

Design and assessment of UV filters and slow sand for efficient nutrient recycling in closed soilless farming

Anchal U. Pandey; Devanshu Dhimmaraj

Department of Rural Development and Agricultural Extension,

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ABSTRACT

Recirculating the leachate in soilless farming systems may increase the efficiency of water and nutrient utilization. However, untreated leachate includes root pathogens and particle debris that might clog drip emitters and endanger crop health if reintroduced into the system. In order to improve the slow sand filter's effectiveness in eliminating root infections, an ultraviolet (UV) filter was created as a supplement. In order to determine how well the UV filter removed pathogens—specifically, *Dickey zeae* and *Xanthomonas*—from the leachate in a closed soilless cultivation system, the experiment was carried out in 2019 and 2020 at Punjab Agricultural University in Ludhiana, Punjab. To assess the UV filter's effectiveness, measurements were taken both before and after treatment 40 and 80 days after transplanting (DAT). The findings showed that the raw leachate was significantly treated by a combination of UV and slow sand filters. The pathogen clearance effectiveness was 94.8% at 40 DAT and 92% at 80 DAT. With a notable increase in the total removal efficiency of root pathogens from the leachate, the results demonstrate the significance and efficacy of using the UV filter as an extra treatment step in closed soilless cultivation systems.

Keywords: UV filter, slow sand filter, efficient pathogen elimination, closed soilless cultivation, and leachate recirculation

Introduction

An inventive technique for growing crops in a rooting media other than soil is soilless farming (Savvas et al. 2013). The production of leachate fraction (LF), which ranges from 20 to 30 percent of the applied nutrient solution and avoids salt buildup while promoting healthy plant development, is a major problem with soilless systems (Massa et al. 2020). To avoid clogging the drippers, this leachate-containing particulate matter must be pre-treated and filtered before being recirculated. Additionally, root infections may be present in the leachate. Therefore, in closed soilless systems, economically viable leachate treatment techniques are essential (Ashraf et al. 2020).

Adsorption and filtration mechanisms are successfully combined in the slow sand filtration approach to remove pollutants, particularly suspended particles (Ranjan and Prem 2018). In order to filter and remove pathogens, a biofilm layer called the *Schutzdecke* layer must grow on the top surface of the filtration tank (Ehret et al. 2001, Fitriani et al. 2020). To eliminate pathogens from the leachate, however, a cost-effective technology must be used with the slow sand filtering process. Among these methods are ultraviolet (UV) filtering, ozonation, and chlorination. The most promising method for improving the nutrient solution's quality in closed soilless agriculture is UV filtering. According to Fan et al. (2018), residual materials from chlorination may build up on filter membrane surfaces and lower filtering performance. According to certain researches, the ozonation treatment method may cause major membrane fouling problems (Wang et al. 2007, Zhu et al. 2010). Therefore, it is suggested that the nutritional solution may be treated using a slow sand filter and UV filter train. It may greatly increase closed soilless cultivation systems' overall efficiency. The design of a filtration system with a slow sand filter and a UV filter is the main goal of this study. Additionally, it assesses how well it eliminates pathogens and particle matter in a closed soilless cultivation system. In order to guaranty the efficient reuse of treated leachate in soilless cultivation systems, the study intends to design a method that permits continuous treatment of the nutrient solution throughout its operation.

MATERIALS AND METHODS

The current research was conducted at Punjab Agricultural University in Ludhiana, India, between 2019 and 2020. Cucumber was used as the test crop in the research, which was carried out in a polyhouse. The filtered leachate was treated

and recirculated using a composite filtration system that included a UV filtration unit and a slow sand filter to increase the efficiency of water and nutrient consumption. Sand and pebbles of different sizes were used in a 1000-liter plastic tank to create the slow sand filter. The tank was filled with 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, in that sequence (Fig. 1). The sand bed, supporting gravel, control valve, and two collecting tanks—one for raw and one for processed leachate—are essential parts of a slow sand filtering system. Water is kept 15 cm above the top layer of sand. With a peak nutrient need of two liters per day, the total amount of nutrient solution needed for 1200 plants was determined to be 2400 liters per day. The 560 m² polyhouse produced 600 liters of leachate, which the UV filtering system was intended to handle (Supplementary Fig. 1). The volume of leachate to be treated, transmittance, solution absorbance, and the targeted microorganisms were taken into consideration while determining the UV dosage. The quantity of leachate that needed to be treated determined the influent flow rate. At a wavelength of 254 nm, transmittance and absorbance through a leachate thickness of 1 cm were determined. Cucumbers were grown in a closed soilless cultivation system for two growing seasons to evaluate the leachate recirculation and treatment system (Ashraf et al. 2020). Leachate samples were collected 40 days after transplanting (DAT) and 80 DAT in both seasons to evaluate the slow sand filter's effectiveness. Filtrated leachate at the exit and raw leachate from the leachate collecting tank were collected. The samples were tested using two dilutions, 10⁻³ and 10⁻⁴. The spread plate approach, which produces observable and isolated colonies of bacteria that are countable and uniformly dispersed throughout the plate, was used for the bacteriological examination (Hartman 2011).

Plant pathogen samples were produced, including several colonies of *Streptomyces scabies*, *Xanthomonas axonopodis* pv. *punicae*, and *Dickeya* sp. The concentration of the prepared laboratory sample was 6×10^5 .

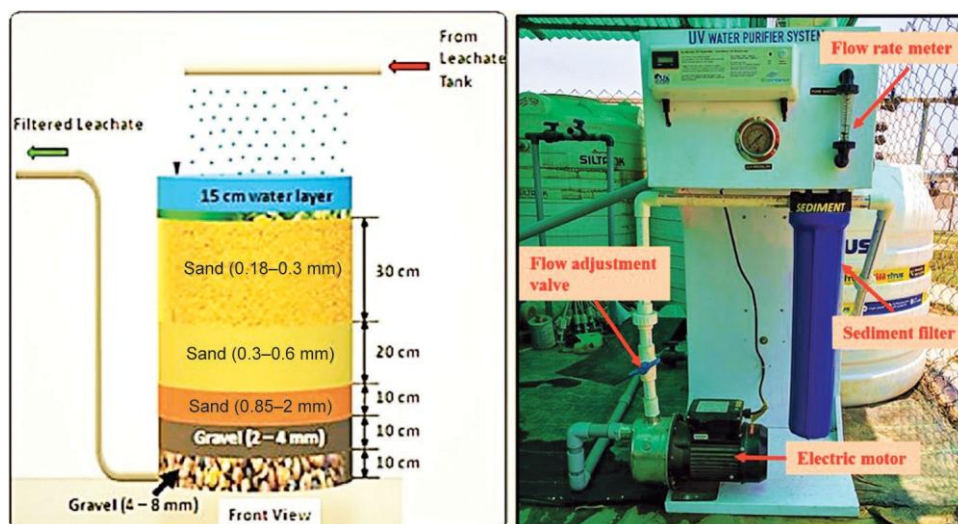


Fig. 1 Slow sand and UV filtration system.

cfu/ml after dilution in a full tank, where CFU stands for Colony Forming Units or the quantity of bacteria/ml. To get rid of the pathogens, the leachate was fed into the UV filtering system. At various flow rates—150, 175, 200, 225, and 250 liters per hour—outflow samples were collected. A UV-VIS spectrophotometer was used to measure the leachate solution's transmittance and absorption. The following formula was used to compute the improvement in water quality measures as a percentage of pollutants (or pathogens) removed.

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

where C_{in} is the concentration of pollutants in influent (mg/L), C_{out} is the concentration of pollutants in effluent (mg/L), and R is the percentage removal.

RESULTS AND DISCUSSION

Total suspended solids: The majority of the total suspended solids (TSS) in the inflow were cocopeat fragments transported by leachate from the cocopeat slabs. Water quality indices as suspended particles, turbidity, and microbiological content are reported to be greatly improved using slow sand filters (Verma et al. 2017). The gravimetric technique was used to measure the amount of TSS in the leachate both before and after treatment. During both growth seasons, the TSS in the inflow ranged from 500 to 650 mg/litre. Over the course of the two years, the outflow data showed an average TSS removal rate of 97.5–100%. Several researches have indicated that slow sand filters may remove 59–90% of TSS (Elbana et al. 2012, Corral et al. 2014). Slow sand filtration is an ideal option for TSS removal due to its efficacy (El-Azazy et al. 2015).

bacteria count reduction: It is well known that slow sand filtration may successfully lower the bacteria counts in water. Microorganisms are eliminated and reduced by the slow sand filter's biological and physical processes. An important part is played by the microorganisms found in the schutzdecke layer, which progressively develops over time (Schuler 2019, Sze et al. 2021). Microorganisms and suspended particles are physically held and eliminated when water flows through the filter bed. Slow sand filtration uses biological mechanisms such adsorption, biological degradation, and predation in addition to physical removal. For four weeks throughout both growth seasons, the slow sand filter's outflow leachates were monitored every week.

There was a 25–40% decrease in microbial burden. The microbial load reduction is significantly increased by the use of roughing filters, which include pre-treatment of wastewater (Nkwonta and Ochieng 2009, Khan and Farooqi 2011). According to studies, slow sand filters may remove a significant amount of microorganisms, usually more than 90% (Verma et al. 2017). The creation of the Schutzdecke layer and the closure of the filtering holes are intended to boost the filter's efficacy when it is used throughout various plant seasons. Nevertheless, lower outflow rates from the slow sand filter coincide with the improvement in filtering efficiency. It is crucial to remember that slow sand filtration is not a sterilization technique, and the filtered water may still contain some bacteria. Therefore, in order to fully eliminate microbiological pollutants, it is sometimes advised to combine slow sand filtration with additional disinfection techniques as chlorination, ozonation, or UV disinfection.

Ultraviolet filter performance: The UV filtration unit's intake was the slow sand filter's output. For microbiological examination, two samples were collected: 40 DAT and 80 DAT. After accounting for the dilutions, the data shown in Table 1 represents the actual mean. Pathogens were reduced by 94.8% at 40 DAT and 92.0% at 80 DAT, according to the data. According to the findings, the filtering procedure greatly decreased the quantity of microorganisms in the solution, allowing the nutrient solution to be reused by combining it with a new solution for agricultural drip irrigation (Fig. 2). However, the buildup of algae and other particles on the biofilm may need cleaning, which might account for the decline in the percentage of pathogen elimination at 80 DAT.

The findings show that the UV radiation filtering system functioned well up to a flow rate of 250 liters per hour, despite the system's design being based on the field requirement of 200 liters per hour. As the influent flow rate increased, the UV filter's efficiency declined. With a leachate flow rate of 200 liters per hour and a leachate volume of 3.9 liters in the UV chamber, the exposure period was 71 seconds. In terms of % pathogen eradication, the effectiveness of the UV filter at various flow rates and related exposure times was calculated. For input rates of 150, 175, 200, 225, and 250 liters per hour, the corresponding exposure times were 95, 81, 71, 63, and 57 seconds. The pathogen population fluctuation in the outflow leachate samples collected at 40 and 80 DAT (Fig. 3). Since 254 nm is thought to be a very efficient wavelength for disinfection, this wavelength is used for the disinfection process (Ghauch et al. 2017). A maximum pathogen elimination effectiveness of 95.9% was achieved at the necessary flow rate of 200 liters per hour (Table 2). Yang (2011) found similar findings. Removal efficiency figures ranging from 70 to 80% were obtained by Wohanka (1995) based on trials on a slow sand filter that was not improved. Research using an updated filter arrangement showed much better results, with an efficiency rate of around 96.5% (Keyikoglu et al. 2021). According to earlier studies, all of the major aquatic pathogenic bacteria may be eliminated with a UV radiation of 10,000 $\mu\text{W}\cdot\text{sec}/\text{cm}^2$ (microwatt seconds per square centimeter). At a flow rate of 150, the maximum removal efficiency was achieved liters per hour since the exposure period was 95 seconds.

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

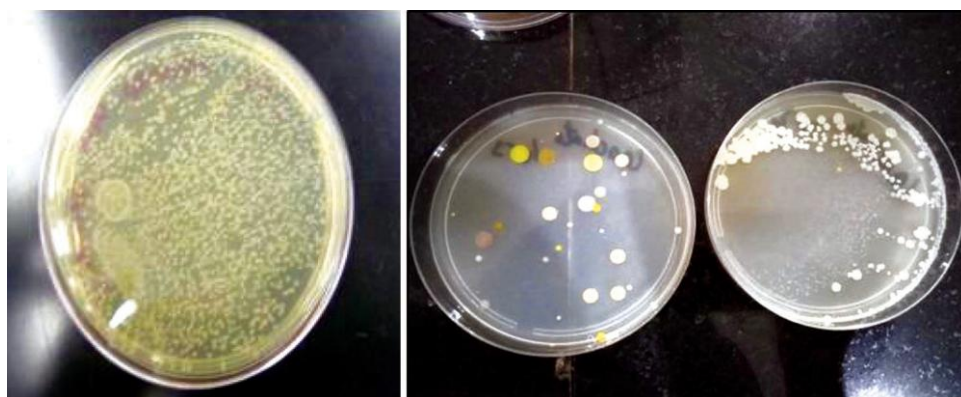


Table 1 Performance of UV filtration unit at 40 DAT and 80 DAT

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	175	600000	4000	95.9–99.3
H ₂			24500	
I ₁	200	600000	40000	95.3–95.9
I ₂			24500	
J ₁	225	600000	4500	98.6–99.2
J ₂			8000	
K ₁	250	600000	36000	94.0–97.5
K ₂			15000	

Cost comparison of UV filters and slow sand for leachate reuse: Determining the cost of design, operation, and maintenance is part of the cost analysis. The tank, pump, sand, gravel, and accessories are all included in the sand filter design cost. The cost of energy used to operate the pump is known as the operational cost. Cleaning the Schmutzdecke layer to keep the filtration rate constant is a maintenance expense. For a constant head of 15 cm over the filter layer, the slow sand filter's filtration rate was calculated to be 152.5 liters per hour. The UV filter's operational costs include running the UV system and pumping leachate from the slow sand filter's outflow tank to the UV filtration system. The expense of maintenance includes cleaning quartz sleeves and replacing lamps. Table 3 shows the overall cost analysis of the UV and slow sand filters.

The crop time for parthenocarpic cucumbers is around ninety days. For every 90-day growth season, 1,200 plants in a 560 m² polyhouse received around 1,26,696 liters of fertilizer solution. Major and minor nutrients cost ₹30,600 for a single growth season (90 days). Each growing season, 105.6 liters of fertilizer solution were applied to each plant, and 24.7 liters of leachate were discharged. Each growing season included four growth stages: the start stage (15 days), the development stage (30 days), the midway stage (35 days), and the end-stage (10 days). The amount of nutrients applied per plant was 15.7, 36.7, 41.9, and 11.3 liters, while the amount of leachate drained per plant was 3.9, 8.4, 10.0, and 2.4 liters. 29,580 liters of leachate, or 23.4% of the total fertilizer solution supplied, needed to be filtered for 1200 plants. One important consideration when making decisions in soilless cultivation systems is the expense of operating separate filtering systems. The pertinent data for both filtration systems was examined in order to emphasize this contrast. The slow sand filter's motor uses 146 kWh of energy when running at a rated power of 0.75 kW and a discharge rate of 152.5 liters per hour for 194 hours. The slow sand filter cost ₹1,460 at an electricity tariff rate of ₹10/unit, but the UV filter with a higher-rated motor (1.5 kW) used 222 kWh of power, resulting in an electricity cost of

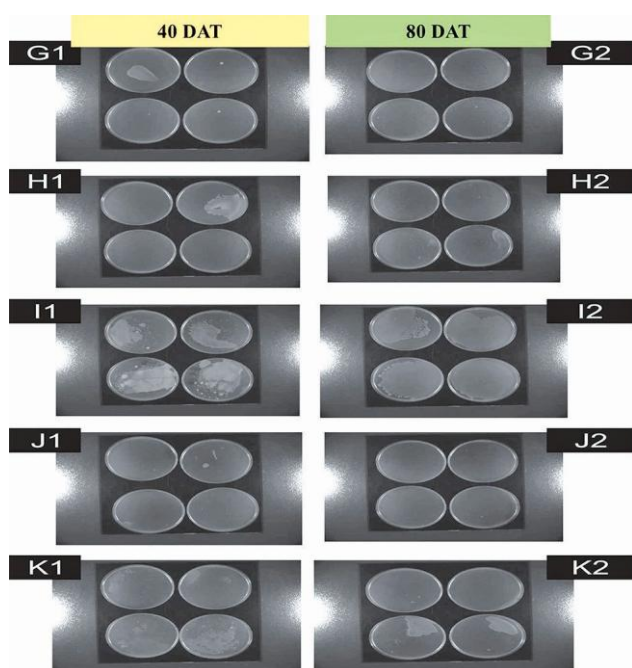


Fig. 3 Variation in pathogen population in inflow and outflow with different flow rates.

₹2,220 for the treatment of leachate. The slow sand filter's cost-effectiveness is shown by this comparative cost study, which shows that it uses less power than the UV filter. But it's crucial to remember that when selecting a filtration system, pricing should not be the only concern. Additionally, certain criteria, such as resource availability and environmental concerns, may influence the decision between different filtering technologies. Therefore, in the context of leachate treatment for soilless cultivation systems, a thorough evaluation is necessary to make an educated decision between the slow sand filter and the UV filter. While the slow sand filter effectively reduces the concentration of suspended dirt and removes a limited amount of pathogens, the UV filter provides a high degree of pathogen elimination. By supplying the best possible water quality and efficiently controlling expenses, combining the two systems offers a balanced approach.

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	

With a clearance percentage ranging from 97.5 to 100%, the slow sand filter showed exceptional effectiveness in eliminating suspended particles. The efficiency of slow sand filtration in enhancing water quality metrics, such as TSS, demonstrates its appropriateness for resolving issues with suspended particles and turbidity in leachate. The development of the Schutzdecke layer was essential to the slow sand filter's 25–40% microbial load decrease. In contrast, the UV filter demonstrated a high pathogen reduction percentage of 94.8% at 40 DAT and 92.0% at 80 DAT. The flow rate had an impact on the UV filter's effectiveness; a flow rate of 200 liters per hour produced the best results, with a pathogen elimination efficiency of 95.9%. The decline after 80 days highlights how crucial routine maintenance is to avoiding biofilm buildup. Due to its cheap cost, the slow sand filter can be more advantageous for polyhouses that are 560 m² or less. However, combining slow sand filtration with UV filtering systems offers a balanced solution for vast areas of 4000 m² or more, successfully treating microbiological pollutants and suspended particles while controlling expenses. The results of this experiment highlight the significance of matching filtering processes to the intended aim of nutrient solution reuse in the context of sustainable agriculture and water resource management.

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