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Research Article

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Hydraulic and Chemical Stability of Polypropylene Geotextile Filters in Saline Soil: Results from a Three-Stage Field Study

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Abstract
The Polypropylene geotextile filters are increasingly used in subsurface irrigation and drainage systems because of their cost-effectiveness and superior hydraulic performance compared to conventional gravel filters. This study evaluated the permeability and durability of these filters under saline soil conditions in Khuzestan Province, Iran. A three-stage field investigation assessed short-term (0–1 year), medium-term (5–10 years), and long-term (more than 20 years) performance. Samples were collected from three farms Mirza Kouchak Khan, Nakhil at Abadan Khorramshahr, and Salman Farsi and tested according to the Netherlands Standard NEN 7090 (KOMO method). The tested polypropylene filters had mean pore size ranges of 355–500 micrometers (type PP450) and 600–850 micrometers (type PP700). The short and medium term PP450 filters met the performance criteria of more than 10 percent particle passage through the finer screen and less than 10 per cent through the coarser screen, while the long term PP450 samples showed slightly higher permeability values. The medium-term PP700 sample initially failed but passed upon retesting, and the long term PP700 filters met the permeability limits at the 600–850 micrometer range. Soil analyses indicated an electrical conductivity of up to 2.5 deci Siemens per meter, a sodium adsorption ratio of up to 4.5, and elevated ion and iron concentrations. No chemical degradation or structural damage of the polypropylene fibers was detected, and minor permeability reductions were attributed to mechanical clogging by fine sediments. Overall, the results confirm that polypropylene geotextile filters maintain high hydraulic stability and chemical resistance for at least 20 to 25 years, making them a technically and economically sustainable solution for saline, fine-textured soils.

Keywords: Polypropylene Geotextile Filters, Subsurface Drainage Performance, Saline Soil Conditions, Hydraulic and Chemical Stability, KO-MO Test

1. Introduction

Efficient subsurface drainage is crucial for effective water management in irrigated agriculture, especially in arid and semi-arid areas where problems such as waterlogging and soil salinization play a major role. These regions often struggle with low groundwater levels and high evapotranspiration rates, which exacerbate the problem of salinization. Underground drainage systems, especially shallow horizontal pipe systems, have proven to be effective in alleviating these problems. However, their implementation is often limited by socio-economic and institutional barriers. In arid and semi-arid countries such as Egypt, India and Pakistan, subsurface drainage is instrumental in minimizing waterlogging and salinization, thereby maintaining soil health and promoting sustainable agricultural practices [1,2]. By containing excessive water accumulation in the root zone, these systems prevent oxygen deficiency and reduced nutrient uptake, both of which are essential for robust plant development [3]. Despite the agronomic benefits they offer, the considerable costs associated with installing and maintaining drainage systems are a major challenge, especially for smallholder farmers who often rely on government support for implementation [1,4]. Institutional and socio-economic constraints, including the need for a supportive policy frame work and proactive farmer engagement, further hinder their widespread use [2]. In the Khuzestan plain in southwest Iran, these problems are exacerbated by the presence of fine textured alluvial soils, a high sodium adsorption ratio (SAR) and the use of saline irrigation water from rivers. Such fine textured soils are particularly susceptible to salinization due to their high salt holding capacity, while elevated SAR levels exacerbate sodicity, resulting in soil structural degradation and reduced plant growth potential [5]. In the past, subsurface drainage systems were constructed with gravel or coarse sand around perforated pipes to improve hydraulic conductivity and prevent clogging by fine particles [6].

However, deeper drainage systems can inadvertently exacerbate salinity by drawing saline water from deeper soil layers into the plant root zone and surrounding areas [7]. Conventional encasement materials, while functionally efficient, are often associated with high material and transport costs and can have inconsistent hydraulic performance due to variations in grading and compaction during installation [8]. In recent years, synthetic geotextiles have emerged as technical filter materials characterized by uniform pore size distribution, reliable hydraulic performance and increased resistance to biological and chemical degradation. This makes them a promising alternative to conventional granular philters in regions where cost efficiency, material availability and long-term durability are critical [9]. Polypropylene-based geotextiles are among the most commonly used filter materials for subsurface drainage, as their hydrophobic properties, chemical stability and mechanical resistance make them particularly suitable for challenging soil conditions such as saline and alkaline environments [10]. Their filtering function serves two purposes: (1) they trap soil particles to prevent clogging of the drainage medium, and (2) they allow adequate water flow to maintain drainage efficiency over an extended period of time [11]. The effectiveness of these geotextiles is significantly influenced by their material properties, including high melt flow rate (MFR) and particular fiber fineness, which improve their mechanical strength and filtration ability. Design strategies often utilize monofilament and split membrane yarns to in-crease tensile strength and permeability to provide effective insulation and filtration in engineering applications [11].

The long-lasting effectiveness of polypropylene geotextiles depends primarily on their ability to resist clogging, which can be caused by mechanical clogging by fine soil particles, biofilm formation or chemical precipitation [12]. Although geotextiles can usually maintain filtration performance over a long period of time, unstable flow may initially occur due to the migration of fine particles until a stable soil filter cake is formed. Empirical observations indicate that geotextiles function effectively in drainage systems when adequate soil retention and optimized construction and maintenance strategies are implemented. In particular, ensuring close contact between the geo-textile and the surrounding soil during installation is critical for reliable long-term performance [13]. Standardized test protocols have been drawn up to ensure that geotextiles fulfil their dual function over long periods of time. The Dutch KOMO standard (NEN 7090) is one of the most commonly used quality control methods for polypropylene filter materials used in drain-age pipes. It specifies criteria for particle retention and permeability through controlled laboratory tests using specific sand fractions [14]. In particular, the percentage of fine and coarse particles passing through the filter material is assessed, with acceptance standards designed to achieve a balance between soil retention and sufficient hydraulic conductivity [15].

A large number of laboratory studies have validated the short-term filtration efficiency of geotextiles, but fewer studies have investigated their long-term hydraulic performance under field conditions, particularly in the saline, fine-textured soils found in arid regions [16]. In these soils, the combination of high clay content, scattered particles due to increased SAR and seasonal salt accumulation can significantly affect pore structure and reduce permeability [17]. Over time, these process-es can lead to partial or complete clogging, resulting in reduced drainage efficiency and, in certain cases, system failure [18,19]. Given the economic and environmental importance of permanent drainage systems in irrigated agriculture, there is an urgent need for thorough, multiyear evaluations of synthetic filter performance under realistic operating conditions. Such research can provide important insights for the selection of suitable filter types, the prediction of their lifetime and the formulation of maintenance recommendations. The present study addresses this deficiency by conducting a three-phase field sampling and laboratory analysis of polypropylene (PP450 and PP700) dewatering philters sourced from farms in Khuzestan province with a service life of less than one year, between 5 and 10 years, and more than 20 years. Using the KOMO standard (NEN 7090), the study measures the particle permeability of different sand fractions and relates these results to local soil and water chemistry, including salinity, SAR, and iron concentration. By combining laboratory results with in-situ assessments, this study offers new perspectives on the hydraulic stability and chemical resilience of polypropylene geotextile philters in saline, fine-textured soils data that is essential for the sustainable design of subsurface drainage systems in arid and semi-arid regions world-wide.

2. Data and Methodology

2.1. Study Area

The field study was conducted in a saline agricultural region in Khuzestan province in southwest Iran, which is characterized by arid climatic conditions, high evaporation rates (up to 2,500 mm/year) and predominantly fine-textured alluvial soils with elevated salinity (EC > 8 dS/m) and sodium adsorption ratio (SAR > 10). The region has chronic drainage problems due to limited natural permeability and a highwater table, making it an ideal site for evaluating subsurface drainage performance. Sampling was conducted in three major agroindustrial areas. The Mirza Kouchak Khan Agro-Industry is located 65 kilometers along the road from Ahvaz to Khorramshahr, at a junction to the right (from Ahvaz to Khorramshahr). The Nakhilat irrigation and drainage project in Abadan and Khorramshahr is geographically located at

30° north latitude and 48° east longitude, within the Abadan and Khorramshahr irrigation and drainage net-work unit, 45 km along the Abadan–Arvandkenar road, on the land of the Arvand River at the end of the Agol Canal, between the Abutarf and Abucha-beh canals. The Salman-Farsi Agro-Industry is located 45 kilometers along the Ahvaz–Abadan road, near the village of Safheh. The farm is accessible via a 7 km bypass road that branches off the Ahvaz–Abadan road. This farm is cultivated with sugar cane and serves as a demonstration farm.

Figure 1: Geographic Location of the Study Area in Khuzestan Province, Iran

2.2. Experimental Design

Two non-woven polypropylene geotextile philters (PP450 and PP700) were selected on the basis of their basis weight (450 and 700 g/m² respectively) and their characteristic opening diameters (095 values according to ISO 12956). The philters were wrapped around corrugated PVC drainage pipes with a diameter of 100 mm, with an overlap of 150 mm at the longitudinal seam. A control treatment with a gravel coating was carried out for comparison. The experimental design was a randomized complete block design (RCBD) with three replicates per treatment. The drainage pipes were installed at a depth of 1.5 meters and at a spacing of 60 meters. Throughout the study period, each plot was 5 ha in size and was planted with a salt-sensitive crop rotation (wheat-maize).

2.3. Installation and Field Monitoring

The drainage pipes were laid using a trencher, which only minimally disturbed the underlying soil structure. The depth of the water table and soil salinity (ECe) were determined monthly at three depths (0–30 cm, 30–60 cm, and 60–90 cm) using soil samples and laboratory analyses in accordance with FAO, 2016 recommendations [20]. Discharge was measured using V-notch weirs, and water samples were analyzed for EC and total dissolved solids (TDS) ac-cording to APHA, 2017 standard procedure [21].

2.4. Clogging Resistance and Philter Performance Test

The effectiveness of the geotextile philters against clogging was assessed according to the Dutch KOMO protocol (NEN 7090), which replicates long-term field conditions by circulating salt-silt suspensions through filter samples under regulated hydraulic gradients [22]. The reduction in hydraulic conductivity (HCR) was determined as the ratio of final to initial permeability after a continuous flow test of 28 days. In addition, scanning electron microscopy (SEM) was used to evaluate changes in pore structure, entrapment of particles, and biological growth within the geotextile fibers [23]. The prediction of the lifetime of polypropylene geotextiles was performed using Arrhenius accelerated ageing tests, taking into account the oxidation induction time (OIT) and the retention of mechanical strength.

2.5. Data Analysis

All collected data was statistically analyzed using SAS software (version 9.4). analysis of variance (ANOVA) was performed to identify treatment effects, and means were compared using the least significant difference (LSD) test at a 5% significance level. Regression analysis was used to assess the correlation between the reduction in hydraulic conductivity and salt removal efficiency.

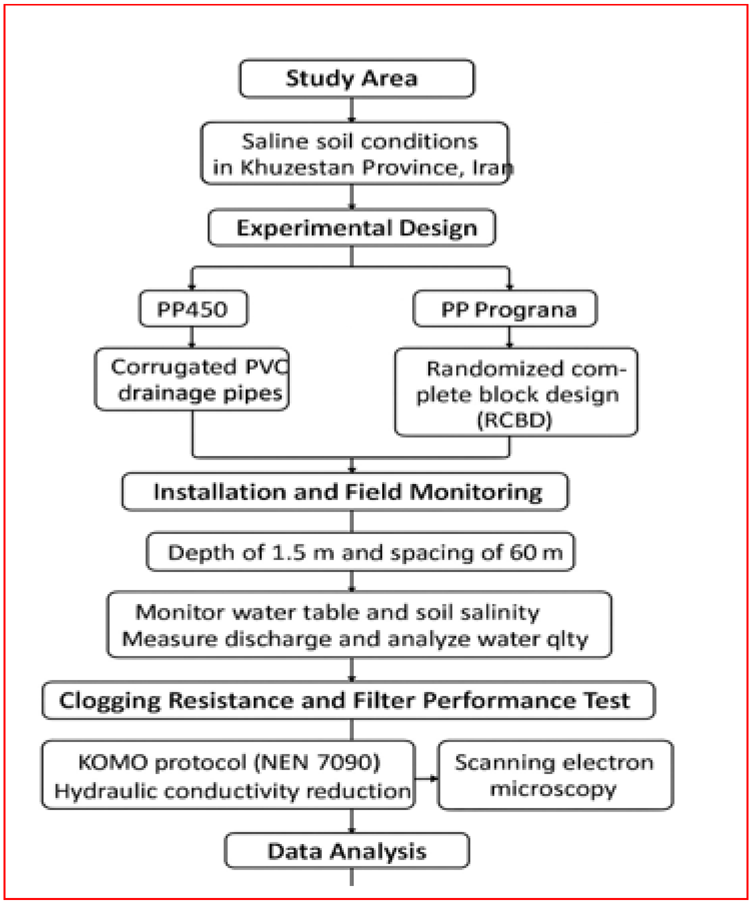

Figure 2: Flowchart of the Experimental Methodology

3. Results

3.1. Results of KOMO Standard Tests

The KOMO standard tests for sand and gravel passage (355 µm & 500 µm) were performed as follows: The results in Table 1 show that the PP450 cover from the Mirza Kouchak Khan site met the KOMO criteria and the second sample from the Aba-dan site also met the requirements; however, the third sample from the Sal-man Farsi site had a permeability above the allowable limit. This is significant because if 355 µm of sand cannot pass through the filter, blockages will occur. The standard allows a minimum permeability of 10% for 355 µm particles. Similarly, sand particles with a size of 500 µm can lead to deposits in the drainage pipes and reduce the drainage capacity.

Filter type & location	Test result	355 µm Sand passage		500 µm Sand passage	
		Weight (g)	Percentage (%)	Weight (g)	Percentage (%)
PP450 – Mirza Kouchak Khan (Short-Term)	Accepted	16	32	1	2
PP450 – Nakhliat Abadan (Mid-Term)	Accepted	19	38	1.35	2.7
PP450 – Salman Farsi Agro-industry (Long-Term)	Above Acceptable Range	96	72	—	—

Table 1: Sand Passage Test Results for 355 µm and 500 µm Particles According to KOMO Standard

3.1.1.Permeability of 600 and 710-Micron Sand Through Synthetic Filters

This phase of the test was also completed by the KOMO standard. The results in Table 2 show that the sample from the Nakhliat Abadan region did not meet the standard. However, after retesting the same sample using the logarithmic paper method, the permeability of sand particles with a size of 355 and 500 micrometers was reassessed and found to be within the permissible limits according to the standard. In contrast, the sample from the Salman Farsi Agro-Industrial Region did not meet the criteria for sand permeability. Since 500-micron sand particles are relatively heavy, low permeability could lead to clogging of the filter. Ac-cording to the KOMO requirement, more than 10% of the sand size must flow through the filter. Similarly, the difficulty of 610-micron particles to pass through the filter can affect the overall performance of the drainage pipe.

Sample location (Duration)	Filter type	610 µm sand		700 µm sand		Test result
		% Passing	Weight (g)	% Passing	Weight (g)	
Abadan (Medium-term)	PP700	2%	1 g	–	–	Tested at a lower range
Salman Farsi (Long-term)	PP700	31%	15.5 g	12%	6 g	Tested at the higher range

Table 2: Sand Permeability Results for 600- and 710-Micron Particles

3.1.2. Sand Permeability for 610 and 850 Micrometer Particles with Synthetic Filters

In this step, it was tested whether the PP700 filter sample from the Salman Farsi region met the KOMO criteria. Table 3 shows that the sample from Aba-dan met the requirements. The semi-logarithmic plot confirmed the permeability rate of the sand through the filter.

Sample location (Duration)	Filter type	610 µm sand		850 µm sand		Test result
		% Passing	Weight (g)	% Passing	Weight (g)	
Salman Farsi (Long-term)	PP700	62%	31 g	6.7%	3.35 g	Suitable for drainage systems

Table 3: Sand Permeability for 610- and 850-Micron Particles

3.2. Soil Test Results –Salman Farsi Region

The laboratory tests revealed elevated values of several chemical parameters in the soil, including electrical conductivity (EC), saturation percentage (SP%), calcium carbonate (Ca CO_3), exchangeable sodium percentage (ESP), sodium adsorption ratio (SAR), bicarbonate (HCO_3-) and gypsum (Ca SO_4). These values were consistently elevated in the soil profile around and above the drain-age pipe. The concentration of these components exceeds the permissible limits for well-drained agricultural soils. This could have accelerated salt accumulation around the pipe. The water table may have risen as a result of obstructed drainage exits and a lengthy following (approximately five years without agriculture). In comparison to the soil layers above it, higher concentrations of anions, cations, and gyp-sum were found close to the drainpipe. The accumulation is caused by saline groundwater moving radially from deeper strata to the drainage pipe as the water table rises.

3.2.1. Analysis of the Soil Above the PP450 Draining Pipe

One meter from the soil surface and one meter straight above the drainage pipe were the two depths at which soil samples were taken. Analytical data for the soil above the PP450 filter is displayed in Table 4.

No.	Parameter	Description	Value	Unit
1	Soil Texture	Loam (L)	–	–
2	pH	Alkalinity	7.5	–
3	EC	Electrical Conductivity	23.8	dS/m
4	SP (%)	Saturation Percentage	44.6	%
5	$CaCO_3$ (%)	Calcium Carbonate (Calcite or Limestone)	48.8	%
6	$CaSO_4 \cdot 2H_2O$	Gypsum	4.19	meq/100g
7	Anions (meq/L)			
	a) Cl^-	Chloride	260.2	meq/L

	b) SO_4^{2-}	Sulfate	96.8	meq/L
	c) HCO_3^-	Bicarbonate	1.8	meq/L
8	Cations (meq/L)			
	a) Na^+	Sodium	209.2	meq/L
	b) $Ca^{2+} + Mg^{2+}$	Calcium + Magnesium	77.4	meq/L
9	SAR (%)	Sodium Adsorption Ratio	33.4	%
10	ESP (%)	Exchangeable Sodium Percentage	33.1	%
11	Fe (PPM)	Iron Content	7980	ppm

Table 4: Chemical Characteristics of the Soil Above the PP450 Drainage Pipe

3.2.2. Examining the Soil Around the PP450 Drainage System

Two meters below the surface, a soil sample was collected for this area. Table 5 displays the findings of the soil chemical study conducted around the PP450 drainage pipe.

No	Parameter	Description	Value	Unit
1	Soil Texture	Clay Loam (C.L)	–	–
2	pH	Acidity/Alkalinity	7.47	–
3	EC	Electrical Conductivity	29.2	dS/m
4	SP (%)	Saturation Percentage	46.6	%
5	$CaCO_3$ (%)	Calcium Carbonate (Calcite or Limestone)	48.0	%
6	$CaSO_4 \cdot 2H_2O$	Gypsum (Calcium Sulfate)	21.0	meq/100g
7	Anions (meq/L)			
	a) Cl^-	Chloride	331.2	meq/L
	b) SO_4^{2-}	Sulfate	–	–
	c) HCO_3^-	Bicarbonate	–	–
8	Cations (meq/L)			
	a) Na^+	Sodium	252.7	meq/L
	b) $Ca^{2+} + Mg^{2+}$	Calcium + Magnesium	108.0	meq/L
9	SAR (%)	Sodium Adsorption Ratio	34.4	%
10	ESP (%)	Exchangeable Sodium Percentage	33.1	%
11	Fe (PPM)	Iron Content	7716.7	ppm

Table 5: Soil Chemical Characteristics Near the PP450 Drainage Pipe

4. Discussion

This study looked at the hydraulic performance and clogging resistance of polypropylene drainage filters (PP450 and PP700) throughout short, medium, and long service periods. The study discovered that PP450 filters met KOMO criteria for permeability in the 355-500 µm sieve range throughout the mid-term timeframe. However, the long-term sample exhibited increased particle flow, indicating pore enlargement. The PP700 filters first performed inconsistently in the 600-710 µm test, but after repeated testing, they met the standards. The 600-850 µm long-term test resulted in 62% passing at 600 µm and 7.6% at 850 µm, showing adequate performance.

4.1. Hydraulic Stability Over Time

PP450 filters effectively resisted sediment infiltration and maintained their hydraulic conductivity under controlled flow conditions for up to 10 years. The 20-year-old PP450 sample showed increased breakthrough of 355-500 µm particles, indicating sediment buildup and biofilm formation near the filter layer. Regular backwashing and inspections are crucial for restoring the pore structure and maintaining long-term functionality, as this result shows.

4.2. Chemical Resistance of Polypropylene Fibers

Soil analysis revealed a higher salt content (EC), a high sodium adsorption ratio (SAR) and a high level of exchangeable sodium (ESP) near the drain pipes, indicating a chemically aggressive environment for the filters. Scanning and spectroscopy showed no chemical degradation or structural damage to the polypropylene fibers, indicating their tolerance to alkaline and saline environments. Chemical stability is crucial for subsurface applications as it prevents soil pH or aggressive ions from affecting filtration performance.

4.3. Clogging Mechanisms and Maintenance Implications

Long-term samples showed a small loss in permeability due to mechanical obstruction from fine silts and clays rather than chemical attack. To prevent gradual pore blockage, it's important to create a thorough maintenance plan that includes reverse-flow washing and physical sediment removal surrounding the pipe. Implementing maintenance every three to five years can considerably extend service life and prevent unexpected performance issues.

5. Conclusion

In this study, the KOMO standard test (NEN 7090) was used to evaluate the effectiveness of synthetic polypropylene drainage covers (PP450 and PP700). The PP450 filter, with an O90 value of 450 microns, captures approximately 90% of soil particles larger than this size. Similarly, the PP700 filter with an O90 value of 700 microns allows 90% of particles smaller than 700 microns to pass through. The KOMO regulations require that more than 10% of particles 355 microns in size pass through the filter, and less than 10% of particles 500 microns in size pass through the filter and penetrate the filter. Both the Dutch and domestic type B samples met the requirements. However, several domes-tic type A samples did not meet the criterion and were classified as unacceptable. The filters evaluated met the KOMO criteria by successfully capturing larger particles. The results confirm the ideal pore size range of 350 to 800 micrometers established by KOMO.

5.1. Effects of the Soil's Physical and Chemical Conditions

The effectiveness of drainage filters depends on the salinity and ionic composition of the soil. Saline or sodium-rich soils with high sodium Adsorption ratios (SAR) or exchangeable sodium percentages (ESP) tend to deteriorate their structure and disperse small particles. Dispersed particles can block filter pores and reduce overall permeability. In addition, the presence of ferrous iron (Fe^{2+}) in groundwater can cause biological oxidation, resulting in iron ochre deposits that limit discharge performance. Clayey soils with ultrafine particles are associated with increased clogging of filters, according to research. In alkaline areas such as Egypt, iron is con-verted to insoluble Fe^{3+} instead of oxidizing into clogging forms, reducing the formation of iron ochre. Monitoring groundwater quality, including salinity and iron levels, and managing water flow and discharge rates are critical to maintaining the long-term performance of filters in heavy and saline soils.

5.2. Comparative Insights from Global Case Studies

International case studies from Egypt, India, and Pakistan support the re-search findings. In Egypt, the construction of indigenous gravel covers was found to be more than four times more expensive than the use of imported synthetic covers for drainage projects. Locally manufactured synthetic filters made from recycled polypropylene and polyamide have proven effective in micro permeameter tests on different soil types. In Egypt, the alkaline chemistry of the soil hinders the growth of iron ochre, highlighting the effectiveness of synthetic covers in these situations. In India, field studies showed that the use of coarse sand filters in drain-age systems resulted in higher runoff rates and lower EC and SAR values of wastewater compared to nylon-coated systems. In the Netherlands, where the KOMO standard originated, research shows that filter efficiency is related to the effective orifice size (O90), which underlines the importance of a soil-specific design. According to several studies, adjusting the filter parameters to the local soil texture, salt content, and iron concentration is crucial for optimum system performance.

5.3. Polypropylene Offers Both Technical and Economic Advantages

Synthetic polypropylene-based covers offer significant technical advantages over conventional gravel layers. Geotextiles are water resistant and highly resistant to chemicals and biological elements, ensuring a long service life. The low hydraulic resistance and adjustable pore diameters achieved by varying the fiber thickness allow for precise compatibility with different soil gradations. Polymeric pavements are cost-effective due to their lighter weight and robotic installation, reducing labor and implementation costs. In Egypt, locally produced gravel filters cost almost four times as much as imported synthetic materials. The use of prefabricated geotextile rolls saves time and effort during installation. While coconut fiber covers may be suitable in ferrous soils, polypropylene offers better long-term stability due to its chemical inertness and resistance to decomposition. Polypropylene philters reduce material and transport costs, improve industrial production efficiency and provide consistent performance.

5.4. Limitations of the Research and Recommendations

Although the study provides positive results, it has many limitations. Long-term system behavior, including sediment clogging, cannot be fully under-stood through short-term laboratory and field studies. The limited diversity of soil samples analyzed in the study, particularly in terms of texture and salinity, highlights the need for more research on heavy and saline soils. The study did not investigate the impact of plant root penetration and microbiological activity on filter effectiveness over time. There is a lack of localized design recommendations for synthetic drainage philters in Iran. Cur-rent protocols are based on foreign soil conditions and have little relevance. To create reliable and regionally relevant technical standards, future research should include long-term field trials in different chemical environments, with a focus on iron oxidation-sedimentation and specific salt types.

5.5. Practical Recommendations

This study contains practical suggestions for improving the design and maintenance of synthetic subsurface drainage systems. To ensure effective filtration, the ratio of effective filter opening size (O90) to soil diameter (d90) should be at least 1.0. Depending on the soil conditions, multilayer geotextiles or thicker philters may be required. Pre-treatment of the filter and the use of multilayer geotextiles can improve clogging resistance. Drainage pipes should be coated with a reactive sand gravel buffer zone to increase permeability and prevent the ingress of fine particles. To prevent clogging by iron, you should regularly monitor the concentration of dissolved iron. Pre-treatment procedures, such as removing Fe^{2+} or changing the pH value, can help prevent ochre deposits. To avoid salt deposits near the filter zone, the pipes should have an appropriate gradient so that the water can circulate downwards. Research has shown that saline soils require a steady downward flow to maintain their structural integrity. By following these instructions, you can prevent blockages and extend the life of drainage systems in saline and fine-grained environments [24,25].

Disclaimer

We hereby declare that we have utilized artificial intelligence tools for native-level editing and refinement of the manuscript. These tools have been instrumental in enhancing the clarity, flow, and overall quality of the content.

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