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Field and numerical experiment of an improved subsurface drainage system in Huaibei plain

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ABSTRACT

New requirements are put forward for agricultural drainage system due to frequent floods and cultivated land shortage in Huaibei plain, China. The improved subsurface drainage is a more efficient drainage system by laying high permeability materials as filter above the drains based on conventional subsurface drainage whose function is limited by soil hydraulic conductivity. Field experiments was used to evaluate the performance of the improved subsurface drainage preliminarily and numerical experiments was used to explore the capacity of the improved subsurface drainage deeply. Based on calibration and validation by field experiment data, HYDRUS model was used to evaluate the impacts of design parameters of filter hydraulic conductivity, filter width and height, drain spacing and depth on improved subsurface drainage discharge with constant ponding depth. Then, water table depths at different distances from the pipe drain for improved and conventional subsurface drainage were simulated under initial conditions of saturated soil and no surface ponding. Besides, the daily water balance under improved subsurface drainage had been also studied. The result of field experiment showed that the discharge of improved subsurface drainage was about 1.9 times of the conventional subsurface drainage discharge under conditions of same surface ponding depths. The results of numerical experiments indicated that the improved subsurface drainage had a real-time drainage function for the reason that cumulative outflow increased by about 87% than conventional subsurface drainage within 12 h after beginning draining. The improved subsurface drainage lowered water table to an appropriate depth faster than conventional ones, which could provide a more favourable soil moisture condition for crop growth. Furthermore, through daily water balance analysis of improved and conventional subsurface drainage with different rainfalls and initial water table depths, the results showed that subsurface drainage could reduce surface runoff effectively, especially for improved subsurface drainage. Good drainability of the improved subsurface drainage was beneficial to decrease the amount of soil water storage after rainfall and helpful to shorten subsequent draining time of water table drawdown. The research results could provide scientific basis for improved subsurface drainage design and lay a good foundation for its application. Meanwhile, it would be beneficial to enrich agricultural drainage technologies and promote development of agricultural drainage in China.

1. Introduction

Abnormal climate change increases the probability of heavy and intense rainfall events in some areas which causes floods frequently (Das et al., 2013; Groisman et al., 2005; Panagoulia, 2009). In China, most farmlands are in monsoon regions where floods happen more frequently influenced by monsoon climate (Loo et al., 2014). So there are higher demands for farmlands drainage facing flood threat. Huaibei plain is a typical region which suffered from waterlogging frequently. It is located in the warm temperate and semi-humid monsoon climate region with an average annual precipitation of 960 mm, occurring mostly from June to September, most prone to surface and subsurface waterlogging. Drainage is needed in Huaibei plain. However, the cultivated area in Huaibei

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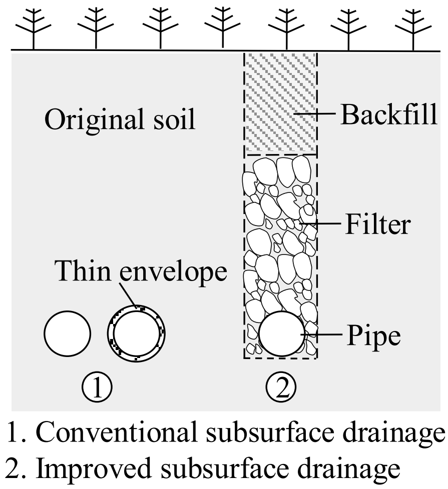

Fig. 1. Sketch of two subsurface drainage patterns.

plain declined gradually because of urbanization and natural disaster. Ditch occupies much farmlands, which may aggravate the problem of farmlands shortage. Subsurface pipe drainage has a better performance in reducing occupying cultivated area. Hence, in view of farmland protection, subsurface drainage was needed in Huaibei plain.

Conventional subsurface drainage has limited discharge due to small soil hydraulic conductivity, shown in Fig. 1. The subsurface drainage by increasing drainage discharge and improving drainage efficiency will accelerate surface ponding infiltration and removal effectively, which also will be beneficial for waterlogging control. Referring to the structure of conventional subsurface drainage and ditches, Tao et al. (2016) proposed an improved subsurface drainage by using high permeability materials (gravels or wood chips or crop stalks et al.) as filter to replace the soil above the drains and backfilling 30–40 cm original soil as a plow layer, shown in Fig. 1. The discharge of improved subsurface drainage larger than conventional ones has also been proved by Tao et al. (2016) based on soil column experiment, roughly. Larger discharge and less land occupied of the improved subsurface drainage may be more potential to solve the problems of waterlogging and farmland shortage, which is also suitable for Huaibei plain.

Field experiment is a preliminary way to evaluate the improved subsurface drainage performance, but it might not be an comprehensive method. Then, the numerical simulation could be a good choice for more detailed study. DRAINMOD and SWAP (Soil-Water-Atmosphere-Plant) and HYDRUS have been widely used to simulate subsurface pipe drainage performence and its abilityofwater table control. DRAINMOD and SWAP are one-dimension models based on hydrological process (Dam et al., 1997; Kroes et al., 2000) and hard to simulate the horizontal heterogeneity soil. However, HYDRUS is a windows-based model, which can simulate two-dimensional and three-dimensional water flow situations. HYDRUS is used to simulate water, heat, and solute movement in variably saturated media. Especially, HYDRUS can handle flow domains delineated by irregular boundaries. The flow region itself may be composed of nonuniform soils having an arbitrary degree of local anisotropy (Šimůnek et al., 2006). TEKİN (2002) has predicted the relationship of drainage discharge and water table depth by simulating water flow into subsurface pipe drain for a layered soil profile based on HYDRUS-2D model. Akay et al. (2008) has simulated the flow dynamics during macropore-subsurface drain interactions. Filipović et al. (2013) has used HYDRUS-2D to evaluate water flow in free drainage lysimeters with respect to soil anisotropy. Ebrahimian and Noory (2014) have applied HYDRUS-2D model to simulate water flow under subsurface drainage in a paddy field for various drain depths and spacing, surface soil textures and crack conditions. Filipović et al. (2014) has used HYDRUS-2D/3D to evaluate the performance of different subsurface drainage systems of pipe drains, pipe drains with gravel trenches, pipe drains with gravel trenches combined with mole drains in water table control and runoff reduction.

The main objective of this paper was to evaluate the performance of the improved subsurface drainage in Huaibei plain by field experiment and numerical simulation. When surface waterlogging generates after heavy rainfall, the purpose of subsurface drainage can divide into two parts of surface waterlogging removing and water table control in chronological order. To analyze the capacity of improved subsurface drainage on surface waterlogging removing, variable factors of filter hydraulic conductivity, filter width and height, drain depth and spacing have been considered under conditions of saturated soil and constant ponding water depth. To evaluate the effect of improved subsurface drainage on water table control, the water table dynamics under improved subsurface drainage was studied by comparing with conventional subsurface drainage under initial saturated soil and no surface ponding conditions. Besides, the effect of improved subsurface drainage on surface runoff reduction during rainfall is also worth to discuss. Hence, daily water balance was calculated under conditions of variable initial water table depths and different rainfalls.

2. Materials and methods

2.1. Agriculture and precipitation in Huaibei plain

Huaibei plain is one of the important commodity grain bases and has the largest area and the most population in Anhui province. The region has two or three main crop seasons and the crops are dominated by dry crops such as corn, wheat, peanut, cotton, etc. Huaibei plain is also one of the typical farmlands that prone to surface and subsurface waterlogging in South China. The precipitation is always more than 50 mm which leads large surface runoff and low rainfall utilization. The backbone of drainage system in Huaibei plain which consists of ditch is relatively well-developed, while the drainage system in field is not enough and need further development.

Besides, heavy and frequent rainfall severely limits the crop yield and agricultural development. Based on the meteorological data from 1984 to 2014, the average annual precipitation is about 960 mm in which over 65% happens in crop growing period from June to September. The average annual maximum monthly precipitation happens in July. To calculate monthly average precipitation in July, the day was cumulated when the precipitation was over 10 mm, shown in Table 1. The average precipitation in July is about 44 mm for a rainfall event. Furthermore, by frequency calculation, the daily precipitation of a 10-year storm event is about 141 mm.

2.2. Field experiment

To solve the problems of waterlogging and farmland shortage in Huaibei plain, the performance of improved subsurface drainage has been preliminarily tested. The field experiment was conducted at Xinmaqiao experiment station in Huaibei plain, China (117°22′ E, 33°09′ N). Two plots of conventional and improved subsurface drainage with gravel filter had been constructed. Each plot was 18 m wide and 17 m long in view of the convenient control of testing condition and contained three 75 mm diameter pipe drains (6 m drain spacing). Drains were installed at 0.80 m depth, considering that the primary mission of field drainage in Huaibei plain was to removing surface and subsurface waterlogging for dry crop. For the soil at pipe drain level, the average contents of clay particle, silt