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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 performed 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 to the absence of soil cover. Numerical modeling revealed large influence of plastic mulch cover on water and nutrient distribution in soil. The study suggests that under this management practice the nitrogen amounts applied via fertigation can be lowered and optimized to reduce possible negative influence on environment.

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, 2012).

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; Amayreh and Al-Abed, 2005). It can also improve water use efficiency and decrease irrigation requirements by 10–20% by

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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 multidimensional 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). 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). Rudish 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 range 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 × 7.5 m 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 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.* at 7, 14 and 21 h, during the period from May 15th till October 10th. 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 4th and October 10th.

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 not to 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