Horizontal Roughing Filter for Reducing Emitter Composite Clogging in Drip Irrigation Systems Using high sediment water

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Abstract： Composite clogging substance is an inevitable issue in irrigation systems that use high-sediment water (HSW), consequently leading to emitter clogging, which may damage the whole irrigation system. So far, settling tanks allow particle deposition before water is applied in the drip irrigation systems, so they reduce particle load and therefore clogging risk is reduced. However, these tanks do not always perform properly, particularly when controlling biologging and organic matter clogging. This study proposed using a Horizontal Roughing Filter (HRF) to relieve composite clogging in irrigation systems using HSW. Results revealed that HRF reduced Sediment concentration (SC), Chemical Oxygen Demand (CODcr), Total Organic Carbon (TOC), and Biochemical oxygen demand (BOD_5) by 73.6-89.6%, 8.1-62.2%, 15.3-51.8%, and 22.8-53.1%, respectively. In addition, compared with control treatment (CK), HRF decreased the clogging substance of lateral and emitter by 32.4-37.6% and 25.5-29.4%, respectively, which obviously alleviated the risk of emitter clogging. Finally, compared with CK, HRF increased the Christiansen of Uniformity (CU) of drip irrigation system and average discharge variation ratio (Dra) 9.2-27.1% and 12.3-22.5%. Moreover, the filter performance of HRF under medium thickness of 60 cm was obviously higher than those with thicknesses of 20 cm and 40 m, only slightly lower than those with thicknesses of 80 cm. The results demonstrated that HRF is an effective filtration treatment with great potential applications for controlling the composite clogging in irrigation systems using high-sediment water.

Keywords: biologging; clogging; filtration; micro irrigation; emitter

1. Introduction

The shortage of freshwater resources has become one of the key factors threatening global food security and sustainable development of human society (Melo et al., 2020; Xu et al. 2020). The application of high sediment water (HSW) for agricultural irrigation in arid areas (e.g., India, China, Egypt, Sudan, Pakistan) is a potential mean to alleviate local crisis of fresh water resources (Ali and Mohammed, 2015; Khattak et al., 2011; Ren et al., 2021). Drip irrigation has been reported to be an efficient agricultural water-saving irrigation technology (Oker et al., 2020; Soliman et al., 2020). However, HSW contains suspended solid particles which inevitably foul and clog emitters and therefore reduce the irrigation uniformity, and shorten the operation life of the drip irrigation systems (Li et al., 2019b; Liu et al., 2019).

Irrigation water with high particle load will quickly overburden screen, disc and media filters, which are frequently used in drip irrigation systems (Nakayama et al., 2007). In this case, large settling tanks are common methods to remove suspended particles from water (Bajcar et al., 2011; Kadewa et al., 2010). Wang et al. (2020a) reported that the sediment removal efficiency of inclined-tube gravity sedimentation tank reaches 64.7 – 69.7%. Goula et al. (2008) found that adding a vertical baffle at the feed section of sedimentation tank led to suspended particles removal efficiency reaching 90.4 - 98.6%. These studies brought valuable insights into the solids removal ability of settling tank. However, HSW not only contains suspended particles, but also contains a high quantity of microorganisms and organic matter (resulting from industrial waste and agricultural pollution), which is easy to cause composite emitter clogging (Zhou et al., 2019a; Zhou et al., 2019b). The traditional settling tanks have low removal efficiency for microorganisms and organic matter present in HSW, and, therefore, it is difficult to inhibit the formation of biologging in the drip irrigation system. Thus, the development of effective control for the mitigation of clogging in HWS drip irrigation system is in urgent need .

Horizontal Roughing Filter（HRF）has attracted extensive interest in water treatment field, due to its characteristics of high efficiency, low cost, simple layout, low energy consumption, and easy operation (Bakare et al., 2019; Zeng et al., 2020). Anh et al. (2020) found that turbidity removal rate of HRF reaches 79-85%. Nkwonta (2010) strongly supported that HRF suspended solid removal was less than 50% for particle sizes of 5-10 µm and almost 100% for particle sizes of 50 - 100 µm. In addition, Nkwonta (2010) pointed out that HRF could effectively remove microorganisms and organic matter from water. Khazaei et al. (2016) indicated that HRF removed the total nitrogen, total phosphorous, and CODcr by 50%, 54%, 68%, respectively. Adlan et al. (2008) indicated that HRF reduced the BOD_5 and coliform organisms content by 51% - 67% and 67% - 96%, respectively. Therefore, HRF is expected to constitute an effective method to control composite clogging in drip irrigation systems using HSW. However, the role of HRF is often used as the pretreatment of slow sand filter (Mushila et al., 2016; Rooklidge 2006). The use of HRF to control fouling is rather a new research area. Particularly, the controlling capacities of HRF on composite clogging in drip irrigation systems using HSW remain unknown.

Thus, the objectives of this study were to: (i) reveal the effect of HRF on the water quality parameters of HSW (ii) evaluate the effect of medium different layer thickness on filter performance (iii) determine whether HRF would effectively control the composite clogging in drip irrigation systems using HSW; (iiii) elucidate the inhibition mechanism of HRF on composite clogging in drip irrigation systems using HSW.

2. Materials and methods

2.1 Experimental setup

The testing system was an outdoor-drip irrigation test platform (Fig. 1). The platform resembles drip irrigation system, having four layers of drip irrigation laterals stacked horizontally. Each layer had the same type of emitter. A total of eight types of emitters were installed , being their structural parameters shown in Table. 2. The HSW used in the experiment was collected from the Yellow River (located in northern Wulan Buh, Dengkou County, Bayan Nur City, Inner Mongolia, China). The HSW was filtered with HRF or gravity desilting filter (CK), and then was conveyed into the drip irrigation test platform. The complete experiment was lasted for a total of 90 days.

#Fig. 1 approximately here#

#Table. 1 approximately here#

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2.2 Experimental treatments

The experimental treatment is HRF (Fig S1), which comprised of peripheral filtering layers and an internal water storage tank. Filtering layers were made with three media layers having a thickness of 30 cm, from outside to inside and the layers were separated from each other by 550 μm steel mesh. These layers were filled up three different sized silica sand media i.e., 10-12 mm (coarse gravel), 6-8 mm (normal gravel) and 2-4 mm (fine gravel). The internal water storage tank was surrounded by filter media layer, and the bottom of the tank was sealed by steel plate. During the experimental operation, HRF was placed in the HSW. Under the action of water pressure, the HSW was filtered by the coarse layer, normal layer and fine layer of HRF in turn and then entered into the internal water storage tank. Filtered water was pumped into the fouling cultivation platform.

Desilting basin（CK）was used as a control treatment. The CK was composed of inlet tank, flow regulating plate, desilting tank pool, diversion wall, sloped tube, filter screen（150μm）, clear water tank and fouling tank (Fig S2). HSW entered the inlet tank through the pipeline, being regulated by the flow adjustment board. The coarse particle settled on the bottom of the pool, while the HSW passed through the filter mesh, thereby entering the clear water tank. Finally, the water was supplied to the drip irrigation system.

The filtration capacity of sand filter is also tested (Fig S3). The sand filter had two filtering layers with 2-4 and 6-8 mm media size, respectively. The operational details of the sand filter were: filtration cross section, 1400 cm^2; inlet and outlet diameter (mm), 50mm; manufacturer, Henan kaiburui, China.

2.3 Water quality parameters

Four replicated samples were taken simultaneously from raw water, HRF outlet and CK outlet. every 4.5 days. In addition, quadruplicated samples were also collected at filter layer thicknesses of 20, 40, 60, 80 and 90 cm, respectively, at 36, 54 and 72 days. In order to compare the filtration capacity of HRF and sand filter, we supplemented the test of sand filter. Four replicated samples were also taken simultaneously from raw water and sand filter outlet, at 5, 10 and 15 days. These samples allowed determining SC (Sediment Concentration), BOD_5 (Biochemical Oxygen Demand), CODcr (Chemical Oxygen Demand) and TOC (Total Organic Carbon). SC was tested with the pycnometer Test Method according to GB/T 50159 – 2015. BOD_5 was tested using a BOD meter (Hach, US, rak® II) according to HJ/T 86-2002. Chemical Oxygen Deman (CODcr) was analyzed using a COD meter (Zhongke, China, type: MI-200K) according to SNI 06-6989.15-2006. TOC was measured with a TOC meter (Manufacturer: Daojing，China；type: 4100) according to GB 13193-91.

2.4 Extraction and testing of clogging substance in laterals and emitters

During the experiment, laterals and emitters samples in each treatment were collected total of nine times. At each sampling event, 18 emitters were randomly collected from irrigation laterals (i.e., 6 at the head, 6 at the middle and 6 at the tail). The length of the lateral is 15 m. To represent the whole laterals, the samples were collected in each section of lateral inlet, middle and tail parts. The length of laterals sample from each part of lateral was 30 cm. The laterals and emitters samples were placed in zip lock plastic bags and stored in refrigerator at 4 ℃.

The emitter samples were weighed using a high-precision electronic balance (manufacturer: Wangtai, type: FA-G; accuracy: 10^{-3} g). Hereafter, the emitter samples were put in an ultrasonic cleaning bath (manufacturer: Chaowei, China; type: GVS-10 L; working power: 240 W; frequency: 60 Hz) for 60 min to remove the clogging substance, and then the samples were dried at 100℃ until they acquired a constant weight. The difference between the weights was the weight of clogging substances on emitter. The same test method was applied in laterals clogging substances

2.5 Particle size distribution testing

The particle size was analyzed by using a laser particle sizer (Malvern Instruments Ltd., Mastersizer 3000). The raw water, HRF and CK outlet water, laterals and emitter clogging substance samples were taken every 100 h. The stirrer speed of laser particle size analyzer was 2500 rpm, and the shading range was 10% ~ 20%. In order to describe the distribution characteristics of particle size, clay ($d \leq 2\mu m$）, silt （$2\mu m \leq d \leq 50\mu m$）and sand（$d \geqslant 50\mu m$）were classified according to the U.S. Department of Agriculture particle size classification (Li et al., 2019a). D_5 and D_{50} were the corresponding particle sizes when the cumulative particle size distribution ratio reaches 5% and 50%, respectively.

2.6 Evaluation of drip irrigation system performance

Along with operation time, the growth of clogging substance would gradually clog the emitters of the drip irrigation system. The average discharge variation ratio (Dra) and Christiansen coefficient of uniformity (CU) were used to evaluate the flow performance of the drip irrigation system. The detailed calculation method of Dra and CU is explained in supplementary material (Section 1.2).

2.7 Statistical analysis

The experimental data basic calculations were done with Microsoft Excel; and statistical analysis was carried out using SPSS (ver. 22.0 IBM, USA). Pearson correlation coefficient was applied to determine the correlation of fouling content among different groups (p adjusted <0.05). Structural equation modelling analysis (SEM) was performed using SPSS AMOS v.24 (AMOS, IBM, USA) to analyze the direct and indirect relationships among HRF, dry weight, and the flow performances of drip irrigation system (Dra).

3 Results

3.1 Effect of HRF on water quality parameters

HRF reduced SC, CODcr, TOC, and BOD$_5$ of HSW by 73.6-89.6%, 8.1-62.2%, 15.3-51.8%, 22.8-53.1% (Fig. 2), respectively. Comparing with CK, HRF greater decreased SC, CODcr, TOC, and BOD$_5$ by 8.9-25.9%, 6.34-54.1%, 4.1-44.4%, and 9.6-44.6%, respectively. The HRF treatment had better effects on D$_5$ and D$_{50}$ of particle size than the CK treatment. Compared with CK, HRF reduced D$_5$ and D$_{50}$ by 0.1-2.1μm and 2.2-15.6μm, respectively. Moreover, the sediment removal capacity of HRF was further improved after 36 days of operation and reached its maximum value at 72 days.

#Fig. 2 approximately here#

3.2 Effect of HRF layer thickness on water quality

The effect of HRF layer thickness on removals of SC, BOD$_5$, CODcr and TOC is shown in Fig. 3. The results show that SC, BOD$_5$, CODcr and TOC decreased with the increase of filter thickness. However, no linear decrease was observed. The values of SC, BOD$_5$, CODcr and TOC showed a gradual decline when the HRF layer thickness was lower than 60 cm. Compared with removal efficiency with filter thickness of 20 cm, filtration capacity of 40 cm filter layer was slightly improved, and the removal efficiency of SC, CODcr, TOC and BOD$_5$ was increased by12.5-19.3%, 3.2-4.7%, 4.1-7.1%, 1.9-5.3%. However, the filtration performance was obvious increased when the filter layer thickness reached 60 cm.. Compared with the removal efficiency with the thickness of 40 cm, removal efficiency of 60 cm filter layer was obviously improved, and the removal efficiency of SC, CODcr, TOC and BOD$_5$ was increased by 35.4-51.2%, 18.9-27.8%,10.3-20.8%,17.5-29.9%. However, the removal efficiency of HRF with thickness of 80 cm were increased slightly compared with thickness of 60 cm and the removal efficiency of SC, CODcr, TOC and BOD$_5$ was only increased by 5.3-9.6%, 1.6-5.1%, 3.5-8.3%, 1.9-4.2%.

#Fig. 3 approximately here#

3.3 Effect of HRF on composite clogging substance in lateral and emitter

The dynamic change of composite clogging substance (Fig. 4,5) shows that HRF controlled the contents of composite clogging substance within laterals and emitters. Compared with CK, HRF significantly ($p<0.05$, Table S1) decreased the composite clogging substance of lateral and emitter by 32.4-37.6% and 25.5-29.4%, respectively, which obviously alleviated the risk of emitter clogging. Moreover, HRF treatments had higher control efficiencies of clay, silt and sand contents in laterals and emitter than CK. Compared with CK treatment, HRF significantly ($p<0.01$, Table S1) decreased the contents of silt, sand and clay in laterals by 23.1-27.4%, 31.8-39.5% and 27.6-39.8%, respectively, and significantly ($p<0.05$, Table S1) decreased the contents of silt, sand and clay in emitter by 24.8-27.4%, 19.3-26.4%、38.1-42.9%.

#Fig. 4 approximately here#

3.4 Influence path of HRF on composite clogging substance in drip irrigation systems

SEM was used to further reveal the influence path of HRF on composite clogging substance in drip irrigation systems (Fig.6). The fitted model ($\chi^2/df=1.76$, $p=0.052$) met the significance criteria. SEMA revealed that HRF presented strongest correlations ($\beta=0.74, 0.66, 0.54, 0.51$; $p<0.01$) with CS, COD ,BOD_5 and TOC. Moreover, SEMA also further showed that water quality parameters (CS, COD, BOD_5, TOC) were significantly correlated ($p<0.05$) with dry weight of laterals (LDW) and emitters (EDW). In addition, the results showed that there were synergistic interactions between LDW and EDW. Finally, EDW directly affected Dra of the drip irrigation system.

#Fig. 5 approximately here#

4. Discussion

4.1 Filtration mechanism of HRF on high sediment water

Desilting basin represents an effective means to remove coarse suspended particles from HSW (Lak et al., 2020). However, due to that fine suspended particles are not always easy to settle (Ma et al., 2019), the removal efficiency of these fine particles in the desilting basin is poor. Therefore, it is necessary to develop a filtration technology which allows removing those fine sediment particles for preventing emitter clogging in drip irrigation system. This study found that HRF can effectively remove the fine sediment particles in HSW (Fig 2). One possible reason is that the filter media of HRF has both the functions of mechanical screening and contact flocculation (Mackiewicz 1983, Wang et al. 2020c). When the HSW reaches the surface of the filter layer, the filter medium uses its screening function to remove the large size sediment particles from HSW (Egemose 2018). Then, HSW flows into the filter layer that could adsorb the fine particles relying on electric double-layer power, van der Waals forces and chemical bonds (Chen et al., 2019). Moreover, due to the lower filtration rate of HRF, the residence time of HSW in the filter layer became longer, which directly increased the chance of collision and adsorption between filter media and fine particles (Nkwonta 2010), and further improved removal capacity of HRF for fine particles. On the other hand, with the increase of HRF operation time, the filter medium is wrapped by microorganisms. These microorganisms will secrete viscous substances and adsorb fine particles from the water (Rooklidge et al., 2002), which also greatly improves HRF's filtration capacity for fine particles. In addition, it is found that the sediment removal capacity of HRF will be improved after 36 days of operation. The reason may be that the microorganisms in the filter media will gradually form biofilm after 36 day of operation, and mature biofilm will be formed after 72 day of operation. Therefore, HRF also reaches the maximum sediment removal capacity after 72 day of operation.

This study also found that HRF effectively reduced CS, BOD_5, COD and TOC in HSW (Fig 2). The reason may be that with the increase of HRF operation time, microorganisms adhered to the filter media gradually grow into mature biofilm, which will capture organic matter and microorganisms from the water as nutrients for growth and reproduction (Hashimoto et al., 2019). Finally, HRF can remove microorganisms and organic matter from the water by the predation, scavenging, adsorption and bio-oxidation of microorganisms adhering to the filter media. Moreover, this paper also found that the filtration capacity of HRF under the thickness of 60 cm was higher than that with 20 cm and 40 cm. The reason is that the HRF under 0-30 cm and 30-60 cm filter layers were filled with coarse gravel media and normal gravel media, respectively (Fig 1). Due to the large gap of the filter media, it is difficult to remove fine particles, microorganisms and organic matter by mechanical screening (Khiari et al., 2020), while the filter media with large particle sizes did not favor biofilm growth (Wang et al., 2014). Thus, HRF under 0-30 cm and 30-60 cm filter layers only could rely on a small number of microorganisms on the surface of the filter media to remove fine particles, microorganisms and organic matter. However, the HRF under 60-90 cm filter layers were filled with fine gravel media with small gap, so it was easy to form biofilm on the surface of the filter media (de Oliveira and Schneider 2019).

4.2 Effect of HRF on composite clogging substance in drip irrigation system

This study further found that HRF could reduce the risk of clogging of emitters. Compared with CK treatment, HRF reduced the clogging substance of emitters by 25.5-29.4%. The reason is that HRF treatment has better water treatment capacity than CK treatment, and therefore greatly reduced the content of fine sediment particles, microorganisms and organic matter in HSW. At the same time, the water quality parameters are directly related to the clogging substance of emitter (Bucks et al., 1979). Thus, HRF directly reduces the content of composite clogging substance formation in the emitter of drip irrigation systems by improving the water quality. On the other hand, some scholars reported that there was a significant correlation between clogging substance of laterals and emitter (Han et al., 2018; Li et al., 2015). Therefore, HRF could also decrease the clogging substance of laterals by affecting the water quality, thereby reducing the risk of particles settled on laterals entering the emitter, and indirectly affect the content of clogging substance of emitter. Moreover, HRF has better removal ability of microorganisms and organic matter than CK, and microorganisms were easy to adsorb particles and organic matter in the emitter to form large particle size clogging substance (Feng et al., 2019). Therefore, HRF can reduce the formation of large size particle clogging substance in the emitter through water quality control. Compared with CK treatment, the content of sand in the clogging substances was reduced by 19.3-26.4%. In this sense, HRF directly affected the CU and Dra of drip irrigation system by reducing the formation of emitter clogging. Compared with CK, HRF increased the Christiansen of Uniformity (CU) and average discharge variation ratio (Dra) of drip irrigation system by 9.2-27.1% and 12.3-22.5% (Fig 7).

4.3 Engineering implications of HRF

Although the results proved that HRF effectively controlled the composite clogging in drip irrigation system, it is necessary to evaluate the engineering implications of the results for its successful application of HRF. Desilting basin is the most common method for controlling clogging in HSW drip irrigation systems(Wang et al., 2020b), compared with HRF in terms of filtration performance, costs, and safety using similar testing devices. In addition, HRF treatment can remove not only bacteria, and pathogenic microorganisms, but also synthetic organic matter, natural organic matter, humus and heavy metal ions (Dalahmeh et al., 2019; Dashti et al., 2019; Jiang and Tay, 2010), avoiding pollutants in water entering into soil through agricultural irrigation. Moreover, capital cost is another major factor closely related with the successful implications of methods. Because of its simple structure and modularization, HRF has low initial cost and no additional operating costs are needed (Zahiruddin and Rahimuddin, 2011). Besides, we also compared the capacity, rate and efficiency of sand filter with HRF. This part is shown in s shown in supplementary material, section 3. The results show that the removal capacity of HRF for CS, COD, BOD_5 and TOC is significantly higher than that of sand filter (Fig.S4). The HRF has relatively lower installation cost than sand filter (Fig.S5). And, the filtration rate of HRF was also lower than sand filter. Hence, the HRF could be more suitable for small scale agricultural irrigation systems (Fig.S5). Based on these results, the HRF is a promising method of clogging substance control in agricultural drip irrigation system.

In addition, HRF can be used in high salinity seawater, reclaimed water, surface lake water and deep groundwater (Khazaei et al., 2016; Kim et al., 2020; van Afferden et al., 2011). HRF has been used in many fields, such as the pretreatment of slow filtration in drinking water engineering (Dastanaie et al., 2007), the treatment of wastewater in industrial field (Khazaei et al. 2015), and the pretreatment of ultrafiltration membrane in seawater desalination field (Naidu et al., 2013). However, HRF filtration rate is slow, suitable for small farmers with small agricultural area and small water demand, and it is best used with water-saving irrigation technology. In addition, other multiple factors are involved which obviously affect the HRF. At present, there is a lack of quantitative relationship between filter layer thickness, filter material, filtration rate and filtration flow and filtration capacity. It is suggested that HRF performance test with different structural parameters should be carried out in the future under different water quality conditions, so as to provide theoretical reference for obtaining the most suitable configuration conditions, engineering design method and optimized operation mode of HRF.

5 Conclusions

(1) Horizontal roughing filter (HRF) reduced SC, COD, TOC, and BOD_5 regarding high sediment water (HSW) by 73.6-89.6%, 8.1-62.2%, 15.3-51.8%, and 22.8-53.1%,

respectively.

(2) Compared with desilting filter (CK), HRF decreased the clogging substance of laterals and emitters by 32.4-37.6% and 25.5-29.4% respectively, which obviously alleviated the risk of emitter clogging.

(3) The filtration performance of HRF under the thickness of 60 cm was obvious higher than that under the thickness of 20 cm and 40 cm.

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References

Adlan, M.N., Aziz, H.A., Han Thein, M., Yung-Tse, H. 2008. Performance of horizontal flow roughing filter using limestone media for the removal of turbidity, suspended solids, biochemical oxygen demand and coliform organisms from wastewater. *International Journal of Environment and Waste Management*. 2(3), 203-214.

Ali, O.A.M. and Mohammed, A.S.H. 2015. Performance evaluation of gated pipes technique for improving surface irrigation efficiency in maize hybrids. *Agricultural Sciences.* 6(5), 550-570.

Anh, B.T.K., Thanh, N.V., Phuong, N.M., Ha, N.T.H., Yen, N.H., Lap, B.Q., Kim, D.D. 2020. Selection of Suitable Filter Materials for Horizontal Subsurface Flow Constructed Wetland Treating Swine Wastewater. *Water Air and Soil Pollution*. 231(2), 88.

Bajcar, T., Steinman, F., Sirok, B., Preseren, T. 2011. Sedimentation efficiency of two continuously operating circular settling tanks with different inlet- and outlet arrangements. *Chemical Engineering Journal*. 178, 217-224.

Bakare, B.F., Mtsweni, S., Rathilal, S. 2019. Pilot study of a horizontal roughing filtration system treating greywater generated from a peri-urban community in Durban, South Africa. *Journal of Water Reuse and Desalination*. 9(3), 330-337.

Bucks, D.A., Nakayama, F.S. and Gilbert, R.G. 1979. Tricle irrigation water-quality and preventive maintenance. *Agricultural Water Management*. 2(2), 149-162.

Chen, C., Ji, W. and Zhao, B. 2019. Size-dependent efficiencies of ultrafine particle removal of various filter media. *Building and Environment*. 160, 106171.

Dalahmeh, S.S., Assayed, A., Stenstrom, Y. 2019. Combined Vertical-Horizontal Flow Biochar Filter for Onsite Wastewater Treatment-Removal of Organic Matter, Nitrogen and Pathogens. *Applied Sciences-Basel*. 9(24), 5386.

Dashti, A.F., Aziz, H.A., Adlan, M.N., Ibrahim, A.H. 2019. Calcined limestone horizontal roughing filter for treatment of palm oil mill effluent polishing pond. *International Journal of Environmental Science and Technology*. 16(10), 6419-6430.

Dastanaie, A.J., Bidhendi, G.R.N., Nasrabadi, T., Habibi, R., Hoveidi, H. 2007. Use of horizontal flow roughing filtration in drinking water treatment. *International Journal of Environmental Science and Technology.* 4(3), 379-382.

de Oliveira, F.F. and Schneider, R.P. 2019. Slow sand filtration for biofouling reduction in seawater desalination by reverse osmosis. *Water Research*. 155, 474-486.

Egemose, S. 2018. Removal of particulate matter and phosphorus in sand filters treating stormwater and drainage runoff: a case study. *Urban Water Journal*. 15(4), 388-391.

Feng, J., Li, Y., Liu, Z., Muhammad, T., Wu, R. 2019. Composite clogging characteristics of emitters in drip irrigation systems. *Irrigation Science*. 37(2), 105-122.

Goula, A.M., Kostoglou, M., Karapantsios, T.D., Zouboulis, A.I. 2008. A CFD methodology for the design of sedimentation tanks in potable water treatment - Case study: The influence of a feed flow control baffle. *Chemical Engineering Journal*. 140(1-3), 110-121.

Han, S., Li, Y., Xu, F., Sun, D., Feng, J., Liu, Z., Wu, R., Wang, Z. 2018. Effect of Lateral Flushing on Emitter Clogging under Drip Irrigation with Yellow River Water and a Suitable Method. *Irrigation and Drainage*. 67(2), 199-209.

Hashimoto, Y., Takashima, H., Jayamohan, S. 2019. Application of Roughing Filter to pre-treat 1,000 NTU raw water for Slow Sand Filter. *Water Practice & Technology* 14(2), 355-364.

Jiang, X. and Tay, J.H. 2010. Microbial community structures in a horizontal biotrickling filter degrading H2S and NH3. *Bioresource Technology*. 101(6), 1635-1641.

Kadewa, W.W., Le Corre, K., Pidou, M., Jeffrey, P.J., Jefferson, B. 2010. Comparison of grey water treatment performance by a cascading sand filter and a constructed wetland. *Water Science and Technology.* 62(7), 1471-1478.

Khattak, M.S., Babel, M.S., Sharif, M. 201. Hydro-meteorological trends in the upper Indus River basin in Pakistan. *Climate Research.* 46(2), 103-119.

Khazaei, M., Nabizadeh, R., Mahvi, A.H., Izanloo, H., Tadi, R.A., Gharagazloo, F. 2016 Nitrogen and phosphorous removal from aerated lagoon effluent using horizontal roughing filter (HRF). *Desalination and Water Treatment*. 57(12), 5425-5434.

Khiari, Z., Alka, K., Kelloway, S., Mason, B., Savidov, N. 2020. Integration of Biochar Filtration into Aquaponics: Effects on Particle Size Distribution and Turbidity Removal. *Agricultural Water Management.* 229, 105874.

Kim, D.-H., Choi, C., Lee, C., Adha, R.S., Nguyen, T.-T., Ahn, S.-J., Son, H.-J., Kim, I.S. 2020. An Improved Configuration of Vertical-Flow Mesh Tube Filters for Seawater Pretreatment: Performance, Cleaning, and Energy Consumption. *Water* 12(10), 2804.

Lak, B., Azadi, A., Firoozabadi, B., Afshin, H. 2020. Evaluation of the Effects of Inlet Conditions on Particle-Laden Flows in Secondary Sedimentation Tanks. *Journal of Environmental Engineering*. 146(3).

Li, Q., Song, P., Zhou, B., Xiao, Y., Muhammad, T., Liu, Z., Zhou, H., Li, Y. 2019a Mechanism of intermittent fluctuated water pressure on emitter clogging substances formation in drip irrigation system utilizing high sediment water. *Agricultural Water Management*. 215, 16-24.

Li, Y., Pan, J., Chen, X., Xue, S., Feng, J., Muhammad, T., Zhou, B. 2019b. Dynamic effects of chemical precipitates on drip irrigation system clogging using water with high sediment and salt loads. *Agricultural Water Management*. 213, 833-842.

Li, Y., Song, P., Pei, Y., Feng, J. 2015. Effects of lateral flushing on emitter clogging and biofilm components in drip irrigation systems with reclaimed water. *Irrigation Science*. 33(3), 235-245.

Liu, Z., Xiao, Y., Li, Y., Zhou, B., Feng, J., Han, S., Muhammad, T. 2019. Influence of operating pressure on emitter anti-clogging performance of drip irrigation system with high-sediment water. *Agricultural Water Management.* 213, 174-184.

Ma, D., Zhou, T., Li, B., Feng, X., Zhang, H. 2019. Study on the movement and deposition of particles in supercritical water. *International Journal of Heat and Mass Transfer*. 136, 55-69.

Mackiewicz, J. 1983. The development of flocculation effects in filter theory. *Chemical Engineering Communications*. 23(4-6), 305-314.

Melo, F.P.L., Parry, L., Brancalion, P.H.S., Pinto, S.R.R., Freitas, J., Manhaes, A.P., Meli, P., Ganade, G., Chazdon, R.L. 2020. Adding forests to the water-energy-food nexus. *Nature Sustainability*.

Ministry of Water Resources of the People’s Republic of China, GB/T 50159 – 2015, Code for measurement of suspended load in open channels, 2015.

Ministry of Environment Protection of the People’s Republic of China, HJ/T 86-2002, Water quality-Determination of biochemical oxygen demand (BOD) Speedy testing method of microorganism sensor, 2002.

Ministry of Environment Protection of the People’s Republic of China, GB 13193-91, Water quality- Determination of TOC by nondispersive infrared absorption method, 1992.

Mushila, C.N., Ochieng, G.M., Otieno, F.A.O., Shitote, S.M., Sitters, C.W. 2016. Hydraulic design to optimize the treatment capacity of Multi-Stage Filtration units. *Physics and Chemistry of the Earth*. 92, 85-91.

Naidu, G., Jeong, S., Vigneswaran, S., Rice, S.A. 2013. Microbial activity in biofilter used as a pretreatment for seawater desalination. *Desalination*. 309, 254-260.

Nakayama, F.S., Boman, B.J., Pitts, D.J.. Maintenance. In: Lamm, F.R., Ayars, J.E., Nakayama, F.S. 2007. Microirrigation for Crop Production. *Design, Operation, and Management*. 389–430.

Nkwonta, O. 2010. A comparison of horizontal roughing filters and vertical roughing filters in wastewater treatment using gravel as a filter media. *International Journal of the Physical Sciences.* 5(8), 1240-1247.

Oker, T.E., Kisekka, I., Sheshukov, A.Y., Aguilar, J., Rogers, D. 2020. Evaluation of dynamic uniformity and application efficiency of mobile drip irrigation. *Irrigation Science*. 38(1), 17-35.

Ren, D., Xu, X., Engel, B., Huang, Q., Xiong, Y., Huo, Z., Huang, G. 2021. A comprehensive analysis of water productivity in natural vegetation and various crops coexistent agro-ecosystems. *Agricultural Water Management*. 243, 106481.

Rooklidge, S.J. 2006. Antimicrobial contaminant removal by multistage slow sand filtration. *Journal American Water Works Association*. 98(1), 2-2.

Rooklidge, S.J., Ketchum, L.H., Burns, P.C. 2002. Clay removal in basaltic and limestone horizontal roughing filters. *Advances in Environmental Research*. 7(1), 231-237.

Soliman, A.I.E., Morad, M.M., Wasfy, K.I. Moursy, M.A.M. 2020. Utilization of aquaculture drainage for enhancing onion crop yield under surface and subsurface drip irrigation systems. *Agricultural Water Management*. 239, 106244.

Van Afferden, M., Rahman, K.Z., Mosig, P., De Biase, C., Thullner, M., Oswald, S.E., Mueller, R.A. 2011. Remediation of groundwater contaminated with MTBE and benzene: The potential of vertical-flow soil filter systems. *Water Research* 45(16), 5063-5074.

Wang, H., Narihiro, T., Straub, A.P., Pugh, C.R., Tamaki, H., Moor, J.F., Bradley, I.M., Kamagata, Y., Liu, W.-T., Nguyen, T.H. 2014. MS2 Bacteriophage Reduction and Microbial Communities in Biosand Filters. *Environmental Science & Technology*. 48(12), 6702-6709.

Wang, K., Li, Y., Ren, S., Yang, P. 2020a. A Case Study on Settling Process in Inclined-Tube Gravity Sedimentation Tank for Drip Irrigation with the Yellow River Water. *Water*. 12(6), 1685.

Wang, K., Li, Y., Ren, S., Yang, P. 2020b. Prototype Observation of Flow

Characteristics in an Inclined-Tube Settling Tank for Fine Sandy Water Treatment. *Applied Sciences-Basel.* 10(10), 3586.

Wang, Z., Sedighi, M., Lea-Langton, A. 2020c. Filtration of microplastic spheres by biochar: removal efficiency and immobilisation mechanisms. *Water Research*. 184, 116165.

Xu, Z., Chau, S.N., Chen, X., Zhang, J., Li, Y., Dietz, T., Wang, J., Winkler, J.A., Fan, F., Huang, B., Li, S., Wu, S., Herzberger, A., Tang, Y., Hong, D., Li, Y., Liu, J. 2020. Assessing progress towards sustainable development over space and time. *Nature*. 577(7788), 74.

Zahiruddin, K. and Rahimuddin, F. 2011. Roughing filtration as an effective pre-treatment system for high turbidity water. *Water Science and Technology*. 64(7), 1419-1427.

Zeng, J., Chabi, K., Hu, Y., Zhang, S., Yu, X. 2020. Ammonium removal of biological roughing filter for rural drinking water pretreatment. *Water Supply.* 20(7), 2768-2778.

Zhou, B., Li, Y., Xue, S., Fen, J. 2019a. Variation of microorganisms in drip irrigation systems using high-sand surface water. *Agricultural Water Management.* 218, 37-47.

Zhou, H., Li, Y., Wang, Y., Zhou, B. and Bhattarai, R. 2019b. Composite fouling of drip emitters applying surface water with high sand concentration: Dynamic variation and formation mechanism. *Agricultural Water Management.* 215, 25-43.

Captions for Figures and Tables in the Paper

Fig. 1 Layout of experiments system

Fig. 2 Effects of HRF on water quality parameters

Fig. 3 Effect of filter layer thickness on the water quality parameters

Fig. 4 Effects of HRF on clogging substances in laterals of drip irrigation system

Fig. 5 Effects of HRF on clogging substances in emitter of drip irrigation system

Fig. 6 Controlling pathway of HRF on composite clogging substance in drip irrigation system

Fig. 7 Effect of HRF on Dra and CU of Drip irrigation system

Table 1 Water quality parameters of the high-sediment water

Table 2 Characteristic parameters of emitters

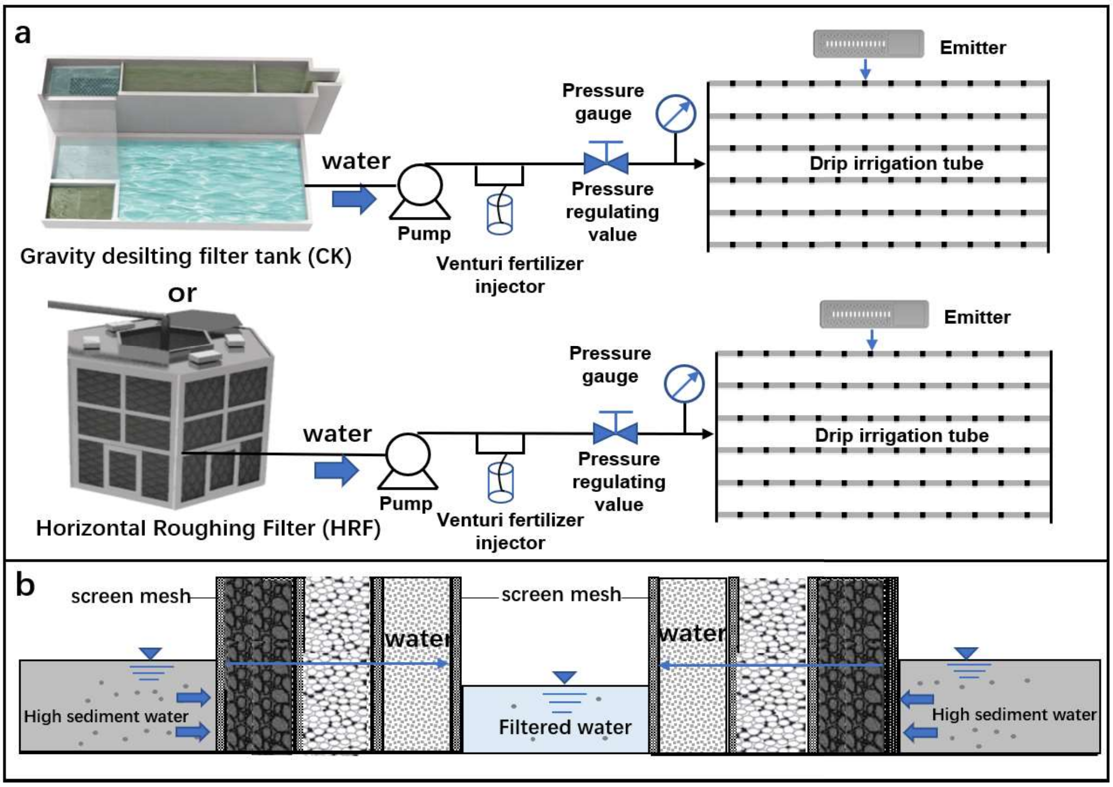

Fig. 1. Layout of experiments system. (a) Layout of the test system platform; (b) Filtration principle of HRF

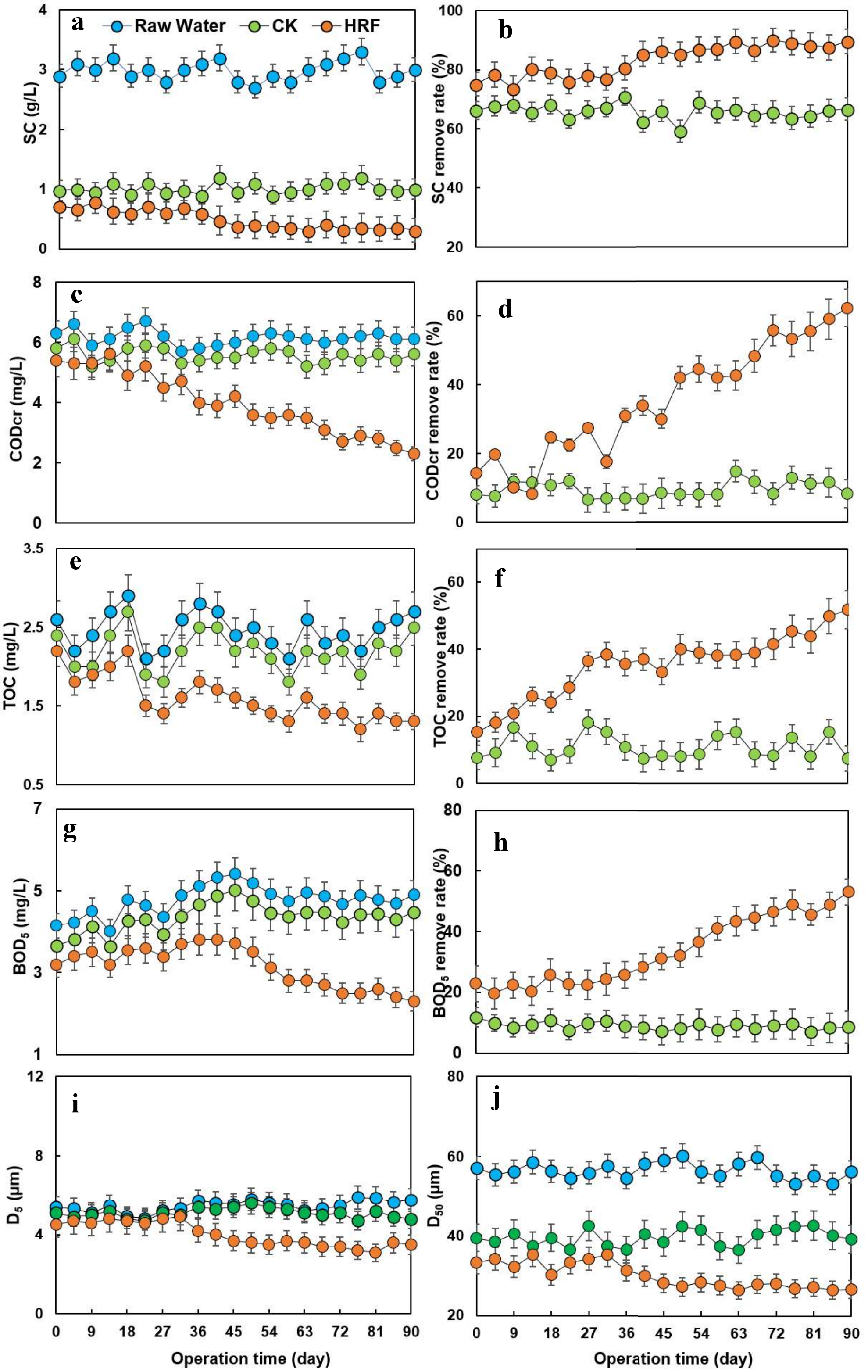

Fig. 2. Effects of HRF on water quality parameters. (a) and (b) SC, Sediment Concentration; (c) and (d) CODcr, Chemical Oxygen Demand; (e) and (f) TOC, Total Organic Carbon; (g) and (h) BOD_5, Biochemical Oxygen Demand; (i) and (j) D_5 and D_{50}, cumulative particle size distribution ratio reaches 5% and 50%. HRF, Horizontal Roughing Filter; CK, Gravity desilting filter.

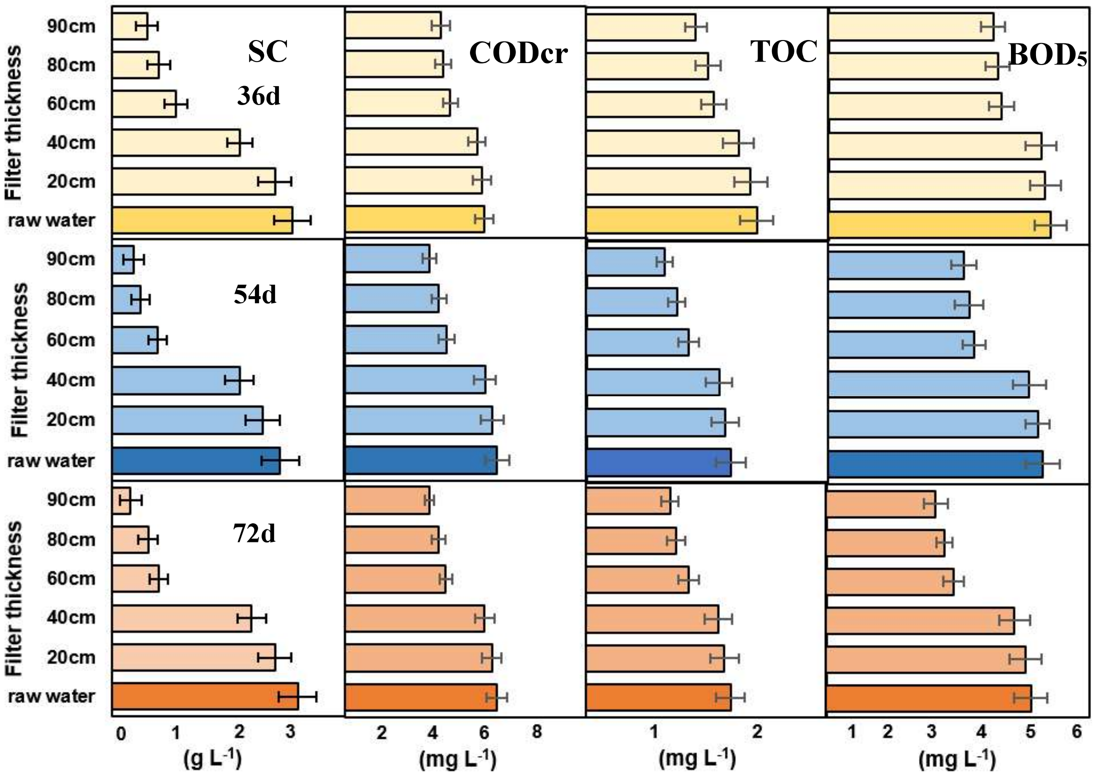

Fig. 3. Effect of filter layer thickness on the water quality parameters. Sampling point at different run times: 36 day (Yellow), 54 day (Blue) and 72 day (Orange). SC, Sediment Concentration; CODcr, Chemical Oxygen Demand; TOC, Total Organic Carbon; BOD_5, Biochemical Oxygen Demand.

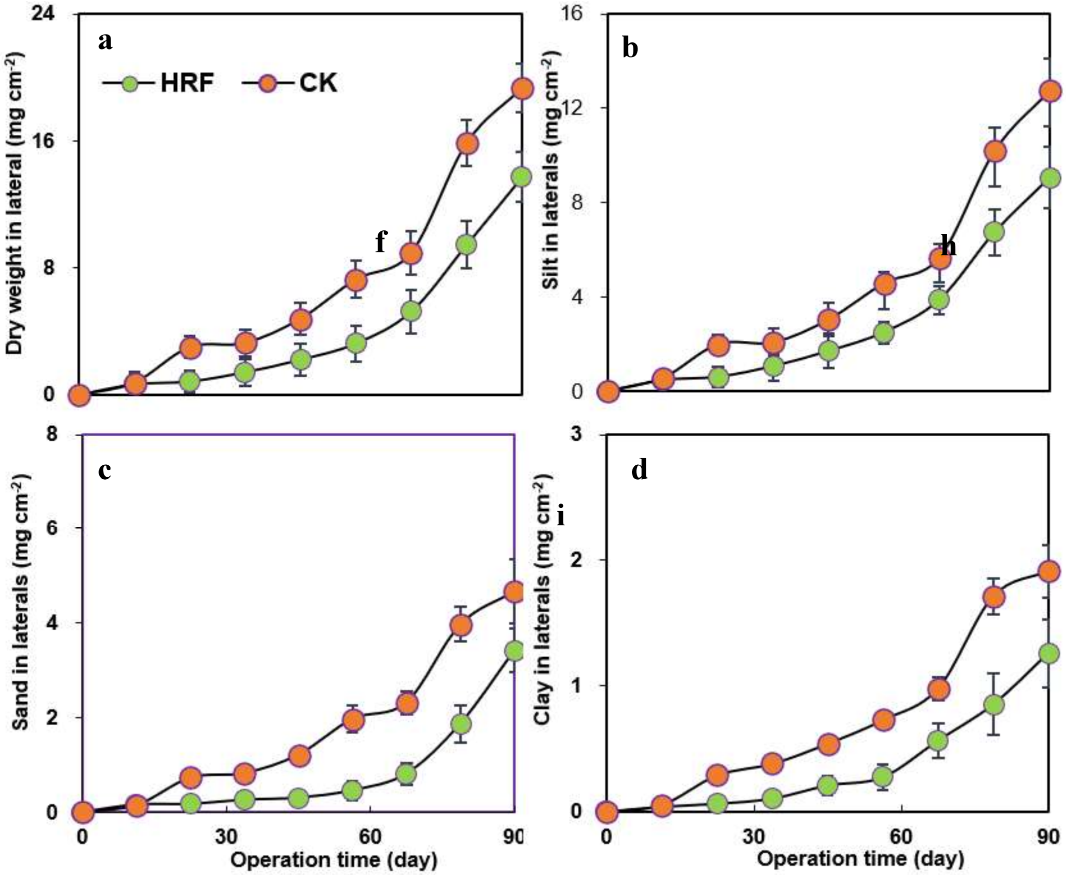

Fig. 4. Effects of HRF on clogging substances in laterals of drip irrigation system. (a) Dry weight represents total clogging substance; (b) represent the content of silt of clogging substance; (c) represent the content of sand of clogging substance; (d) represent the content of clay of clogging substance. HRF, Horizontal Roughing Filter; CK, Gravity desilting filter.

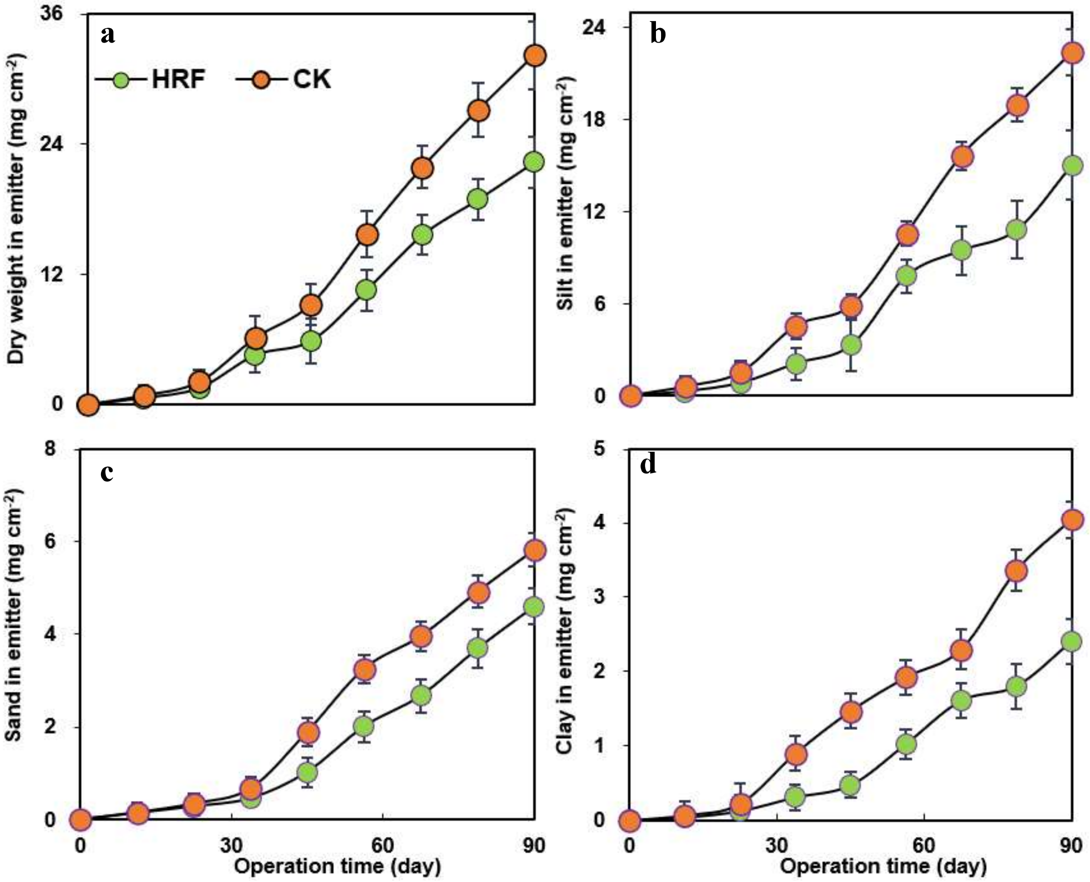

Fig. 5 Effects of HRF on clogging substances in emitter of drip irrigation system. (a) Dry weight represents total clogging substance; (b) represent the content of silt of clogging substance; (c) represent the content of sand of clogging substance; (d) represent the content of clay of clogging substance. HRF, Horizontal Roughing Filter; CK, Gravity desilting filter.

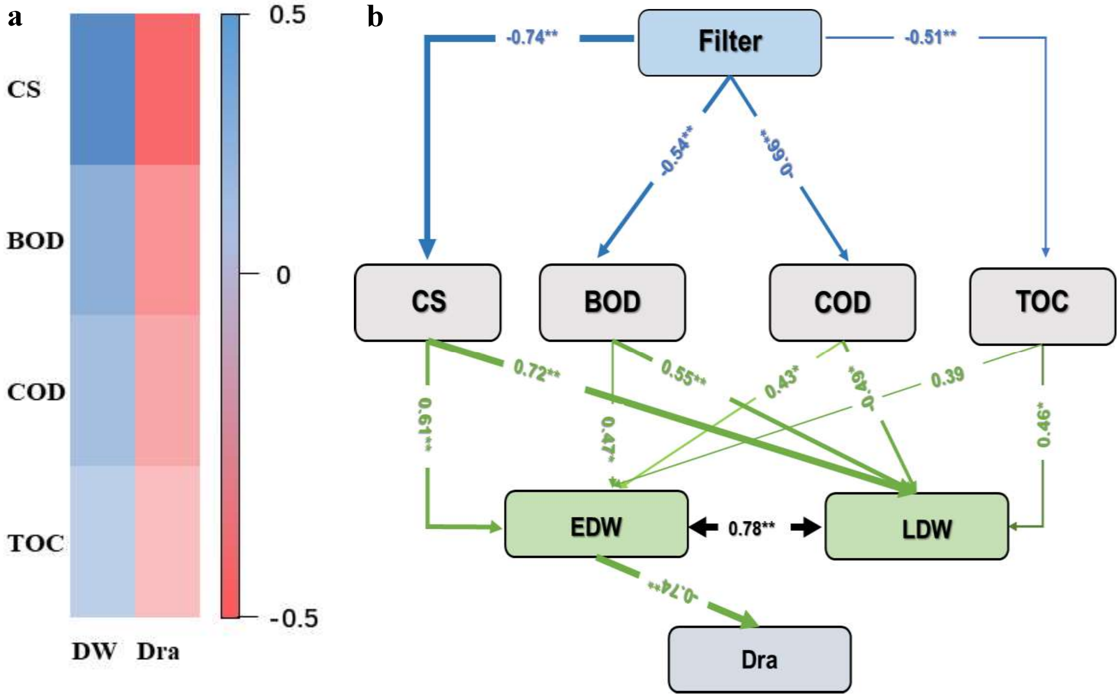

Fig. 6 Controlling pathway of HRF on composite clogging substance in drip irrigation system. (a) Spearman correlation of water quality, DW (Dry Weight) and Dra; (b) is the structural equation model analysis (SEMA). The SEMA shows the relationship between the HRF treatment, water quality parameters (CS, BOD_5, COD, TOC), emitter dry weight (EDW), laterals dry weight (LDW) and the Dra. Green and blue radial lines respectively represented significant positive correlation ($p<0.05$) and significant negative correlation ($p<0.05$). The blue and green single-headed arrows represent positive and negative interactions, respectively, and the thickness of the arrow represents the strength of the correlation. The number on the arrow represents the standard path coefficient (β).

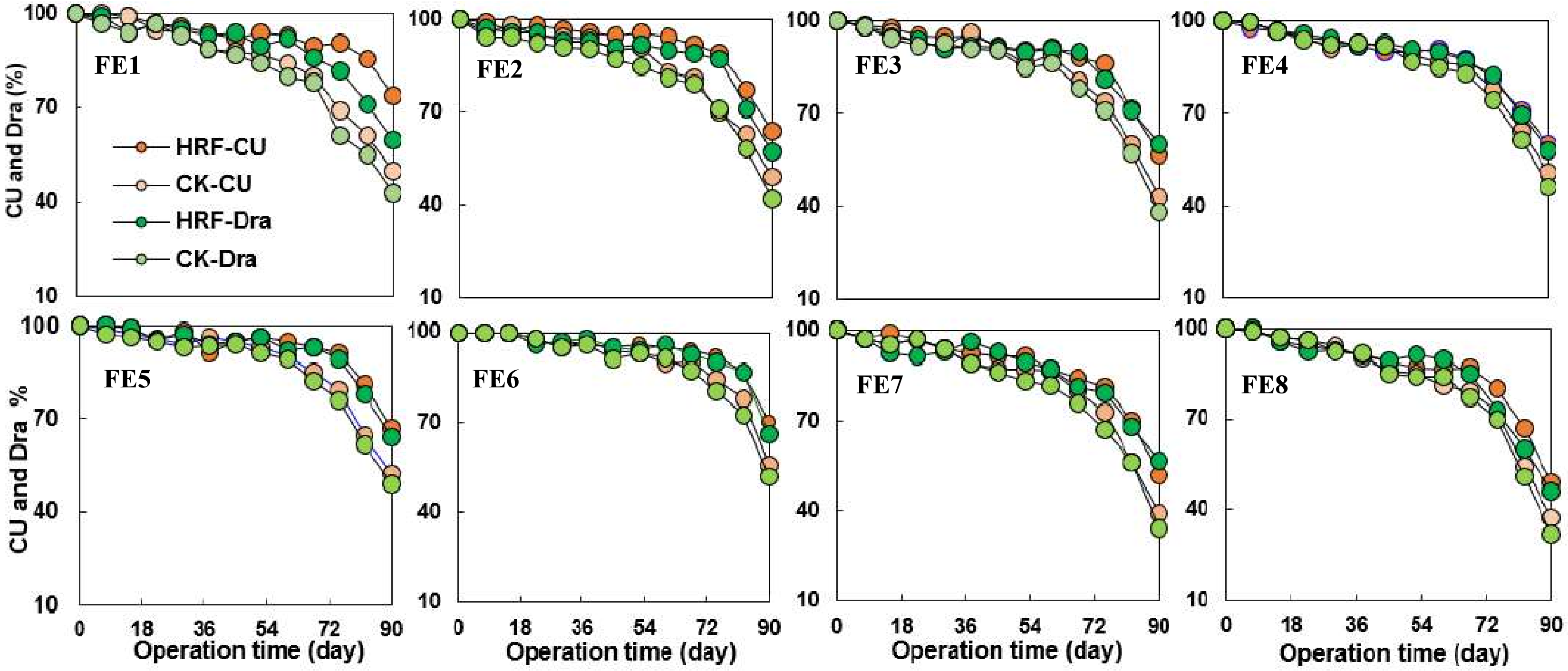

Fig. 7. Effect of HRF on Dra and CU of Drip irrigation system. HRF, Horizontal Roughing Filter; CK, Gravity desilting filter. CU, Christiansen coefficient of uniformity; Dra, average discharge variation ratio.

Table 1 Water quality parameters (average ± standard deviation) of the high-sediment water

Parameter	Results	Parameter	Results
pH	7.3 ± 0.6	Bicarbonate (HCO_3^-) (mg L^{-1})	152±21
Suspended solids SS (mg l^{-1})	73.7 ± 5.2	Phosphate (PO_4^{3-}) (mg L^{-1})	0.25±0.08
Electrical conductivity EC (μS cm^{-1})	740±52	Phosphorus (P) (mg l^{-1})	0.04±0.01
Nitrogen (N) (mg l^{-1})	1.2±0.3	Calcium (Ca^{2+}) (mg l^{-1})	53.6±8.4

Table 2 Characteristic parameters of the tested emitters

Emitter	Initial outflow Q (L/h)	Flow path length L (mm)	Flow path width W (mm)	Flow path depth D (mm)	Flow index x
FE1	0.8	21.52	0.50	0.45	0.51
FE2	1.0	23.06	0.50	0.52	0.51
FE3	1.2	23.02	0.63	0.52	0.50
FE4	1.4	25.07	0.63	0.52	0.51
FE5	1.6	29.74	0.63	0.52	0.51
FE6	2.8	41.13	0.67	0.56	0.50
FE7	1.1	17.71	0.56	0.61	0.51
FE8	2.0	26.41	0.71	0.68	0.56