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Modeling water flow in a plastic mulched ridge cultivation system on hillslopes affected by South Korean summer monsoon

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ABSTRACT

Intensive agricultural land use in combination with heavy rain storm events during the summer monsoon season plays a key role in groundwater pollution by nutrients and agrochemicals in agricultural catchments in South Korea. A widespread measure for weed control in this region is plastic mulched ridge cultivation. However, it is not well understood, how and to which extent the water flow regime in sloped fields is hereby modified. To evaluate the effect of plastic mulched ridge cultivation (RT_{pm}) on soil water dynamics, we carried out a two-dimensional process-based modeling study using the numerical model Hydrus 2/3D. Subsequently, RT_{pm} was compared to model simulations of ridge cultivation without plastic cover (RT) and flat conventional tillage without ridges and without plastic cover (CT). Datasets of soil water potentials obtained by field measurements at two plastic mulched potato fields (*Solanum tuberosum* L.) provided the basis for optimizing soil hydraulic parameters inversely by the Levenberg–Marquardt algorithm. We found, that plastic mulching induced horizontal pressure head gradients and forced soil water to move laterally from furrows to ridges under normal weather conditions. During monsoon events, soils were fully saturated and interflow occurred in coarse textured and ploughed topsoil. Further, the water balance of the different model scenarios showed that plastic mulching reduced drainage water up to 16% but concurrently increased the surface runoff up to 65%. The consequences are an increase in runoff peak flow, flood risk and erosion. Therefore, we recommend the application of perforated and biodegradable plastic mulch in regions affected by summer monsoon.

1. Introduction

Agricultural management practices, soil properties and field topography lead to a high variability in soil water movement, solute transport and leaching of nutrients and agrochemicals. In South Korea, ridge tillage with impermeable black plastic mulch covering the ridges is the most common practice for dryland crops such as radish (*Raphanus sativus*), cabbage (*Brassica rapa susp. Pekinensis* (*lour.*), *Hanelt*, *Brassica aleracea convar. Capitata var. alba*), beans (*Glycine max* (L.) *Merr.*) and potatoes (*Solanum tuberosum* L.), which are predominately grown on slopes. Intense fertilization together with heavy rainfalls during summer monsoon season poses a high risk of groundwater pollution in the Haean catchment. Additionally, the discharge of phosphorus associated with sediments from agricultural areas causes eutrophication and deterioration of water quality in downstream reservoirs in South Korea (Kim et al., 2001). This is of major significance because the river system of Haean contributes to the Soyang Lake, which is a major source of freshwater for the metropolitan area of Seoul.

The effect of flat row-interrow cultivation on soil water dynamics was investigated for soybean and corn crops in previous studies (Timlin et al., 2001; van Wesenbeeck and Kachanoski, 1988; Paltineanu and Starr, 2000). The findings showed increased soil moisture in row positions due to interception and stemflow. The same effect was also found for potato crops cultivated in ridges (Saffigna et al., 1976), but with the addition of concurrently higher water contents in furrows because of surface runoff from ridges and leaf drip from the outer foliage. Soil and plant biological effects of the plastic mulch were studied by Gürsoy et al. (2011) and Laszlo and Gyuricza (2004), who found favorable physical soil conditions and improved growth and yield of maize and corn crops. Previous research on plastic mulched ridge cultivation focused mainly on rain water harvesting in combination with irrigation techniques in semiarid and arid regions, in which the plastic covered ridges induce runoff to the planted furrow area, leading to an increased crop yield and water availability (Wang et al., 2008; Li and Gong, 2002; Li et al., 2008; Tian et al., 2003; Mahajan et al., 2007). In contrast, dryland crops in South Korea are planted in the plastic covered ridges to suppress weed growth and to

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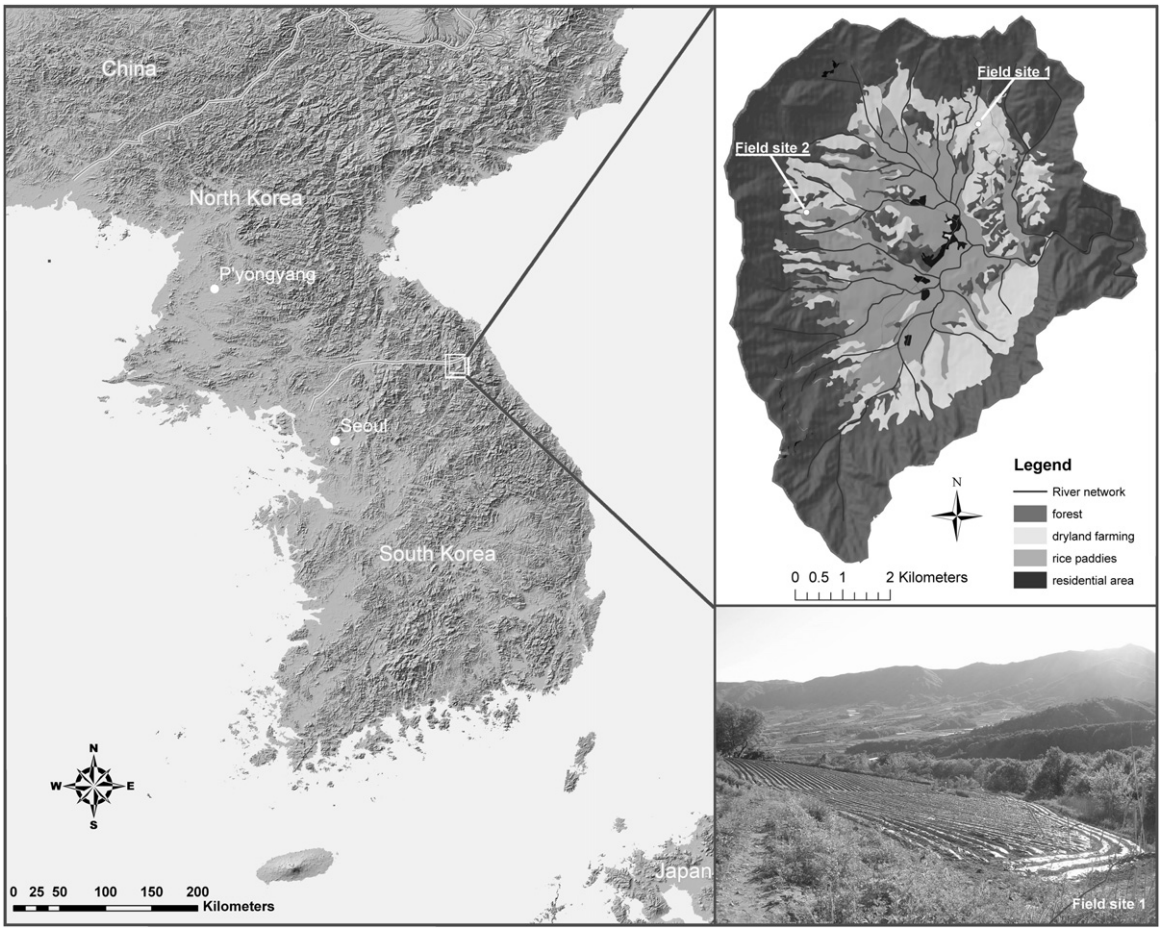

Fig. 1. Topographical map of South Korea (left), land use map of the Haean catchment (top right) and picture of field site 1 (bottom right).

support early plant emergence due to increased soil temperature in the ridges.

Only a few modeling studies about ridge cultivation systems exist. Solute transport of pesticides in an irrigated potato ridge cultivation system was investigated by Leistra and Boesten (2010). They demonstrated that the risk of pesticide leaching in furrow soil can be substantially higher than in corresponding level field soil. Abbasi et al. (2004) simulated water flow in a long furrow system with furrow irrigation using Hydrus 2/3D to estimate inversely soil hydraulic properties and transport parameters. Dusek et al. (2010) used the S1D and S2D models to simulate water flow and solute transport in a drip irrigated plastic mulched pineapple cultivation.

Since there are no modeling studies about plastic mulched ridge cultivation in mountainous areas affected by extreme rain events, the aim of this study was to evaluate the effect of plastic mulched ridge cultivation on soil water dynamics under a summer monsoonal climate. Therefore, we used a monitoring network of tensiometers and FDR sensors in two potato fields in the mountainous Haean basin in South Korea to observe soil water dynamics in ridge and furrow positions. The field data sets of standard tensiometers were used to estimate soil hydraulic parameters using an inverse modeling approach based on Levenberg–Marquardt nonlinear minimization algorithm. Subsequently we used the optimized parameters of the water flow model to run scenarios regarding ridge tillage without plastic mulch and flat conventional tillage. The comparison of plastic mulched ridge tillage (RT_{pm}), ridge tillage without plastic coverage (RT) and a flat conventional tillage (CT) allows a better understanding of soil water dynamics and water movement influenced by the plastic mulch.

2. Materials and methods

2.1. Study area

The agriculturally used Haean catchment is located in Gangwon Province in the North-eastern part of South Korea (Fig. 1). While rice paddies are dominating in the flat parts of the basin, dryland farming is practiced in the hillsloped areas of the catchment. The annual precipitation sum in Haean basin is about 1577 mm (11-years average) with 50–60% of the annual rainfall occurring during summer from June to August. The Korean peninsula is characterized by two rainfall peaks, one in July and one in August. The maximum rainfall, however, shifted in the recent decades from July to August (Lee et al., 2010). The precipitation during the 2010 observation period is shown in Fig. 3.

Plastic mulched ridge cultivation is the common practice to cultivate dryland crops in Haean catchment. Ridges (35 cm width and 15 cm height) are covered with an impermeable black polyethylene film and alternate with uncovered furrows (35 cm width). Planting holes (diameter 5 cm) in the plastic cover are located at the top of the ridges with a plant-to-plant spacing of 25 cm.

Cambisols developed on the granitic bedrock material are widespread over the catchment. Due to high erosion rates, however, the application of sandy soil material before the growing season is a commonly used method to compensate for soil loss. Thus, highly disturbed soil profiles are characterized by light-textured, permeable and ploughed top layers, which are prone to nutrient and pesticide leaching and subjacent B horizons.