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PERFORMANCE EVALUATION OF IMPROVED SUBSURFACE DRAINAGE SYSTEM

EVALUATION DES PERFORMANCES D'UN SYSTEMDE DE DRAINAGE SOUTERRAIN AMELIORE

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ABSTRACT

High requirements are put forward for agricultural drainage system due to frequent floods and cultivated land shortage in China. Based on soil column experiment, the performance of an improved subsurface drainage system with less land occupied and higher drain discharge was discussed by considering five factors of water table depth, filter width, ponding depth, outflow condition and soil medium. The results showed that the discharge of improved subsurface drainage was 2~3 times of that of conventional subsurface pipe drainage when filter width varied from 2cm to 6cm in completely saturated fine-sand. The greater the hydraulic conductivity gaps between soil and filter, the more effective the improved subsurface drainage was. Besides, in larger water table depth, improved subsurface drainage was still functioning. In fine-sand medium, when water table depth was 2 times of subsurface drain depth, the discharge of improved subsurface drainage was still comparable to 2 times of that of conventional subsurface pipe drainage in completely saturated soil. And filter width had large impact on the ratio of drain discharge and seepage quantity into groundwater.

RÉSUMÉ

Le drainage agricole doit présenter de hautes exigences pour répondre aux suspicions d'accroissement de la fréquence des crues et de diminution de la superficie agricole (drainage par tuyaux v/s drainage par fossés). Sur la base de colonnes de sols, la performance d'un drainage enterré occupant moins de terrain et avec un débit plus élevé est étudié en considérant 5 facteurs à savoir la charge totale, la largeur du filtre, la superficie inondée, les conditions de débit, le sol. Les résultats montrent que le débit est 2-3 fois supérieur à celui d'un tuyau conventionnel quand l'épaisseur du filtre varie de 2 à 6-cm dans un sable fin complètement saturé. Plus l'écart de conductivité entre le sol et le filtre était important, plus le drainage amélioré était performant. De plus, dans le cas de grandes charges, le drainage amélioré continue de fonctionner. Dans le cas du sable fin, lorsque la hauteur de la nappe ést deux fois supérieure à la profondeur du drain, le débit du drain amélioré équivaaut encore à deux fois le débit du drain conventionnel dans des conditions de sol saturé. La largeur du filtre a un impact important sur le débit du drain et les flux vers la nappe.

Keywords: improved subsurface drainage; conventional subsurface pipe drainage; drain discharge; filter

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1. Introduction

Abnormal global climate bring potential for heavy and intense rainfall. Influenced by monsoon climate and topography, South China is prone to surface and subsurface waterlogging, with annual rainfall ranging from 1,000 to 2,000 mm, occurring mostly from May to September. When heavy rainfall happens, water table will reach the ground surface within short duration in shallow groundwater (GW) areas and surface ponding occurs. While for deep GW areas, short duration and intense rainfall will generate surface ponding before the water table rises to ground surface. Drainage is an effective way to improve the situation, which is challenged by sudden and anomalous floods.

Farmland shortage and agricultural pollution in China provide more opportunities to subsurface pipe drainage which occupies less farmland, reduces soil erosion and non-point source pollution. Traditionally, subsurface pipe drainage was mainly used for water table control, not for removing excess surface water due to smaller drain discharge. To overcome this disadvantage, a special pattern of drain drainage was proposed and hereinafter called ‘improved subsurface drainage’ with high permeability material as filter above the drains. Its structure is like ‘French drain’ which is usually used for yard, lawn, municipal drainage engineering and even golf course. However, little research had been done on its farmland drainage performance. The purpose of this paper is to evaluate the performance of improved subsurface drainage under conditions of different ponding depths, water table depths, soil mediums, filter widths and outflow conditions.

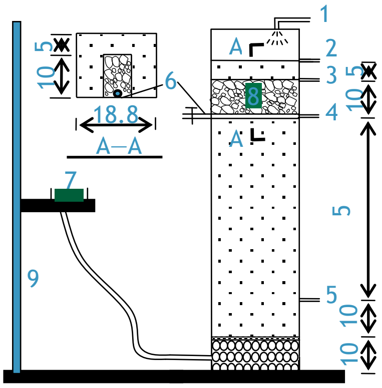
2. Materials and methods

2.1 Structure of improved subsurface drainage

The improved subsurface drainage consists of drain pipe and filter. Appropriate gradation sand and gravel or other high permeability materials can be used as filter, which is laid from drain level to bottom of plough zone with 20-40cm width or more by layers or mixture. Then 30~40cm original soil should be backfilled as plough layer. In rainy seasons, it can accelerate the infiltration of surface water so as to alleviate the duration of crop submerged. The improved subsurface drainage can greatly improve air permeability of the soil to provide favourable conditions for crop growth.

2.2 Experimental design

The experiments were conducted in a laboratory soil column composed of a plexiglass cylinder of 18.8cm in inner diameter and 100cm in height as shown in Fig.1. 10cm high permeability materials were filled in the column bottom. Then 60cm soil medium was put in. At the height of 70cm from bottom, a 1.2 cm external diameter smooth copper pipe was installed with an open porosity of 1.5% and filter screen was wrapped outside to prevent clogging. For conventional subsurface pipe drainage, the 15cm height above the drains was filled of soil medium completely. While for improved subsurface drainage, 10cm height of filter materials were put above the drains with 2cm, 4cm and 6cm width respectively, taking the pipe as axis of symmetry. Four piezometers were placed. 192 group experiments were conducted in a completely randomized design, including four water table depths of 0D (D is the depth of drain pipe, 15cm), 2D, 3.7D and 5D, four filter widths of 0 cm, 2 cm, 4 cm and 6cm, three ponding surface depths of 3 cm, 5cm and 7cm, two outflow conditions of free and submerged (4.5cm of submerged height), and two soil mediums of coarse-sand and fine-sand texture.



1.Inlet；2-5.Piezometers；6.Drain pipe；
7.Water tank；8.Filter 9.Removable support

Fig.1 Sketch of test equipment (cm)

3. Results and discussion

3.1 Completely saturated soil with ponding water

3.1.1 Effects of filter width on drain discharge under free outflow

In saturated soil, with the same ponding surface depth, the drain discharge increased with increasing filter width in both fine-sand and coarse-sand as shown in Fig.2. However, the increased percentage of drain discharge decreased gradually as filter width increase. Compared to conventional subsurface pipe drainage, the discharge of improved subsurface drainage with 2cm, 4cm, 6cm filter width increased 45.7%, 54.9%, 66.2% in coarse-sand and 128.1%, 164.8%, 202.4% in fine-sand under a ponding depth of 7cm. The increased percentage of drain discharge in fine-sand was much larger than that in coarse-sand. That was to say, improved subsurface drainage was more effective in fine-sand than in coarse-sand because of the large hydraulic conductivity gap between soil and filter.

The relationship curves between filter width and drain discharge were roughly parallel under different surface ponding depths. Under ponding water depths of 7cm, 5cm and 3cm, the increased percentages of the discharge of improved subsurface drainage were commensurate, comparing with conventional subsurface pipe drainage. For instance, the increased percentages of drain discharge for 2cm filter width in fine-sand were128.1%, 130.7% and 131.3% with 7cm, 5cm and 3cm ponding depths respectively, 164.8%, 174.0% and 171.9% for 4cm filter width, and so on.

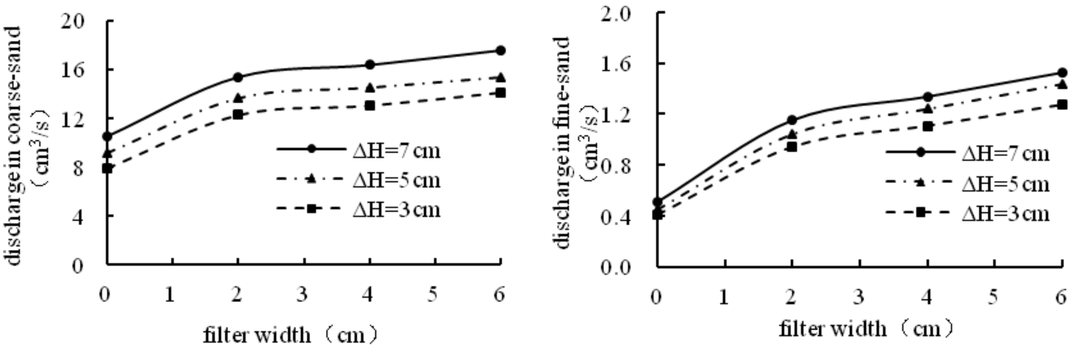


Figure 2 Effect of filter width on drain discharge under different ponding depths

3.1.2 Effects of submerged outflow on drain discharge

Submerged outflow would inevitably happen in practice， especially when the outlet ditches had no capacity to remove the drainage water quickly enough after short duration and intense rainfall. Experimental results clearly showed that the drain discharge under submerged outflow in fine-sand medium decreased about 20% than that of free outflow under the same ponding depth and filter width. They were 24.8%, 23.6% and 22.1% corresponding to the ponding depths of 3cm, 5cm and 7cm on average. Compared to the conventional subsurface pipe drainage, the increased percentage of submerged outflow in improved subsurface drainage were 119.2% for 2cm filter width, 156.6% for 4cm filter width and 200% for 6cm filter width respectively with 7cm ponding depth.

3.2 Partly saturated soil with ponding water

3.2.1 Effects of water table depth on free drain discharge

Generally speaking, drain discharge decreased with the increase of water table depth for both conventional and improved subsurface drainage. Under 7cm ponding depth and fine-sand medium, the free discharge of conventional subsurface pipe drainage at a water table depth of 30cm (2*D*) was about 80% of that at 0cm water table depth (completely saturated soil), indicating that the conventional subsurface pipe drainage could still function. But the drainability of conventional subsurface pipe drainage was almost lost with only 20% of free discharge at 0cm water table depth when the water table depth reached 75cm (5*D*). Conclusions could also be drawn that conventional subsurface pipe drainage was quite limited in a deep GW area.

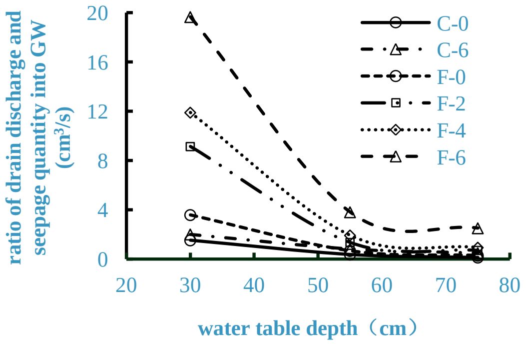


Figure 3 Effect of water table depth on ratio of drain discharge and seepage quantity into GW under 7cm ponding depth

While for improved subsurface drainage, the drainability was still obvious until the water table depth reached 75cm (5*D*). Under 7cm ponding depth and 2cm filter width, the free discharge of improved subsurface drainage at 30cm, 55cm and 75cm water table depth were 1.0cm^3/s, 0.414cm^3/s and 0.305cm^3/s, which were 1.98, 0.75 and 0.61 times of that in conventional subsurface pipe drainage in completely saturated soil respectively. Furthermore, when the filter width was 6cm, the free drain discharges at 30cm, 55cm and 75cm water table depths were 1.357cm^3/s, 0.652cm^3/s and 0.620cm^3/s, corresponding to 2.69, 1.29 and 1.23 times respectively.

3.2.2 Effects of water table depth on the ratio of drain discharge and seepage quantity into GW

Under surface ponding water without water table up to surface, a part of water was drained by pipe and the other part would enter into GW across the drains. The ratio of drain discharge and seepage quantity into GW could indirectly reflect the performance of improved subsurface drainage. Figure 3 presented the effect of water table depth on ratio of drain discharge and seepage quantity into GW under 7cm ponding depth. C-0 and F-0 represent 0cm filer width in coarse-sand (C) and in fine-sand (F), and so on. Obviously, the ratio in coarse-sand was smaller than that in fine-sand for both conventional and improved subsurface drainage, which reflected that water flow into GW more easily when soil hydraulic conductivity was large. Besides, the ratio decreased with the increase of water table depth and the decrease rate was larger in fine-sand than that in coarse-sand when water table depth was smaller than 55cm (3.7*D*). While when the water table depth was between 55cm and 75cm, the ratio was stable. For fine-sand texture, the ratios for improved subsurface drainage were 2.5, 3 and 5.5 times of that in conventional subsurface pipe drainage when filter width were 2cm, 4cm and 6cm respectively.

3.3 Theoretical calculation under saturated soil

Under saturated soil covered by ponding water, based on the equations of subsurface drain discharge derived by Kirkham, the discharge equation of improved subsurface drainage with great depth of impermeable layer was developed. The calculated and observed discharges were compared. The results showed that the calculated drain discharges also matched well with the observed values. This showed that the derived equation for improved subsurface drainage could well predict the discharge. The results also proved that the experiment design was reasonable and effective.

4. Conclusions

Based on the experimental and calculation results, conclusions could be drawn as follows. Firstly, improved subsurface drainage had a larger drain discharge than conventional subsurface pipe drainage. The drainability of improved subsurface drainage increased with filter width increase. Secondly, submerged outflow would cause a decrease in drain discharge. In this case, improved subsurface drainage could still function. Thirdly, the drain discharge decreased with the increase of water table depth in both conventional and improved subsurface drainage. When the water table depth was large enough, the conventional subsurface pipe drainage almost lost its function, but the improved subsurface drainage still had larger drainability. Furthermore, the calculated drain discharge matched well with the observed value. Generally speaking, the improved subsurface drainage had a large impact on reducing the surface runoff on the precondition of saving land. And the results had reference value on the field application of improved subsurface drainage.

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