



Design and evaluation of slow sand and UV filters for effective nutrient recycling in closed soilless cultivation

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Received: 13 October 2023; Accepted: 25 January 2024

ABSTRACT

Nutrient and water use efficiency can be improved in soilless cultivation systems by recirculating the leachate. However, untreated leachate contains particulate matter that may clog drip emitters and root pathogens which can pose a threat to the crop health if reintroduced into the system. To address this issue, an ultraviolet (UV) filter was developed to complement the slow sand filter to enhance its treatment efficiency in removing root pathogens. The experiment was conducted during 2019 and 2020 at Punjab Agricultural University, Ludhiana, Punjab to assess the effectiveness of the UV filter in removing pathogens, specifically *Dickey zeae* and *Xanthomonas*, from the leachate in a closed soilless cultivation system. Pre and post-treatment measurements were made 40 days after transplanting (DAT) and 80 DAT to evaluate the efficiency of the UV filter. The results revealed that combined UV and slow sand filters substantially treated the raw leachate. At 40 DAT, the pathogen removal efficiency was 94.8%, while it was 92% at 80 DAT. The findings highlight the importance and effectiveness of using the UV filter as an additional treatment step in closed soilless cultivation systems with significant improvement in the overall removal efficiency of root pathogens from the leachate.

Keywords: Closed soilless cultivation, Leachate recirculation, Pathogen removal efficiency, Slow sand filter, UV filter

Soilless cultivation is an innovative method to grow crops in a rooting medium other than soil (Savvas *et al.* 2013). One significant challenge associated with soilless systems is the generation of leachate fraction (LF) ranging from 20–30% of the applied nutrient solution which prevents salt accumulation and supports successful plant growth (Massa *et al.* 2020). This leachate-containing particulate matter needs pre-treatment filtration before recirculation to prevent clogging of the drippers. Besides, the leachate may also contain root pathogens. Thus, economically sustainable methods of treating leachate are major requirements in closed soilless systems (Ashraf *et al.* 2020).

The slow sand filtration technique effectively combines adsorption and filtration mechanism for removing contaminants specifically the suspended particles (Ranjan and Prem 2018). The formation of a layer of biofilm known as the Schutzdecke layer on the top surface of the filtration tank plays a crucial role in filtration and removal of pathogens (Ehret *et al.* 2001, Fitriani *et al.* 2020). However, there is a need to combine slow sand filtration method with an economically effective method to remove pathogens

from the leachate. Amongst chlorination, ozonation and ultra-violet (UV) filtration techniques. UV filtration has emerged as the most promising technique for enhancing the quality of nutrient solution in closed soilless cultivation. The residual matter produced in chlorination can accumulate on the surface of filter membranes and reduce the filtration efficiency (Fan *et al.* 2018). Some researchers have reported ozonation treatment process can lead to serious issues of membrane fouling (Wang *et al.* 2007, Zhu *et al.* 2010). It is, therefore, hypothesized that a slow sand filter and UV filter train can be adopted to treat the nutrient solution. It can significantly improve the overall efficiency of closed soilless cultivation systems. This research is focused on designing a filtration system consisting of a slow sand filter and a UV filter. It also evaluates its performance in removing particulate matter and pathogens in a closed soilless cultivation system. The research aims at developing a system that enables continuous treatment of the nutrient solution during its operation to ensure the effective reuse of treated leachate in soilless cultivation systems.

MATERIALS AND METHODS

Present study was carried out during 2019 and 2020 at Punjab Agricultural University, Ludhiana, India. The study was conducted in a polyhouse with cucumber as the test crop. The composite filtration system consisting of a slow

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sand filter and UV filtration unit was developed to treat and recirculate the filtered leachate to improve nutrient and water use efficiency. The slow sand filter was designed using various sizes of gravel and sand in a 1000-litre plastic tank. Layers of coarse gravel (4–8 mm), fine gravel (2–4 mm), coarse sand (0.85–2 mm) each of 10 cm depth, medium fine sand (0.3–0.6 mm) of 20 cm depth and fine sand (0.18–0.3 mm) of 30 cm depth were filled in the tank in that order (Fig. 1). The critical components of a slow sand filtration system are the sand bed, supporting gravel, a control valve, and two collection tanks one each for raw and treated leachate. Water is maintained at 15 cm above the top sand layer. The total nutrient solution required was calculated as 2400 litres/day for 1200 plants considering peak nutrient requirement of 2 litres/day. The UV filtration set-up was designed to treat 600 litres of leachate generated from the polyhouse of 560 m² area (Supplementary Fig. 1). The UV dose was determined based on the amount of leachate to be treated, transmittance, absorbance of the solution and the targeted microorganisms. The influent flow rate was calculated based on the amount of leachate to be treated. Transmittance and absorbance through a 1 cm thickness of leachate at a wavelength of 254 nm were measured. The leachate recirculation and treatment system was tested for two growing seasons which involved growing cucumber in closed soilless cultivation system (Ashraf *et al.* 2020). To test the efficiency of the slow sand filter, leachate samples were taken 40 days after transplanting (DAT) and 80 DAT during both the seasons. Raw leachate from the leachate collection tank and filtrated leachate at the outlet were collected. Two dilutions were used for testing the samples, i.e., 10⁻³ and 10⁻⁴. The bacteriological analysis was carried out using the spread plate method that yields visible and isolated colonies of bacteria, which are countable and evenly distributed in the plate (Hartman 2011).

Samples of plant pathogens comprising different colonies of *Dickeya* spp., *Xanthomonas axonopodis* pv. *punicae* and *Streptomyces scabies* were prepared. The laboratory sample prepared had a concentration of 6 × 10⁵

cfu/ml (CFU represents Colony Forming Units or number of bacteria/ml) after dilution in a full tank. The leachate was supplied to the UV filtration system to remove the pathogens. Outflow samples were collected at different flow rates, i.e. 150, 175, 200, 225, and 250 litres/hour. The transmittance and absorbance of the leachate solution were determined using a UV-VIS spectrophotometer. Improvement in water quality parameters was calculated as percentage pollutant (or pathogens) removal as per formula below.

$$R_i (\%) = \frac{C_{in} - C_{out}}{C_{in}} \times 100$$

where R_i, Percentage removal; C_{in}, Pollutant concentration in influent (mg/L); C_{out}, Pollutant concentration in effluent (mg/L).

RESULTS AND DISCUSSION

Total suspended solid: Total suspended solids (TSS) in the inflow were primarily bits of cocopeat carried by leachate from the cocopeat slabs. Slow sand filter is known to significantly improve water quality parameters such as suspended solids, turbidity, and microbial content (Verma *et al.* 2017). The assessment of TSS in the leachate before and after treatment was carried out using the gravimetric method. The TSS in the inflow varied from 500–650 mg/litre in both the growing seasons. The outflow results revealed an overall average TSS removal percentage of 97.5–100% during the two years. TSS removal in the range of 59–90% using slow sand filters has been reported by several researchers (Elbana *et al.* 2012, Corral *et al.* 2014). The effectiveness of slow sand filtration makes it a perfect choice for TSS removal (El-Azazy *et al.* 2015).

Microbial count reduction: Slow sand filtration is known to effectively reduce the microbial counts in water. The biological and physical processes within the slow sand filter contribute to the removal and reduction of microorganisms. The microorganisms present in the schützdecke layer, which gradually develops over time, play a crucial role (Schuler 2019, Sze *et al.* 2021). As water passes through

the filter bed, suspended particles and microorganisms are physically trapped and removed. In addition to physical removal, slow sand filtration also involves biological processes such as predation, adsorption, and biological decay. The outflow leachates from the slow sand filter were observed weekly for 4 weeks for both growing seasons.

Microbial load reduction was observed to be in the range of 25–40%. The use of roughing filters which includes pre-treatment of

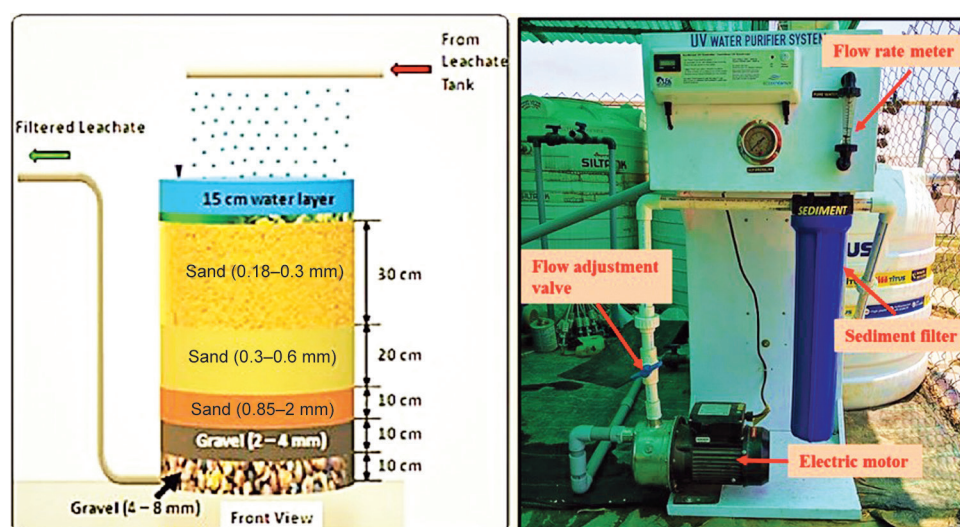


Fig. 1 Slow sand and UV filtration system.

wastewater increases the microbial load reduction substantially (Nkwonta and Ochieng 2009, Khan and Farooqi 2011). Studies have shown that slow sand filters can achieve a high level of microbial removal, typically exceeding 90% or more (Verma *et al.* 2017). As the filter is operated over different plant seasons, its efficiency is expected to increase due to the schutzdecke layer's formation and the filtration pores closing. However, the increase in filtration efficiency is accompanied by reduced outflow rates from the slow sand filter. It is important to note that slow sand filtration is not a sterilization method, and some microorganisms may still be present in the filtered water. Therefore, it is often recommended to combine slow sand filtration with some other disinfection methods, such as chlorination, ozonation or UV disinfection, to completely remove microbial contaminants.

Performance of Ultraviolet filter: The outflow from the slow sand filter was used as inflow to the UV filtration unit. Two samples were taken for microbial analysis: 40 DAT and 80 DAT. The data given in Table 1 is the real mean after taking care of the dilutions. The results showed 94.8% reduction in pathogens at 40 DAT and 92.0% reduction at 80 DAT. The data indicates that the filtration process significantly reduced the number of microbes in the solution making the nutrient solution suitable for reuse by mixing it with fresh solution for drip irrigation of the

crops (Fig. 2). However, the decrease in the percentage of pathogen removal at 80 DAT could be attributed to the accumulation of algae and other particles on the biofilm, which may require necessary cleaning.

The UV radiation filtration system was designed based on the field requirement of 200 litres/h, but results indicate that it worked effectively up to a flow rate of 250 litres/h. The efficiency of the UV filter decreased with increasing flow rate of influent. The exposure time was 71 sec for a leachate flow rate of 200 litres/h and volume of leachate in UV chamber as 3.9 litres. The efficiency of UV filter at different flow rates and corresponding exposure time was determined in terms of percentage pathogen removal. The exposure time for an inflow rate of 150, 175, 200, 225 and 250 litres/h was 95, 81, 71, 63 and 57 sec, respectively. The variation of pathogen population in the outflow leachate samples taken at 40 DAT and 80 DAT (Fig. 3). The disinfection is carried out at a wavelength of 254 nm since this wavelength is considered highly effective for disinfection (Ghauch *et al.* 2017). At a required flow rate of 200 litres/h, maximum pathogen removal efficiency of 95.9% was obtained (Table 2). Similar results were reported by Yang (2011). Wohanka (1995) based on experiments on a non-optimized slow sand filter achieved removal efficiency results ranging from 70–80%. Studies conducted with an enhanced filter configuration demonstrated significantly

improved performance, achieving an efficiency rate of approximately 96.5% (Keyikoglu *et al.* 2021). Previous research has shown that a UV dose of 10,000 $\mu\text{W}\cdot\text{sec}/\text{cm}^2$ (microwatt seconds per square centimetre) can destroy all the significant waterborne pathogenic microorganisms. The highest removal efficiency was obtained at a flow rate of 150 litres/h since the exposure

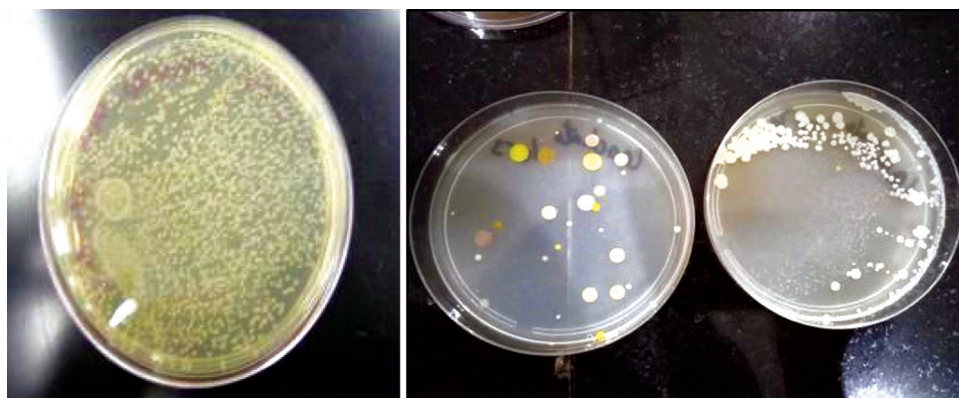


Fig. 2 Petri dish showing colonies in the raw and UV filtered leachate.

Table 1 Performance of UV filtration unit at 40 DAT and 80 DAT

Sample	40 DAT				80 DAT			
	Dilution 10 ⁻³		Dilution 10 ⁻⁴		Dilution 10 ⁻³		Dilution 10 ⁻⁴	
	Bacterial colony count				Bacterial colony count			
	R ₁	R ₂	R ₁	R ₂	R ₁	R ₂	R ₁	R ₂
Raw leachate	94	134	211	239	74	117	182	201
Filtered leachate	16	8	21	9	24	34	8	11
Raw leachate	11.4×10 ⁴		225×10 ⁴		9.5×10 ⁴		191.5×10 ⁴	
Filtered leachate	1.2×10 ⁴		15×10 ⁴		2.91×10 ⁴		9.5×10 ⁴	
	Final mean of two dilutions		% Removal		Final mean of two dilutions		% Removal	
Raw leachate	118.2×10 ⁴		94.8 %		100.5×10 ⁴		92.0%	
Filtered leachate	8.1×10 ⁴				6.2×10 ⁴			

DAT, Days after transplanting.

Table 2 Performance of UV filter at different flow rates

Sample code	Flow rate (litres/h)	Initial pathogen concentration (cfu/ml)	Final pathogen concentration (cfu/ml)	Range of filter efficiency (%)
G ₁	150	600000	6500	98.9–99.6
G ₂			2000	
H ₁			4000	
H ₂	175	600000	24500	95.9–99.3
I ₁			40000	
I ₂			24500	
J ₁	225	600000	4500	98.6–99.2
J ₂			8000	
K ₁			36000	
K ₂	250	600000	15000	94.0–97.5

time was 95 sec.

Comparative cost analysis of slow sand and UV filters for reuse of leachate: The cost analysis involves determining the cost of design, operation and maintenance. The design cost for sand filter comprise the cost of the tank, pump, sand, gravel and accessories. The operating cost is the cost of energy to run the pump. Maintenance cost involves cleaning the Schmutzdecke layer to maintain the filtration rate. The filtration rate of the slow sand filter was estimated to be 152.5 litres/h for a constant head of 15 cm over the filter layer. The operating cost for the UV filter involves pumping leachate from the outflow tank from the slow sand filter to the UV filtration system and running the UV system. The maintenance cost involves lamp replacement and cleaning of quartz sleeves. The total cost analysis of the slow sand filter and UV filter is given in Table 3.

The parthenocarpic cucumber crop period is around 90 days. The quantity of nutrient solution supplied for 1,200 plants for each growing season of 90 days in a 560 m² polyhouse was approximately 1,26,696 litres. The cost of major and minor nutrients for one growing season (90 days) was ₹30,600. The total nutrient solution applied during each growing season was 105.6 litres/plant and the total leachate drained was 24.7 litres/plant. For each growing season, in 4 growth stages, viz. initial stage (15 days), development stage (30 days), midseason stage (35 days), and end-stage (10 days), per plant nutrient applied was 15.7, 36.7, 41.9, and 11.3 litres and leachate drained/plant was 3.9, 8.4, 10.0 and 2.4 litres. For 1200 plants, the total leachate to be filtered was 29,580 litres which is 23.4% of the total nutrient solution applied. The cost of running individual filtration systems is a crucial aspect of decision-making in soilless cultivation systems. To highlight this comparison, the relevant data for both filtration systems was analysed.

The motor for the slow sand filter operates at a rated power of 0.75 kW, with a discharge rate of 152.5 litres/hour for 194 h of operation, consuming 146 kWh of electricity. At an electricity tariff rate of ₹10/unit, the slow sand filter accrued an electricity cost of ₹1,460, while the UV filter equipped with a higher-rated motor (1.5 kW) consumed 222 kWh of electricity, resulting in an electricity cost

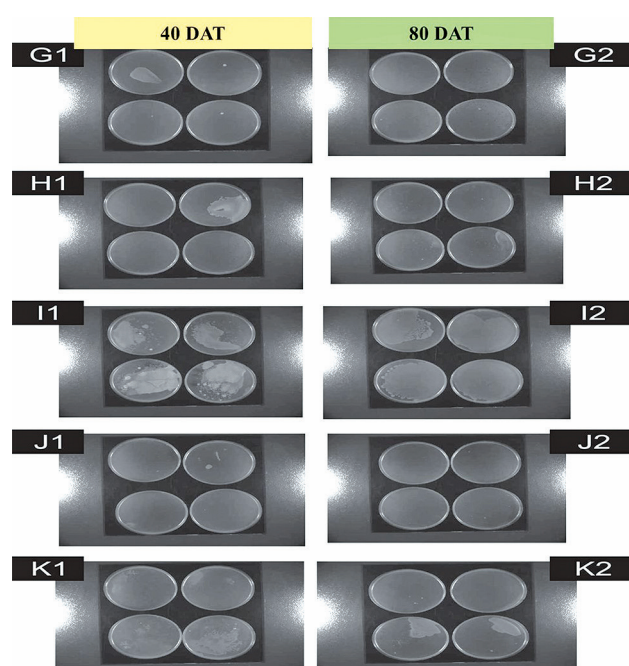


Fig. 3 Variation in pathogen population in inflow and outflow with different flow rates.

of ₹2,220 for leachate treatment. This comparative cost analysis underscores the cost-effectiveness of the slow sand filter, demonstrating a lower electricity expense compared to the UV filter. However, it's important to note that cost considerations should not be the sole factor in choosing a filtration system. Additionally, the choice between these filtration systems may vary depending on specific priorities, including the availability of resources and environmental concerns. Therefore, a comprehensive assessment is essential for making an informed choice between the slow sand filter and the UV filter in the context of leachate treatment for soilless cultivation systems. The UV filter offers a high level of pathogen removal, whereas slow sand filter is effective in lowering the suspended soil concentration and limited removal of pathogens. Combining both systems provides a balanced approach by delivering optimum water quality while managing the costs effectively.

Table 3 Cost analysis of the slow sand filter and UV filter

Particulars of material	Slow sand filter		UV Filter	
	Quantity	Cost (₹)	Quantity	Cost (₹)
Sand	0.74 m ³	625	-	-
Gravel	0.25 m ³	305	-	-
Online emitters	120	900	-	-
End cap	15	18	-	-
Pipe	6 m	600	6 m	600
HDPE Tanks (1000 litre)	2	18,000	2	18,000
Motor	1	6000	1	6000
Water purifier	-	-	1	27,730
UV alfa filter	-	-	1	23,600
Expected life (Years)	10		8	
Total fixed cost (₹)	26,448		75,930	
Per year cost (₹)	2644.80		9491.25	

The slow sand filter demonstrated remarkable efficiency in removing suspended solids, achieving a removal percentage ranging from 97.5–100%. The effectiveness of slow sand filtration in improving water quality parameters, including TSS, highlights its suitability for addressing suspended solids and turbidity concerns in leachate. The slow sand filter exhibited a microbial load reduction in the range of 25–40%, with the formation of the schutzdecke layer playing a crucial role in this process. The UV filter, on the other hand, showed a high percentage of pathogen reduction of 94.8% at 40 DAT and 92.0% at 80 DAT. The UV filter's efficiency was influenced by the flow rate, with optimal results achieved at a flow rate of 200 litres/h and a pathogen removal efficiency of 95.9%. The decrease at 80 days emphasizes the importance of regular maintenance to prevent biofilm accumulation. For polyhouse of 560 m² or less area, the slow sand filter may be more beneficial as it is low cost. However, for large areas of 4000 m² or more, combining both slow sand filtration and UV filtration systems provides a balanced approach, addressing suspended solids and microbial contaminants effectively while managing costs efficiently. In the context of sustainable agriculture and water resource management, the findings of this experiment underscore the importance of using the filtration techniques to match the intended purpose of reuse of nutrient solution.

REFERENCES

- Ashraf A, Singh K G and Singh A. 2020. Development and evaluation of nutrient reuse system in soilless media grown cucumber under protected cultivation. *Journal of Plant Nutrition* **44**(9): 1241–257.
- Corral A F, Yenal U and Strickle R. 2014. Comparison of slow sand filtration and microfiltration inland desalination via reverse osmosis. *Desalination* **334**: 1–9.
- Ehret D, Alsanius B, Wohanka W, Menzies J and Utkhede R. 2001. Disinfestation of recirculating nutrient solutions in greenhouse horticulture. *Agronomie* **21**(4): 323–39.
- El-Azazy M, El-Fadel M and Zeinati M. 2015. Slow sand filtration for wastewater treatment in agricultural applications. *Journal of Environmental Management* **150**: 189–98.
- Elbana M, de Cartagena F R and Puig-Bargues J. 2012. Effectiveness of sand media filters for removing turbidity and recovering dissolved oxygen from a reclaimed effluent used for micro-irrigation. *Agricultural Water Management* **111**: 27–33.
- Fan M, Wang Y, Xue N, Zhao Y, Wang Z, Wang M and Gao B. 2018. Coagulation of TiO₂ nanoparticles-natural organic matter composite contaminants in various aquatic media: Fluorescence characteristics, flocs properties and membrane fouling abilities. *Separation and Purification Technology* **205**: 113–20.
- Fitriani N, Ardiyanti P E, Kuncoro E P, Budiyo W D, Isnadina D R M, ahyudianto F E and Mohamed R M S R. 2020. Behaviour of schmutzdecke with varied filtration rates of slow sand filter to remove total coliforms. *Heliyon* **6**(4): 03736.
- Ghauch A, Baalbaki A, Amasha M, El Asmar R and Tantawi O. 2017. Contribution of persulfate in UV-254 nm activated systems for complete degradation of chloramphenicol antibiotic in water. *Chemical Engineering Journal* **317**: 1012–025.
- Hartman D. 2011. Perfecting your spread plate technique. *Journal of Microbiology and Biology Education* **12**(2): 204–05.
- Keyikoglu R, Karatas O, Rezanian H, Kobya M, Vatanpour V and Khataee A. 2021. A review on treatment of membrane concentrates generated from landfill leachate treatment processes. *Separation and Purification Technology* **259**: 118182.
- Khan Z and Farooqi R. 2011. Roughing filtration as an effective pre-treatment system for high turbidity water. *Water Science Technology* **64**: 1419–427.
- Massa D, Magan J J, Montesano F F and Tzortzakis N. 2020. Minimizing water and nutrient losses from soilless cropping in southern Europe. *Agricultural Water Management* **241**: 106395.
- Nkwonta O and Ochieng G. 2009. Roughing filter for water pre-treatment technology in developing countries: A review. *International Journal of Physical Sciences* **4**: 455–63.
- Ranjan P and Prem M. 2018. Schmutzdecke-A filtration layer of slow sand filter. *International Journal of Current Microbiology and Applied Sciences* **7**(7): 637–45.
- Savvas D, Gianquinto G, Tuzel Y and Gruda N. 2013. Soilless culture. *Good Agricultural Practices for Greenhouse Vegetable Crops*, pp. 303–54. Food and Agriculture Organization of the United Nations, Rome.
- Schuler A J. 2019. Design and performance of slow sand filters. *Water Environment Research* **91**(6): 539–49.
- Sze Y S, Aris A, Zaidi N S and Bahrodin M B. 2021. Performance of sand filtration system with different sand bed depth for polishing wastewater treatment. *Journal of Environmental Treatment Techniques* **9**(2): 452–57.
- Verma S, Daverey A and Sharma A. 2017. Slow sand filtration for water and wastewater treatment: A review. *Environmental Technology Reviews* **6**(1): 47–58.
- Wang X, Wang L, Liu Y and Duan W. 2007. Ozonation pre-treatment for ultrafiltration of the secondary effluent. *Journal of Membrane Science* **287**(2): 187–91.
- Wohanka W. 1995. Disinfection of recirculating nutrient solution by slow sand filtration. *Acta Horticulturae* **382**: 246–55.
- Yang Q, Zhang F and Li A. 2011. Effect of different drip irrigation methods and fertilization on growth, physiology and water use of young apple tree. *Science Horticulture* **129**: 119–26.
- Zhu H, Wen X and Huang X. 2010. Membrane organic fouling and the effect of pre-ozonation in microfiltration of secondary effluent organic matter *Journal of Membrane Science* **352**(1–2): 213–21.