 1986. Hydraulic conductivity and diffusivity: laboratory methods. In: Methods of soil analysis. Part 1. Physical and mineralogical methods. Agronomy Monograph no. 9. ASA-SSSA, Madison, USA.

19. Liu, M.X., Yang, J.S., Li, X.M., Yu, M., Wang J., 2013. Numerical Simulation of Soil Water Dynamics in a Drip Irrigated Cotton Field Under Plastic Mulch. Pedosphere 23(5): 620–635.

20. Monteith, J.L., 1981. Evaporation and surface temperature. Q. J. R. Meteorol. Soc. 107:1–27.

21. Mualem, Y., 1976. A new model for predicting the hydraulic conductivity of unsaturated porous media. Water Resour. Res. 12 (3):513–522.

22. Nash JE, Sutcliffe JV., 1970. River flow forecasting through conceptualmodels. Part I. A discussion of principles. J. Hydrol. 10:282–90.

23. Ngouajio, M., Ernest, J., 2005. Changes in the physical, optical and thermal properties of polyethylene mulches during double cropping. HortScience 40(1), 94–97.

24. Phogat, V., Skewes, M.A., Cox, J.W., Alam, J., Grigson, G., Šimůnek, J., 2013. Evaluation of water movement and nitrate dynamics in a lysimeterplanted with an orange tree. Agric. Water. Manage 127, 74– 84.

25. Romić, D., Romić, M., Borošić, J., Poljak, M., 2003a. Mulching decreases nitrate leaching in bell pepper (Capsicum annuum L.) cultivation. Agric. Water. Manage. 60:87–97.

26. Romić, D., Borošić, J., Poljak, M., Romić, M., 2003b. Polyethylene mulches and drip irrigation increase growth and yield in watermelon (*Citrullus lanatus* L.). Europ. J. Hort. Sci. 68(4), 192-198.

27. Rudish, M., Kettering, J., Arnhold, S., Huwe, B., 2013. Modeling water flow in a plastic mulched ridge cultivation system on hillslopes affected by South Korean summer monsoon. Agric. Water. Manage. 116: 204– 217.

28. Schaap, M.G., Leij, F.J., van Genuchten, M.Th., 2001. ROSETTA: a computer program for estimating soil hydraulic parameters with hierarchical pedotransfer functions. J. Hydrol. 251, 163–176.

29. Šimůnek, J., van Genuchten, M.Th., Šejna, M., 2008. Development and applications of the HYDRUS and STANMOD software packages and related codes. Vadose Zone J. 7:587–600. http://dx.doi.org/10.2136/vzj2007.0077.

30. Skaggs, T., Trout, T., Šimůnek, J., Shouse, P., 2004. Comparison of HYDRUS-2D Simulations of Drip Irrigation with Experimental Observations. J. Irrig. Drain. Eng. 130(4), 304–310.

31. van Genuchten M.Th., 1980. A closed form equation for predicting the hydraulic conductivity of unsaturated soils. Soil Sci. Soc. Am. J 44:892–1037.

Highlights

- Field data revealed positive effect of plastic mulch on crop yield and soil temperature.
- Water and nitrate distribution were affected by plastic MULCH cover.
- HYDRUS-2D simulations showed good agreement with the field data.
- Modeling revealed faster transport of nitrates below drip line in CONT system.
- Research suggests that MULCH systems can reduce nitrate leaching from fertigation.

Table 1. Basic soil physical and chemical parameters at the study site

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Bulk density (g cm^{-3})	pH (H_2O)	OM (%)
0–40	12.4	57.5	30.1	1.36	7.20	13.08
40–60	19.0	54.8	25.2	1.27	7.05	nd*
60–92	18.5	53.3	28.2	1.22	7.11	nd
92–120	9.8	63.9	48.6	1.18	6.95	nd

* nd: not determined.

Table 2. Optimized soil hydraulic properties at the field site used in numerical simulations.

Layer (cm)	θr (cm^3 cm^{-3})	θs (cm^3 cm^{-3})	*Alpha* (cm^{-1})	*n* (-)	*Ks* (cm day^{-1})
0–40	0.08	0.45	0.0073	1.54	42.82
40–60	0.07	0.48	0.0063	1.59	38.86
60–92	0.05	0.45	0.0050	1.51	29.35
92–200	0.08	0.45	0.0064	1.57	12.85

Table 3. Average soil temperature in uncovered (control) and plastic mulch covered (white, silver, brown, and black) treatments during bell pepper cultivation (June 4th till October 10th).

Soil covering	Soil temperature (°C)
Control – no covering	21.4 b *
White plastic mulch	22.5 a
Silver plastic mulch	22.8 a
Brown plastic mulch	23.2 a
Black plastic mulch	23.3 a

* Means with the same letter are not significantly different at $P<0.05$.

Table 4. Effect of nitrogen fertigation, plastic mulch and their interaction on the bell pepper yield (total) and growth parameters measured on 23.06.

Treatment	**Yield ($t\ ha^{-1}$)**	**Plant height (cm)**	**Number of fruits**	**Number of flowers**
N fertigation				
N_{70}	69.6 a *	32.9 a	2.5 a	8.8 a
N_{140}	74.4 a	32.6 a	2.3 a	9.2 a
N_{210}	71.7 a	34.1 a	2.7 a	9.5 a
Plastic mulch				
Control	63.9 b	31.2 b	1.9 b	8.3 b
White	68.9 ba	30.6 b	1.8 b	7.7 b
Silver	69.3 ba	31.6 b	2.2 b	8.1 b
Brown	78.5 a	36.6 a	3.4 a	11.1 a
Black	78.9 a	36.0 a	3.2 a	10.7 a

* Means with the same letter are not significantly different at P<0.05.

Table 5. Nitrogen mass balance (originating from ammonium/nitrate fertilizer) for CONT and MULCH subplots at the end of simulation period.

	$CONT_{210}$	$CONT_{140}$	$CONT_{70}$	$MULCH_{210}$	$MULCH_{140}$	$MULCH_{70}$
	kg N ha^{-1}					
Root Uptake	78	59	31	76	56	29
Leaching	73	50	22	28	24	12
Accumulated in soil profile	59	31	17	106	60	29

Figure 1. Daily rates of precipitation, irrigation, evaporation, and transpiration during and after the bell pepper growing season on Vrana field site.

Figure 2. Boundary conditions and domain description of the selected field experiment used in HYDRUS-2D simulations: a) MULCH system (plastic mulch cover), with upper boundary conditions only, and b) CONT system (control, without mulch cover) boundary conditions; the lysimeter, lateral and bottom boundary conditions were identical in both scenarios.

Figure 3. Average daily (left axis) and cumulative (right axis) soil temperature (5 cm depth) during research period at different mulching types: black, brown, silver, white, and control plot (without plastic mulch).

Figure 4. Observed and simulated cumulative water outflow (mm) from lysimeter during experimental period in the CONT and MULCH systems cultivated with bell pepper.

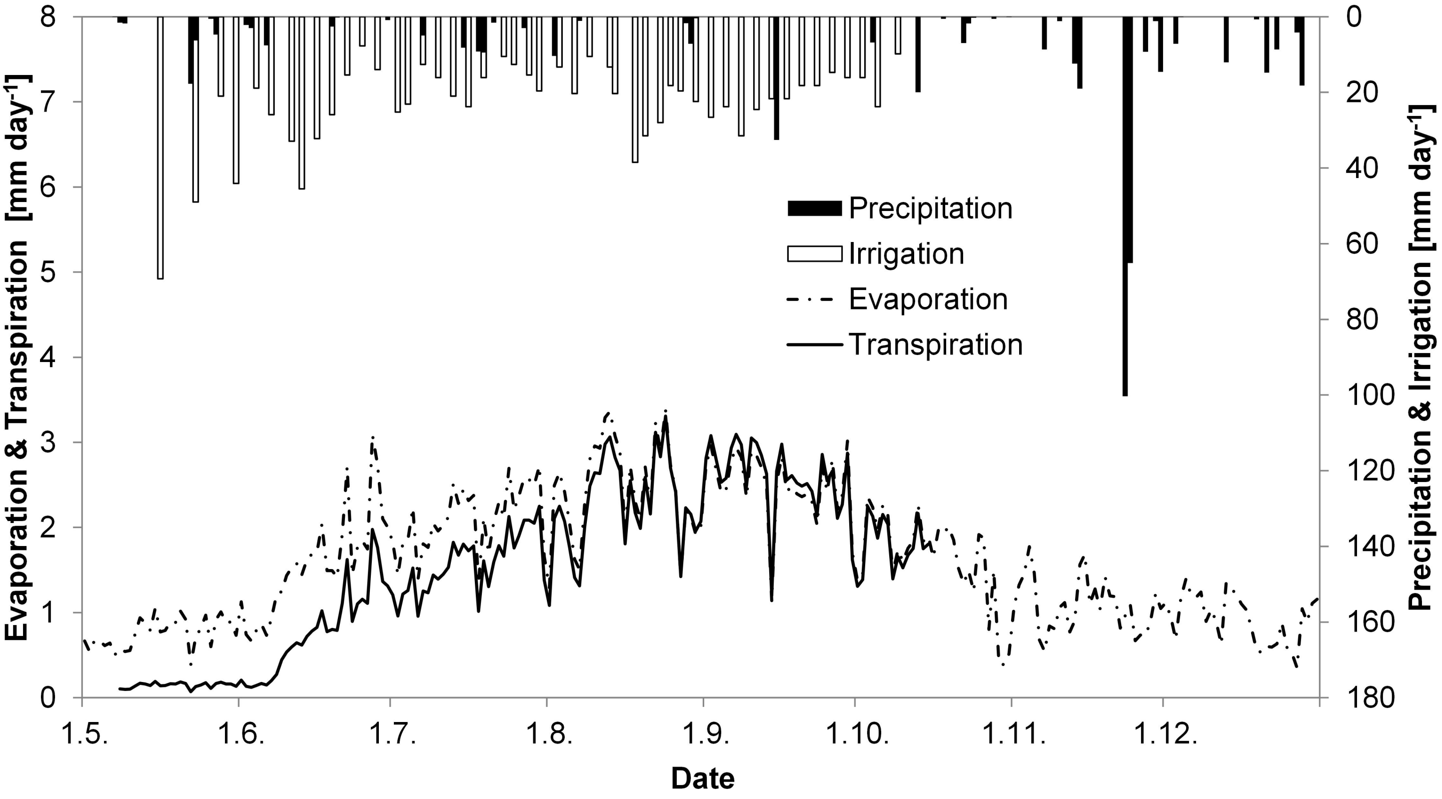
Figure 5. Pressure head (cm) distribution on September 15th (138 days after the beginning of experiment) on CONT (left) and MULCH (right) systems.

Figure 6. Observed and simulated cumulative nitrate outflows in lysimeters from CONT system (without mulch cover) with different rates of nitrogen input *i.e.* 210, 140 and 70 kg ha^{-1}.

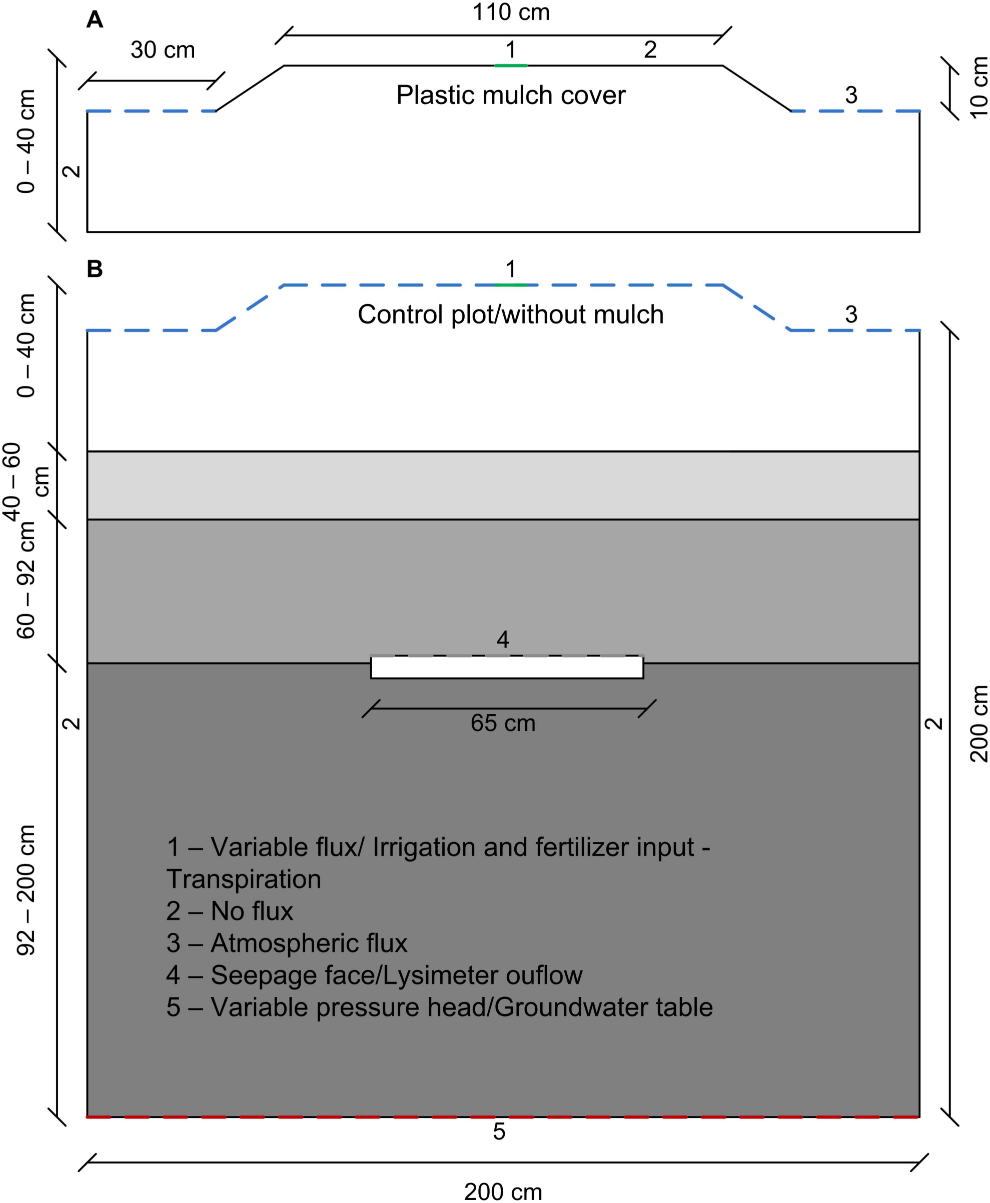
Figure 7. Observed and simulated cumulative nitrate outflows in lysimeters from MULCH system (the data represent average from black and brown plastic covers) with different rates of nitrogen input *i.e.* 210, 140 and 70 kg ha^{-1}.

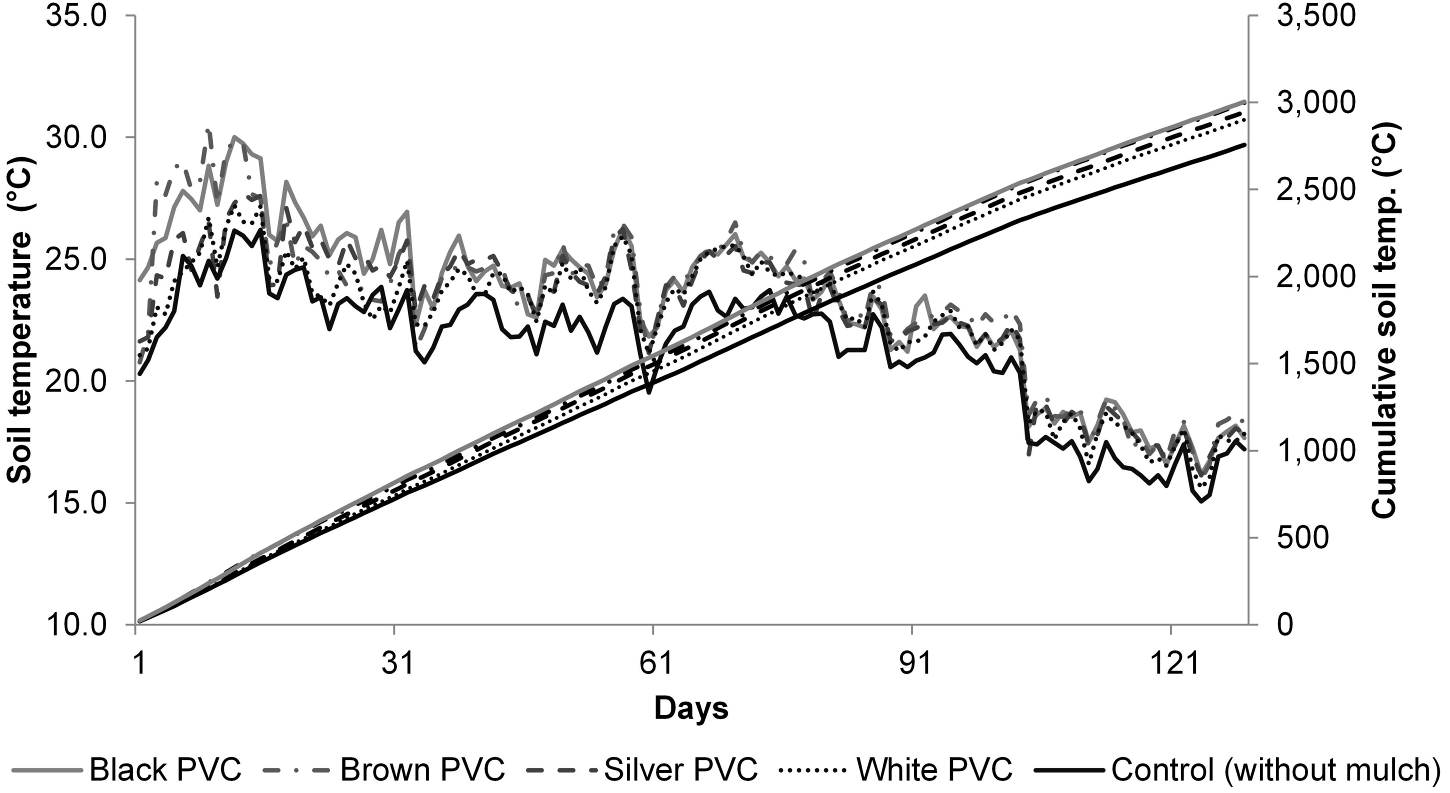
Figure 8. Spatial distribution of ammonium in the soil profile (200 x 200 cm) and around dripper 105 days after the beginning of the simulation for CONT and MULCH system.

Figure 9. Spatial distribution of nitrate in the soil profile (200 x 200 cm) during different time steps *i.e.* 42, 77, 105, 138, 208, 245 days after the beginning of the simulation for CONT and MULCH system.

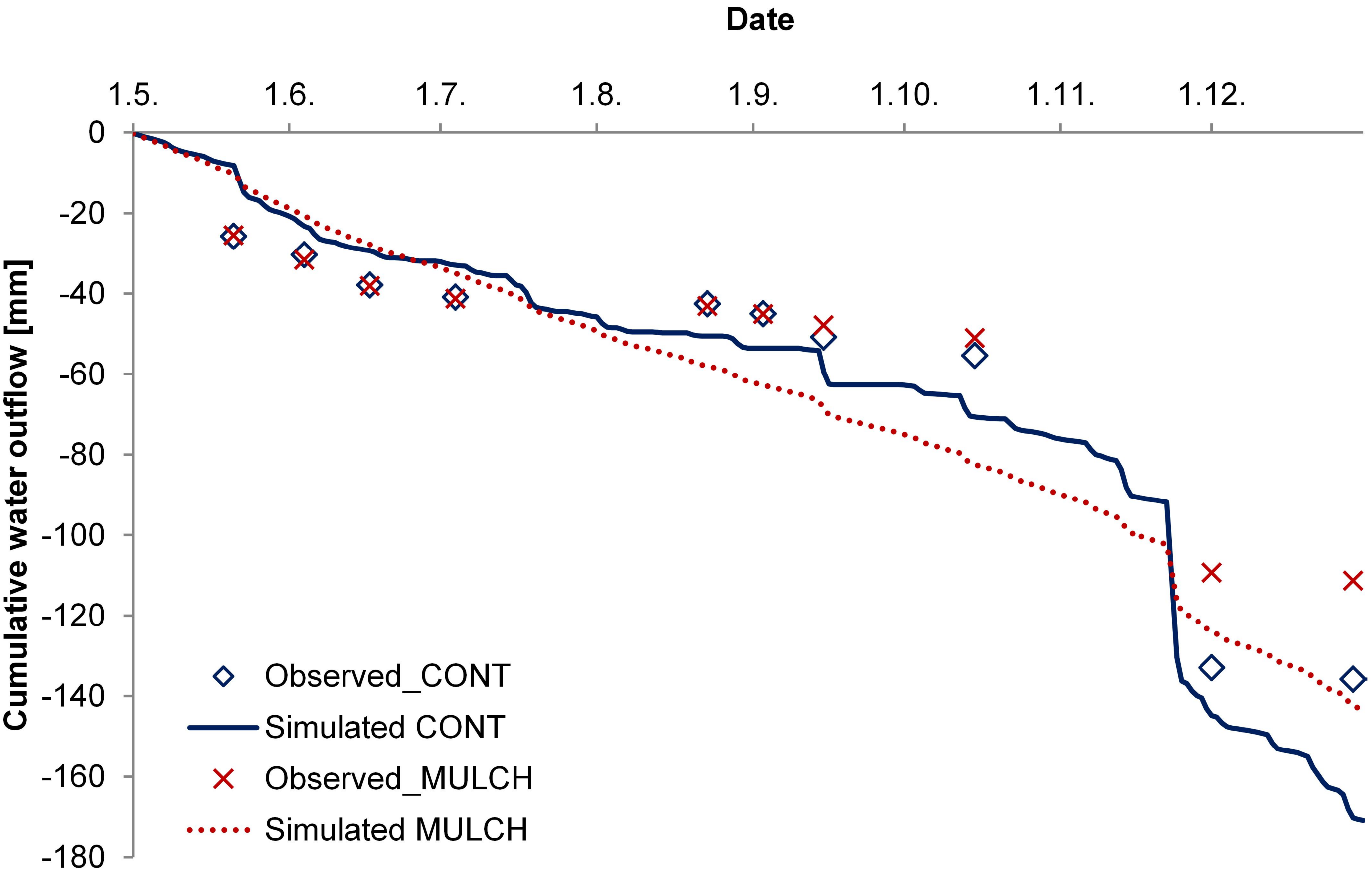


Evaporation & Transpiration [mm day-1]
Precipitation & Irrigation [mm day-1]
Precipitation
Irrigation
Evaporation
Transpiration
Date
0
1
2
3
4
5
6
7
8
0
20
40
60
80
100
120
140
160
180
1.5.
1.6.
1.7.
1.8.
1.9.
1.10.
1.11.
1.12.

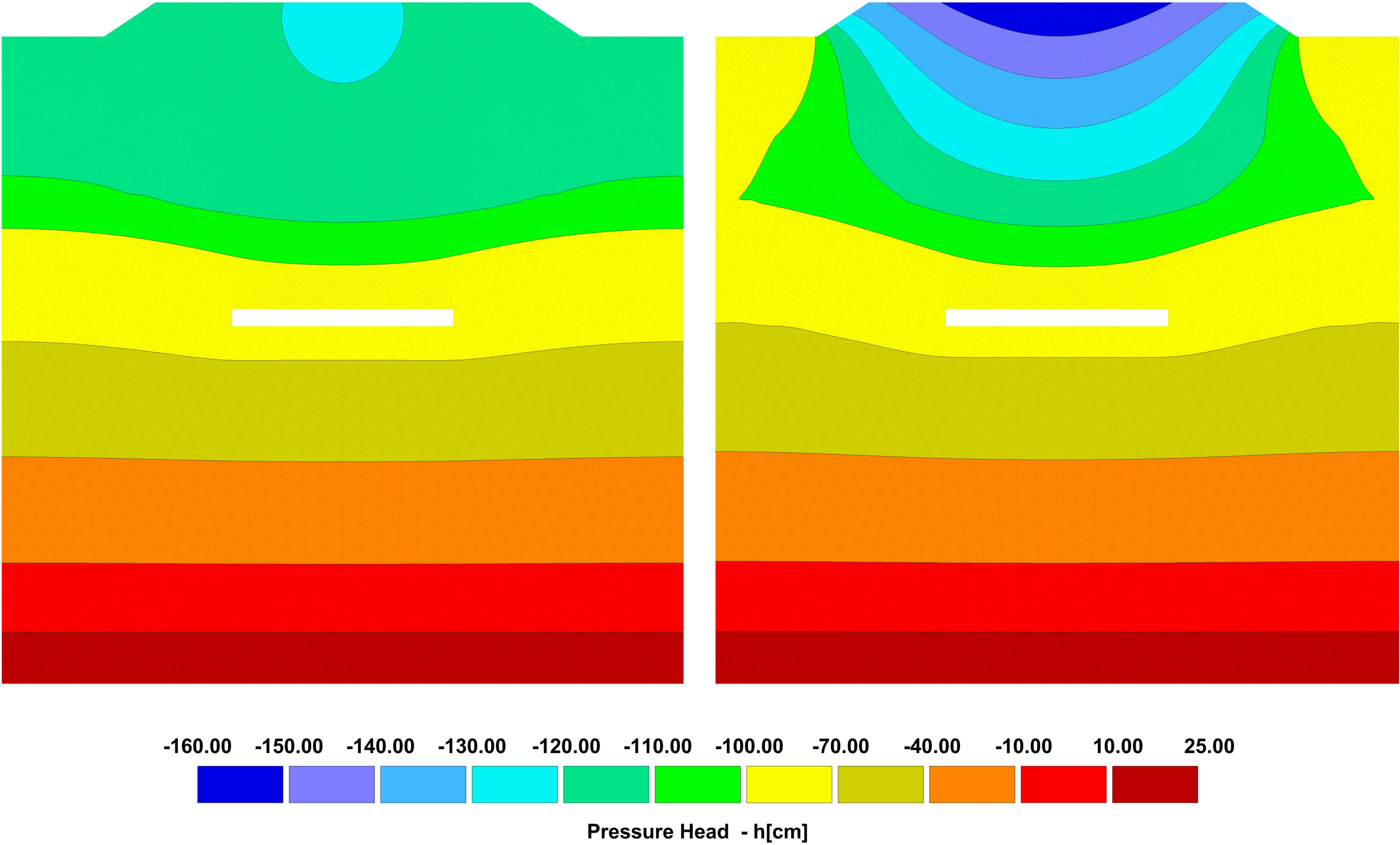

A
110 cm
30 cm
1
2
10 cm
Plastic mulch cover
3
0 – 40 cm
2
B
1
Control plot/without mulch
3
0 – 40 cm
40 – 60 cm
60 – 92 cm
4
65 cm
2
2
200 cm
92 – 200 cm
1 – Variable flux/ Irrigation and fertilizer input - Transpiration
2 – No flux
3 – Atmospheric flux
4 – Seepage face/Lysimeter ouflow
5 – Variable pressure head/Groundwater table
5
200 cm



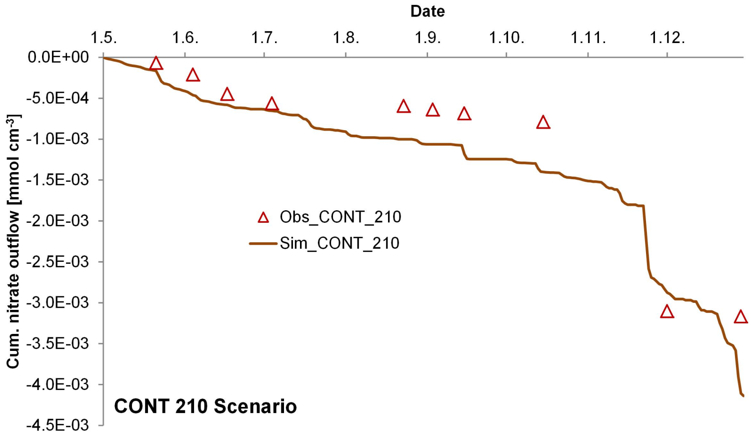
35.0
30.0
25.0
20.0
15.0
10.0
Soil temperature (°C)
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Cumulative soil temp. (°C)
1
31
61
91
121
Days
Black PVC
Brown PVC
Silver PVC
White PVC
Control (without mulch)

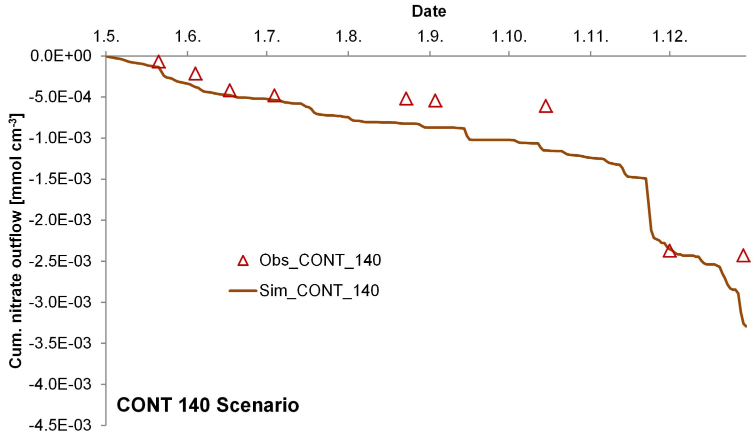


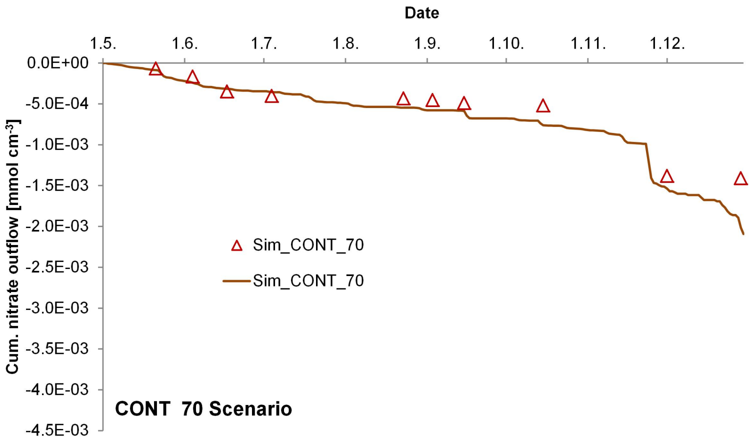
Date
1.5.
1.6.
1.7.
1.8.
1.9.
1.10.
1.11.
1.12.
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
Cumulative water outflow [mm]
Observed_CONT
Simulated CONT
Observed_MULCH
Simulated MULCH

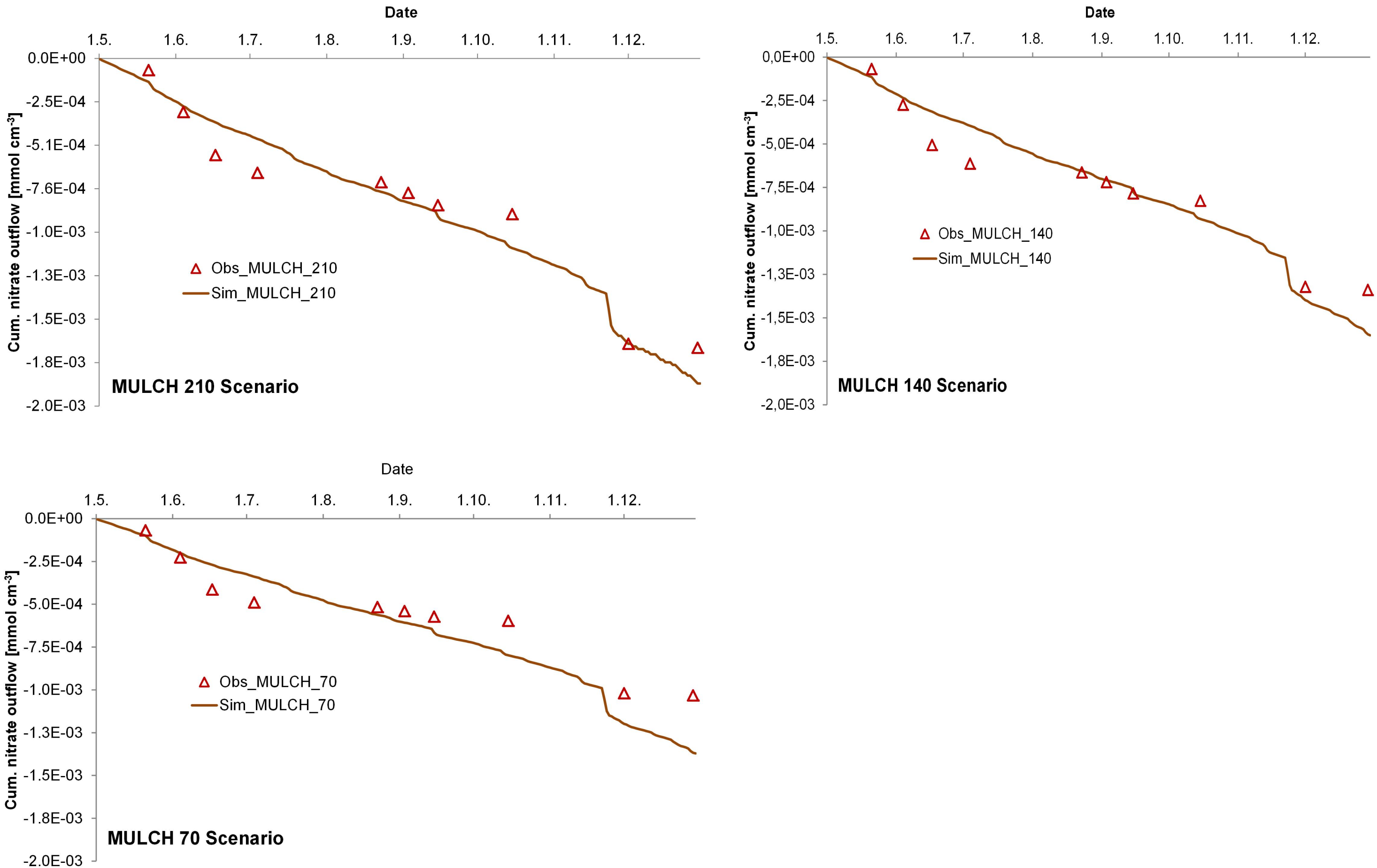


-160.00
-150.00
-140.00
-130.00
-120.00
-110.00
-100.00
-70.00
-40.00
-10.00
10.00
25.00
Pressure Head - h[cm]

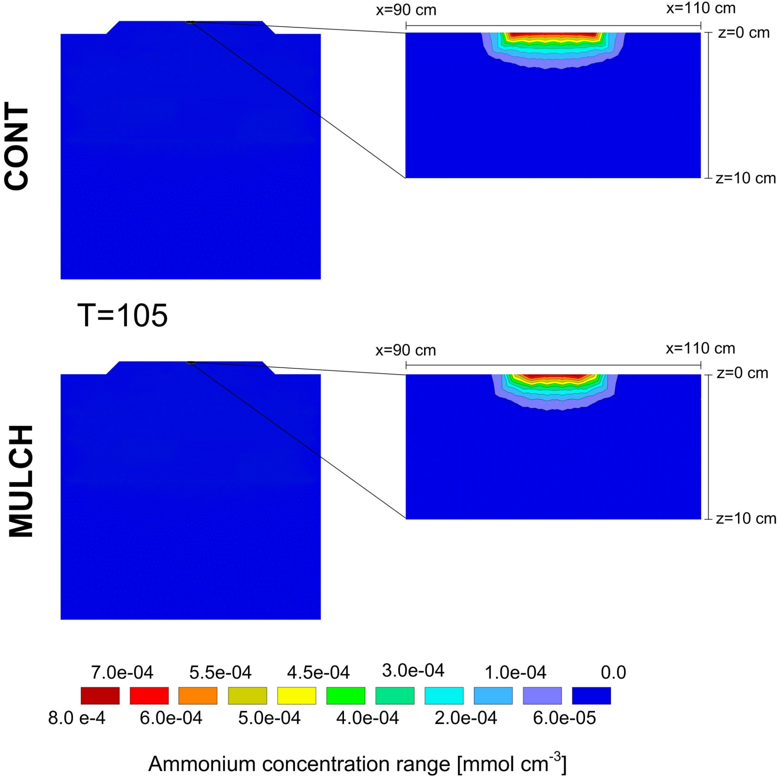

Date
1.5.
1.6.
1.7.
1.8.
1.9.
1.10.
1.11.
1.12.
0.0E+00
-5.0E-04
-1.0E-03
-1.5E-03
-2.0E-03
-2.5E-03
-3.0E-03
-3.5E-03
-4.0E-03
-4.5E-03
Cum. nitrate outflow [mmol cm-3]
Obs_CONT_210
Sim_CONT_210
CONT 210 Scenario


Date
1.5.
1.6.
1.7.
1.8.
1.9.
1.10.
1.11.
1.12.
0.0E+00
-5.0E-04
-1.0E-03
-1.5E-03
-2.0E-03
-2.5E-03
-3.0E-03
-3.5E-03
-4.0E-03
-4.5E-03
Cum. nitrate outflow [mmol cm-3]
Obs_CONT_140
Sim_CONT_140
CONT 140 Scenario

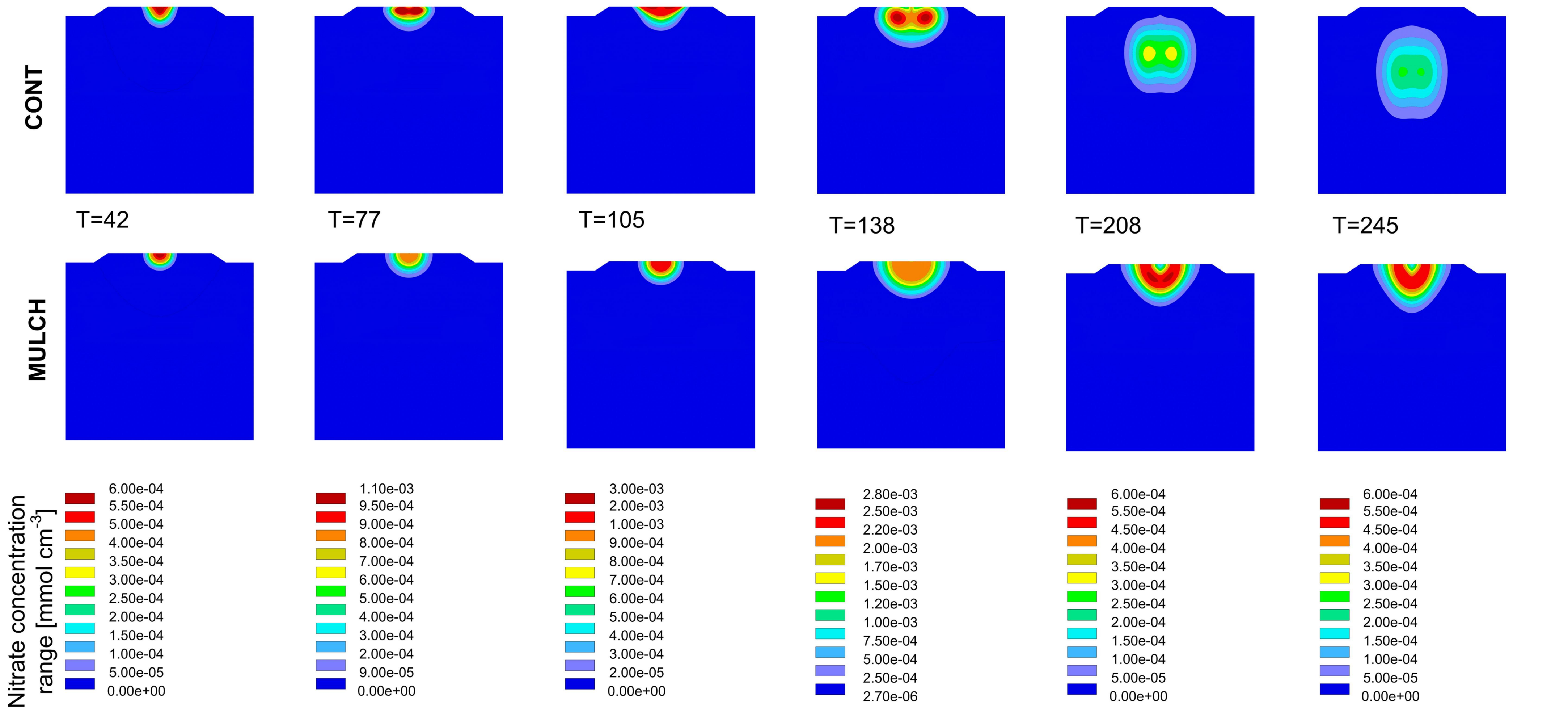

Date
1.5.
1.6.
1.7.
1.8.
1.9.
1.10.
1.11.
1.12.
0.0E+00
-5.0E-04
-1.0E-03
-1.5E-03
-2.0E-03
-2.5E-03
-3.0E-03
-3.5E-03
-4.0E-03
-4.5E-03
Cum. nitrate outflow [mmol cm-3]
Sim_CONT_70
Sim_CONT_70
CONT 70 Scenario



Date
1.5.
1.6.
1.7.
1.8.
1.9.
1.10.
1.11.
1.12.
0.0E+00
-2.5E-04
-5.1E-04
-7.6E-04
-1.0E-03
-1.3E-03
-1.5E-03
-1.8E-03
-2.0E-03
Cum. nitrate outflow [mmol cm-3]
Obs_MULCH_210
Sim_MULCH_210
MULCH 210 Scenario
Date
1.5.
1.6.
1.7.
1.8.
1.9.
1.10.
1.11.
1.12.
0,0E+00
-2,5E-04
-5,0E-04
-7,5E-04
-1,0E-03
-1,3E-03
-1,5E-03
-1,8E-03
-2,0E-03
Cum. nitrate outflow [mmol cm-3]
Obs_MULCH_140
Sim_MULCH_140
MULCH 140 Scenario
Date
1.5.
1.6.
1.7.
1.8.
1.9.
1.10.
1.11.
1.12.
0.0E+00
-2.5E-04
-5.0E-04
-7.5E-04
-1.0E-03
-1.3E-03
-1.5E-03
-1.8E-03
-2.0E-03
Cum. nitrate outflow [mmol cm-3]
Obs_MULCH_70
Sim_MULCH_70
MULCH 70 Scenario



CONT
x=90 cm
x=110 cm
z=0 cm
z=10 cm
T=105
MULCH
x=90 cm
x=110 cm
z=0 cm
z=10 cm
7.0e-04
5.5e-04
4.5e-04
3.0e-04
1.0e-04
0.0
8.0 e-4
6.0e-04
5.0e-04
4.0e-04
2.0e-04
6.0e-05
Ammonium concentration range [mmol cm-3]


CONT
MULCH
T=42
T=77
T=105
T=138
T=208
T=245
Nitrate concentration range [mmol cm-3]
6.00e-04
5.50e-04
5.00e-04
4.00e-04
3.50e-04
3.00e-04
2.50e-04
2.00e-04
1.50e-04
1.00e-04
5.00e-05
0.00e+00
1.10e-03
9.50e-04
9.00e-04
8.00e-04
7.00e-04
6.00e-04
5.00e-04
4.00e-04
3.00e-04
2.00e-04
9.00e-05
0.00e+00
3.00e-03
2.00e-03
1.00e-03
9.00e-04
8.00e-04
7.00e-04
6.00e-04
5.00e-04
4.00e-04
3.00e-04
2.00e-05
0.00e+00
2.80e-03
2.50e-03
2.20e-03
2.00e-03
1.70e-03
1.50e-03
1.20e-03
1.00e-03
7.50e-04
5.00e-04
2.50e-04
2.70e-06
6.00e-04
5.50e-04
4.50e-04
4.00e-04
3.50e-04
3.00e-04
2.50e-04
2.00e-04
1.50e-04
1.00e-04
5.00e-05
0.00e+00
6.00e-04
5.50e-04
4.50e-04
4.00e-04
3.50e-04
3.00e-04
2.50e-04
2.00e-04
1.50e-04
1.00e-04
5.00e-05
0.00e+00