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Modelling soil water dynamic in rain-fed spring maize field with plastic mulching

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ABSTRACT

Numerical solution of the Richards equation with Hydrus-2D model is a low cost and fast way to get information on spatio-temporal soil water dynamics. Previous researches with Hydrus-2D have developed two different approaches to represent the rainfall infiltration in irrigated field with plastic mulching: 'BP' – an approach comprised by bare strip boundary and plastic strip boundary without consideration of film side infiltration;'BP + '- an approach comprised by bare strip and plastic strip with integrating the process of film side infiltration by increasing the rainfall infiltration amount in bare strip. Nevertheless, the performance of these approaches has not yet been evaluated in rain-fed fields. Considering much more dominant role of rainfall infiltration in rain-fed agriculture, we tested an additional approach which comprised a bare strip, plastic strip and planting hole (BPH) to take into account the effect of the rainfall canopy redistribution and film side infiltration, and we compared its performance to the two existing approaches. Results suggested BP completely failed to reproduce the soil water content (SWC) in all soil layers of plastic strip and in the deep soil layers of bare strip. BP+ overestimated the SWC in 0–20 cm of the bare strip, while the performance of BPH was acceptable in different positions. After that, we compared the soil water distribution between no-mulched field (NM) and plastic mulched field (PM) with approach BPH. Our simulation showed that the highest SWC in PM occurred near the planting hole, SWC in the center zone of plastic strip was lower, while SWC in the bare strip was lowest. PM improves the soil water availability not only in the plastic strip but also in the bare strip as compared to NM.
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1. Introduction

Rain-fed agriculture, makes up approximately 80% of global cropland and produces 60–70% of the world's food (Falkenmark and Rockström, 2004; Rost et al., 2008). It plays a dominant role in the global food supply, especially considering the increasing global water shortage (Rockström et al., 2010). In China, rainfed agriculture accounts for approximately 25 Mha of the arable land and is mainly located on the semi-arid Loess Plateau and in northeast China, where the crop yields are limited by the soil water deficit and the low soil temperatures in the spring (Deng et al., 2006; Xiao et al., 2016). Plastic mulching has become a popular agricultural technology in those area, since it is thought to maintain soil moisture and increase the soil temperature (Tarara, 2000; Kader et al., 2017). For economic reasons, farmers usually do not cover the entire field with plastic film, but use polyethylene (PE) plastic strips which are alternated with bare strips, a technique called partial plastic mulching.

Soil water dynamics in fields with plastic mulching has received wide attention (Fisher, 1995; Wu et al., 2017; Ren et al., 2017; Dong et al., 2009; Zhao et al., 2012), since not only crop performance, but also environmental processes such as nitrate leaching and the emission of greenhouse gasses depend heavily on soil moisture dynamics (Qin et al., 2015; Filipovic et al., 2016; Liu et al., 2016). Measurement methods such as gravimetric soil water determination on soil samples and time domain reflectometry, and simulations have been used to obtain information on soil water dynamics and distribution (Wu et al.,

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2017; Ren et al., 2017; Filipovic et al., 2016; Li et al., 2015; Liu et al., 2013). Compared to field measurements, modelling studies are low-cost and present a high temporal and spatial resolution.

Models that can be used to obtain soil water information mainly include WaSim-ETH, Community Land Model, SiSPAT-Isotope, Hydrus and crop models such as SWAP, CERES, WOFOST and Aquacrop (Vereecken et al., 2016). Hydrus is mainly used at the pedo up to field scale. Crop models are mainly applied at field scale or regional scale, while the WaSim-ETH, Community Land Model, SiSPAT-Isotope are mainly applied at catchment scale or landscape scale. In fileds with plastic mulching, the different water infiltration and evaporation characteristics of plastic strips and bare strips may lead to obvious inhomogeneous soil water distribution. However, the soil water transport modules in most crop models are one-dimensional, and they are un-able to describe the spatial variation of soil water. Soil hydraulic model such as Hydrus-2D model can solve this problem by applying different type of boundary conditions for the plastic strip and bare strip. For these reasons, the Hydrus-2D model was adopted for the current study.

Hydrus-2D has been widely used to simulate soil water dynamic in irrigated field with plastic mulching, but not yet under rain-fed conditions. Different from the irrigated field, rainfall is the only source of soil water in the rain-fed field and a good understanding of rainfall infiltration processes is decisive for a correct prediction of the spatio-temporal patterns of soil water. In case of partial plastic mulching, rainfall can infiltrate into the soil through three pathways: (i) interception by maize leaves and transfer along the stem into the planting hole (i.e. canopy redistribution). Rainfall that is not intercepted by the maize leaves will (ii) reach the ground directly and infiltrate into the bare soil, or (iii) reach the surface of the plastic film and flow towards the bare soil and infiltrate into the soil at the film side (film-side infiltration)(Chen et al., 2017). Previous studies have applied two approaches to represent the rainfall infiltration in irrigated fields with plastic mulching: (i) In arid regions (annual rainfall amount < 200 mm), Han et al. (2015), Li et al. (2015) and Liu et al. (2013) simplified reality by neglecting canopy redistribution and film side infiltration. They assumed that rainfall directly reached the bare strip and infiltrated there (without canopy redistribution) and they omitted rainfall that reached the plastic strip; (ii) In the humid regions (annual rainfall amount > 800 mm), Filipovic et al. (2016) and Dusek et al. (2010) also neglected canopy redistribution, but integrated the process of film side infiltration by increasing the rainfall infiltration amount in bare strip with a factor which was equal to the ratio of plastic strip width to bare strip width. However, the performance of those two methods has not been evaluated under rain-fed conditions, where the redistribution may play an even bigger role, since no additional water is added under the plastic sheets through irrigation tubes.

In this study, we developed and applied a modelling strategy taking into account of both canopy redistribution and film side infiltration in field with plastic mulching. The objectives of this study were therefore (i) to compare the performance of different simulation strategies on reproducing soil water dynamic in rain-fed field with plastic mulching; (ii) to quantify the spatial variation of the SWC in rain-fed field with plastic mulching using the optimized simulation strategy. We hypothesized that rainfall redistribution and film side infiltration play important roles in soil water dynamics, and are not negligible under rain-fed conditions. In this study, the performance of Hydrus-2D was tested with 2 years of field data from a spring maize (*Zea may* L.) field that located on the Loess Plateau of China. We chose to focus on maize, since it was one of the main crops in the studied region and of great importance for Chinese agriculture (38.1 million hm^2 in China in 2015 (NBSC (National Bureau of Statistics of China), 2016)).

2. Materials and methods

2.1. Research site

The research site (37°45′N, 113°12′E, 1202 m altitude) is located at the Shouyang County which belongs to Shanxi Province, on the eastern part of the Loess Plateau, about 500 km west from the China's capital Beijing. The majority of the farmland in Shouyang County produces crops, especially maize, soy bean and potato. The research area is characterized by a semiarid temperate continental monsoon climate with four distinct seasons. According to the weather record from Shouyang weather station, which is located at 15 km from our research site, the experimental site has a mean annual air temperature of 7.4 °C, a mean annual frost-free period of 140 days and a mean annual rainfall amount of 480 mm during the past 48 years (year 1967–2014). During the experimental year 2015 and 2016, the rainfall amount was 386 mm and 461 mm, which was 20% and 4% lower than the historical mean, respectively.

The soil texture is sandy loam, and the soil is classified as a calcaric Cambisol according to the World Reference Base for soil resources (FAO, 2006). The upper 20 cm of soil has a pH of 7.8, a soil organic matter content of 18.03 g kg^{-1}, total N of 0.85 g kg^{-1}. The soil profile has three horizons: 0–20 cm, 20–60 cm and 60–100 cm, and their soil texture parameters are shown in Table 1. The topography of experimental field is flat, and the groundwater is at depths deeper than 150 m below the surface (Gong et al., 2017). For the soil hydraulic parameters, please see 2.5.2.

Spring maize (*Zea mays* L.) is sown every year on the research site, and typically no crop rotation is applied. Usually, maize is sown in late April or early May and harvested in early October. After harvest, there is a fallow period until sowing in the next year. The early stage of maize growing season is usually characterized by low temperature and few rainfall and accompanied by high risk of spring drought and spring chill, and high temperature and heavy rainfall mainly happen at the middle of maize growing season, while temperature and rainfall become lower at the late growing season (Gong et al., 2015). In 2015, the maize was sown in May 1 st and harvested in September 30th, and in 2016, the maize was sown in May 5th and harvested in October 1st.

2.2. Field experiment

Two treatments were selected in this study: a no mulch system (NM) and a partial plastic mulching system (PM). Each treatment has three replications, and each replication was carried out in a plot with a width of 6 m and a length of 10 m (60 m^2). As shown in Fig. 1, the PM system included a plastic strip with a width of 80 cm and a bare strip with a width of 40 cm. PE film with thickness of 10 μm was applied in the PM treatment. For both the PM and NM treatments, the planting spacing was 30 cm, the row distance was 60 cm and the sowing density was 56,000 plants/ha. For the detailed filed management practices in NM and PM, please see Chen et al. (2017).

During the growing season, the soil water content was determined gravimetrically to a depth of 1 m at 0.1-m intervals at the middle of plastic strip and at the middle of bare strip (Fig. 1). Theoretically, the higher temporal resolution the soil moisture measurement was, the more favorable for the model evaluation. However, considering the cost of gravimetric determination and the rare rainfall in semi-arid area, the soil moisture was measured every 10 days. When the weather did not allow sampling at the planned date (e.g., due to heavy rainfall), sampling was postponed for 1-2 days. As Hydrus-2D do not include the crop growth module, we used the measured leaf area index (LAI) to calculate the potential evaporation and transpiration together with the field-recorded

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