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Performance of abaca fiber geotextile as perforated pipe geo-envelope for agricultural subsurface drainage systems

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Abstract. Waterlogging, defined as the complete saturation of the crop’s root zone, is a widespread problem in agricultural areas. This problem has been exacerbated in recent years by extreme weather conditions caused by climate change. Currently, the most common solution to waterlogging is the installation of subsurface drainage systems, which consist of perforated pipes wrapped in geotextiles. However, due to most geotextiles being synthetic, there has been emerging research interest in manufacturing these from sustainable sources, one of which is abaca. This study evaluated the performance of manually fabricated nonwoven geotextiles produced from 3% NaOH-treated S2-grade abaca fibers as geo-envelopes. To this end, a customized sand tank with a removable perforated pipe attachment was fabricated to simulate in-situ waterlogged conditions. The geotextiles were first wrapped around the perforated pipe prior to gradually filling the tank with pre-saturated sand. A constant head of water was supplied, and hydraulic readings were obtained only after the piezometric water levels had stabilized. One, two, and three-layer abaca geo-envelope configurations and a one-layer commercial geo-envelope configuration were each tested five times. Experimental testing found that the three-layer abaca geo-envelope had the highest, statistically significant, average drainage intensity among the four configurations. Furthermore, the one-layer commercial geotextile performed roughly in line with the one-layer abaca geotextile. The results indicate that as the thickness of the abaca geo-envelope is increased, its water entrance resistance decreases and its effective radius increases, leading to increased drainage performance. Lastly, the abaca geotextile underwent scanning electron microscopy (SEM) before and after it had been used as a geo-envelope. SEM results revealed that although fine soil particles adhered to the fibrous surface, pore spaces remained visible. These findings highlight the material’s soil retention ability and clogging resistance. Overall, the study concludes that abaca fiber geotextiles are suitable for subsurface drainage systems.

1. Introduction

Waterlogging is a frequent issue in many agricultural areas worldwide. This condition occurs when the soil in the crop’s root zone is completely saturated with water, leaving no room for oxygen. The lack of oxygen reduces the roots’ hydraulic conductivity and biological nitrogen

fixation, thereby disrupting the plant's physiological processes [1]. Excessive rainfall, snowmelt, poor soil drainage, and high groundwater tables are some of the leading causes of waterlogging. Among these, rainfall has increased in both severity and frequency due to climate change. Naturally, this has exacerbated waterlogging, especially in tropical regions such as the Philippines [2]. A recent vulnerability assessment of farmlands in Agusan del Norte even concluded that climate change-induced flooding was the most critical agricultural hazard in that region [3].

To mitigate waterlogging, subsurface drainage systems consisting of perforated pipes wrapped with geotextiles and subsequently covered with filter material are commonly used. The pipes provide a path for water to exit the soil while the coarse-grained filter and geotextile work together to prevent clogging of the pipe's perforations [4]. However, most geotextiles are made from non-degradable polymers such as polyolefins or polyesters, which deposit microplastics into the soil, polluting it. As a result, significant effort has been devoted to research on bio-based geotextiles [5]. Abaca, in particular, which is abundant in the Philippines, has been found to be viable for this purpose due to its high tensile and flexural strength [6]. Although extensive literature exists on the reinforcement capabilities of bio-based geotextiles, there is limited research on their feasibility as geo-envelopes in subsurface drainage systems. This study aims to remedy this by manufacturing and evaluating the performance of an abaca-based geo-envelope.

2. Materials and Methods

2.1 Abaca fiber geotextile

To produce the non-woven geotextile, 30 kilograms of untreated, S2-grade spindle machine-stripped abaca fibers were purchased from a Philippine Fiber Industry Development Authority (PhilFIDA)-recommended retailer. After sun-drying, the fibers were cut to a uniform length of 25 cm and submerged in a 3% aqueous sodium hydroxide (NaOH) solution for 3 hours at room temperature. Additionally, the immersion had a fiber-to-solution mass ratio of 1:28. After treatment, the fibers were thoroughly rinsed with tap water until the runoff was clear, indicating removal of excess alkali. The fibers were again sun-dried and then combed on a carding board until smooth. The fibers were then cut into 5-10 cm lengths. The fiber preparation method was based on a previous study on abaca fiber-reinforced mortars [7].



Figure 1. Abaca geotextile production. From left to right: NaOH soaking, carding board combing, needle punching, and finished non-woven abaca fiber geotextile

Manual needle punching was used to turn the abaca fibers into a geotextile. The fibers were first placed between a double-layer steel screen, after which a needle board with felted needles was repeatedly passed through the fibers. The abaca fibers tangled with one another, resulting in the random distribution characteristic of nonwoven geotextiles. The textile manufacturing process was based on a previous study on nonwoven geotextiles produced from recycled fibers [8]. Images of the treatment and manufacturing process and the finished product are shown in Figure 1.

After production, the nonwoven abaca-based geotextile was sent to the Philippine Textile Research Institute of the Department of Science and Technology (DOST-PTRI) for testing. The results of the tests conducted are shown in Table 1 [9].

Table 1. Abaca geotextile properties

Property	Standard/Reference	Sample Size	Mean Value
Air permeability (K_a), $\text{cm}^3/\text{sec}/\text{cm}^2$	ASTM D737-18	10	456
Apparent opening size (AOS), μm	ASTM D4751-21a	5	1564
90% Opening size (O_{90}), μm			1509
Mass per unit area, g/m^2	ASTM D5261-10	10	675
Thickness (d_G), mm	ASTM D5199-12	10	11.65
Water permeability (k_G), cm/s	Blair et al. (1981)	-	7.54

The permeability of the geotextile in water is also shown in Table 1 and was calculated using Equation 1, a modified Darcy formulation proposed by Blair et al [9]. Where μ_{at} is the absolute viscosity of air at the test temperature, μ_{w20} and γ_{w20} are the absolute viscosity and unit weight of water at 20 °C, L is the thickness of the fabric, and ΔP is the applied pressure difference.

$$k_G = K_a \left(\frac{\mu_{at}}{\mu_{w2}} \right) \left(\frac{L\gamma_{w2}}{\Delta P} \right) \quad (1)$$

Additionally, the abaca-based geotextile was also compliant with both the anti-clogging criterion proposed by Dierickx [10] and the hydraulic criterion proposed by Vlotman et al [11]. However, it was suboptimal according to the retention criteria proposed by Stuyt et al [12]. The details of the criteria evaluation are shown in Table 2. Despite this, a recent study has claimed that the lower bound of the retention criteria may be overly conservative since filters that had an O_{90}/d_{90} ratio lower than 1 still effectively retained filter material and prevented clogging [13].

Table 2. Abaca geotextile performance criteria evaluation

Criteria	Recommended Range	Evaluation
Anti-clogging	$O_{90} > 0.20 \text{ mm}$	Optimal
Hydraulic	$k_G/k_S > 10$	Optimal
Retention	$1 \leq O_{90}/d_{90} \leq 5$	Suboptimal

2.2 Fine sand

Although high-plasticity, hydrophilic clays that are prone to swelling are the most susceptible to waterlogging, their extremely low permeability makes it difficult to observe drainage performance within a reasonable amount of time [14]. Furthermore, most subsurface drainage

systems utilize coarse-grained filter material in conjunction with drainpipes. Hence, the soil used for this study was sand, with the properties shown in Table 3.

Table 3. Fine sand properties

Property	Standard	Sample Size	Mean Value
Gravel, %			6.85
Sand, %			92.89
Fines, %			0.26
Effective Particle Size (D_{10}), mm			0.1979
Grain Size at 30% Finer (D_{30}), mm	ASTM D6913-17	3	0.3128
Grain Size at 60% Finer (D_{60}), mm			0.6181
Grain Size at 90% Finer (D_{90}), mm			3.5362
Coefficient of Uniformity (C_u)			3.1243
Coefficient of Curvature (C_c)			0.8003
Liquid Limit (LL), %	ASTM D4318-17	4	17
Plastic Limit (PL), %		2	NP
Specific Gravity of Soil Solids (G_s)	ASTM D854-23	3	2.67
Hydraulic Conductivity (k_s), cm/s	ASTM D2434-22	5	0.00415

The laboratory tests on the soil indicate that it is classified as Poorly Graded Sand (SP) according to the Unified Soil Classification System (USCS). Additionally, based on the criterion proposed by Vlotman et al., an envelope is still necessary for this specific soil [11].

2.3 Commercial geosynthetic

The commercial geotextile used was ordered through an online retailer. According to the manufacturer's data sheet, the nonwoven geosynthetic was manufactured from polyester and polypropylene, had a mass per unit area of 100 g/m², and a thickness of 0.9 mm. Aperture and hydraulic properties were unavailable, although the product is marketed to have excellent filtration and drainage performance. Since the commercial geotextile serves only as a comparative baseline, its exact specifications are assumed to meet all the previously stated geo-envelope criteria. Furthermore, back-calculation of its hydraulic properties only requires actual installation and discharge measurements.

2.4 Customized soil tank

A customized soil tank, patterned after one used in an earlier study on the effect of knitted-sock geotextile envelopes, was fabricated [13]. The tank measured 120 × 40 × 130 cm (L×W×H), and was made of stainless steel, painted with a metal primer to prevent corrosion. A 20-cm-diameter hole was made at the center of the tank, its center 35 cm from the bottom. Through this cutout, a 3-row regular-perforated pipe with perforation length and width of 2.08 and 0.16 cm, respectively, was installed. The drainpipe was epoxied to the tank at one end, and, at the other end, a removable cleanout valve was installed to allow drainage. An overflow pipe, to maintain a constant head, and a drain valve were also installed at the top and bottom of the tank, respectively. Piezometers were placed to measure the head of water above the soil ($M1$), at the interface between the geo-envelope and the soil ($M2$), and inside the corrugated pipe ($M3$). Figure 2 shows the relevant details of the soil tank.

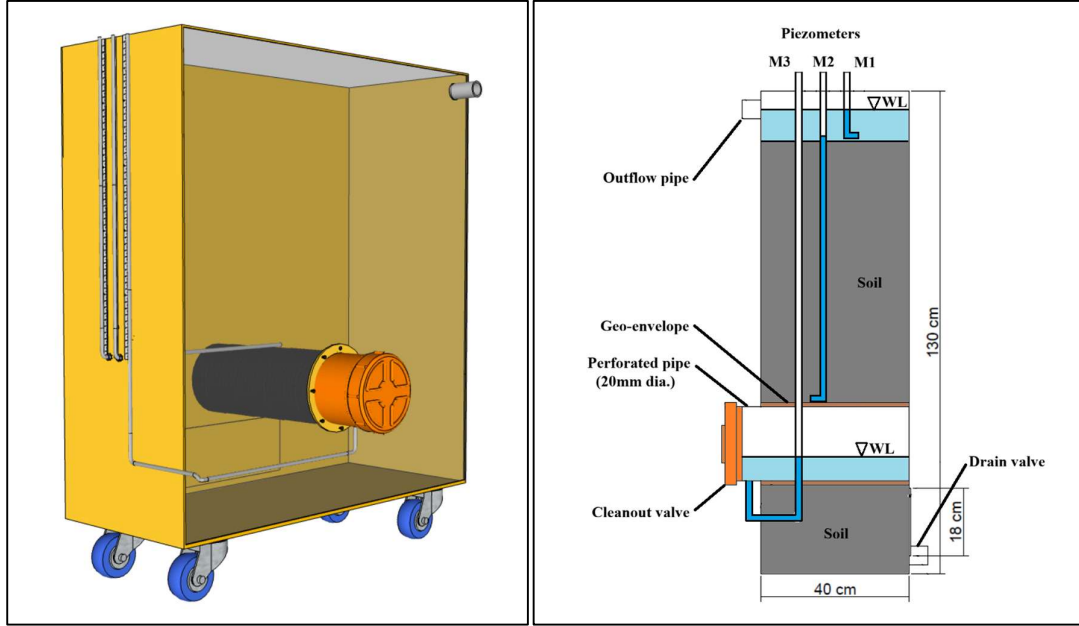


Figure 2. Customized soil tank. left: 3D render, right: side profile

2.5 Discharge measurement

The methodology for measuring drainage capacity was adopted from the study of Ghane et al [13]. Wet sand was placed in lifts of 10 cm or less. After each lift, the soil was lightly tamped, and a generous amount of water was sprayed with a hose to saturate it. This was repeated until a drain depth (D_d) of 75 cm was reached. The geo-envelope was also installed prior to filling the tank. In this study, four different geo-envelope configurations were investigated: one-layer, two-layer, and three-layer abaca geotextiles, and a one-layer commercial synthetic geotextile.

Once the desired soil level was reached, the cleanout valve was closed, and a continuous supply of water was provided at the top of the tank, sufficient to maintain a significant discharge from the outflow pipe. The setup was maintained for 24 hours to ensure complete soil saturation and to achieve steady-state conditions. This is indicated by the near-equality in the water levels of all three piezometers. Afterward, the cleanout valve was opened, allowing water to drain from the perforated pipe. Once the piezometric levels stabilized at their new levels, they were recorded, and discharge was measured by timing how long it took to fill a 1 L beaker with water. Five trials were performed for each geo-envelope configuration.

2.6 Drainage intensity

The efficiency of each geo-envelope configuration was measured by back-calculating its drainage intensity (DI), which is the rate of water removal when the midway water table between two pipes just touches the ground level [15]. The higher the value of DI of the system, the better its drainage efficiency is. First, the entrance head loss (h_e), in cm, for each measurement was calculated using Equation 2.

$$h_e = M2 - M3 \quad (2)$$

Next, the flow rate per unit length of the drainpipe (q_L), in cm^2/day was calculated via Equation 3, where Q is the measured drain flow rate, in cm^3/s , and L_p is the length of the perforated pipe, in cm.

$$q_L = \frac{Q}{L_p} \quad (3)$$

The water entrance resistance (W_e), in day/cm , and the dimensionless entrance resistance factor (α_e), were then calculated using Equations 4 [16] and Equation 5 [13], respectively. The value of k_s that was used in the following equations was converted to cm/h .

$$W_e = \frac{h_e}{q_L} \quad (4)$$

$$\alpha_e = 24 \times k_s W_e \quad (5)$$

After this, the effective radius of the perforated pipe (R_{ef}), in cm, which is the radius of an imaginary drainpipe with a completely open wall, was calculated from Equation 6 [17], where R_o represents the outer diameter of the perforated pipe, which was measured to be 10.95 cm.

$$R_{ef} = R_o e^{-2\pi\alpha_e} \quad (6)$$

Next, the equivalent depth (d_e), in cm, was calculated using Equation 7, a formulation derived by van der Molen and Wesseling [18]. Where S is the drain spacing, in cm, and $F(x)$ is a unitless constant which is a function of another unitless constant, x . $F(x)$ is calculated through Equation 8, with x itself being obtained from Equation 9. The values of S and d were assumed to be 1500 cm and 200 cm, respectively, in accordance with an earlier study by Ghane et al [13].

$$d_e = \frac{\pi S}{8 \left[\ln \left(\frac{S}{\pi R_{ef}} \right) + F(x) \right]} \quad (7)$$

$$F(x) = \frac{\pi^2}{4x} + \ln \left(\frac{x}{2\pi} \right) \quad (8)$$

$$x = \frac{2\pi}{S} \quad (9)$$

Finally, the actual drainage intensity (DI), in cm/day , was calculated through Equation 10. As mentioned, the drain depth (D_d) was equal to 75 cm.

$$DI = 24 \times \frac{8k_s d_e D_d + 4k_s D_d^2}{S^2} \quad (10)$$

2.7 Scanning electron microscopy (SEM)

In addition to recording discharge measurements, SEM testing was also conducted to qualitatively evaluate the extent of particle entrapment within the geo-envelope's nonwoven matrix. Two 1×1 cm specimens were extracted from the single-layer abaca configuration. One before it was attached to the perforated pipe, and another after soil embedment and discharge measurement. The samples were sent to the Ateneo de Davao University (AddU) chemistry department for SEM.

3. Results and Discussion

3.1 Calculated drainage intensities

The drainage intensities are calculated from discharge measurements using the fabricated soil tank. Figure 3 shows some actual images of the experimentation. It is worth noting that fluid flowed into the pipe only through the side and bottom perforations, similar to that observed in the earlier study by Ghane et al [13]. This was the case for all configurations tested.



Figure 3. Soil tank experimentation. From left to right: Soil saturation, discharge measurement, in-pipe fluid flow in one-layer abaca geo-envelope, geotextile extraction.

The measured flow rates for each trial of each geo-envelope configuration are presented in Table 4. The mean ($\bar{x}$), standard deviation (SD), and coefficient of variation (CV) for each group is also shown. It is worth noting that the CV for all four groups were well below 10%, indicating that the data collected had a high level of precision.

Table 4. Measured flow rates (cm^3/day)

Envelope	1-Layer Abaca	2-Layer Abaca	3-Layer Abaca	1-Layer Commercial
Trial 1	1.529E+07	1.238E+07	1.252E+07	1.382E+07
Trial 2	1.382E+07	1.344E+07	1.428E+07	1.430E+07
Trial 3	1.309E+07	1.305E+07	1.464E+07	1.249E+07
Trial 4	1.350E+07	1.335E+07	1.428E+07	1.317E+07
Trial 5	1.428E+07	1.319E+07	1.405E+07	1.389E+07
$\bar{x}$	1.400E+07	1.308E+07	1.396E+07	1.354E+07
SD	8.45E+05	4.21E+05	8.29E+05	7.14E+05
CV (%)	6.04	3.22	5.94	5.27

On the other hand, the entrance head losses (h_e) for each trial of each geo-envelope configuration are presented in Table 5. Consistent with the measured flow rates, the observed piezometric levels and, consequently, the calculated head losses during flow rate measurement were precise. From these, the drainage intensities (DI) for each trial of each geo-envelope configuration were then calculated and these are presented in Table 6. Since both flow rate and head loss data were precise, the drainage intensity was also highly precise. Interestingly, the 3-layer abaca geo-envelope exhibited the highest average DI , at 15.23 cm/day . Moreover, the single-layer abaca geo-envelope performed roughly at par with its commercial counterpart.

Table 5. Calculated head losses (cm)

Envelope	1-Layer Abaca	2-Layer Abaca	3-Layer Abaca	1-Layer Commercial
Trial 1	24.90	20.80	20.60	22.60
Trial 2	23.60	21.20	20.40	23.90
Trial 3	24.05	20.90	20.20	23.90
Trial 4	24.10	20.70	20.50	23.50
Trial 5	24.40	20.80	20.60	23.20
$\bar{x}$	24.21	20.88	20.46	23.42
SD	0.48	0.19	0.17	0.54
CV (%)	1.98	0.92	0.82	2.33

Table 6. Calculated drainage intensities (cm/day)

Envelope	1-Layer Abaca	2-Layer Abaca	3-Layer Abaca	1-Layer Commercial
Trial 1	15.193	15.182	15.190	15.192
Trial 2	15.176	15.204	15.236	15.184
Trial 3	15.148	15.199	15.247	15.132
Trial 4	15.159	15.210	15.235	15.160
Trial 5	15.176	15.204	15.228	15.184
$\bar{x}$	15.17	15.20	15.23	15.17
SD	0.02	0.01	0.02	0.02
CV (%)	0.11	0.07	0.15	0.16

Additionally, one-way, single-factor analysis of variance (ANOVA) was conducted on the drainage intensity data; the results of which are summarized in Table 7. Based on the results, a significant difference existed between the groups since the probability value (P) was less than the significance level (α) of 0.05. Hence, a post-hoc analysis was also performed. Since there were 4 groups, the Bonferroni-adjusted significance level adopted was 0.00833. The results of the two-sample t-test for each pair, using the new significance level, are summarized in Table 8. Two pairs had significant differences: 1-layer abaca vs. 3-layer abaca, and 3-layer abaca vs. 1-layer commercial geo-envelopes. The results indicate that the drainage performance of the 3-layer abaca geotextile was statistically superior to that of the others, save for the 2-layer configuration. It can also be concluded that the commercial geotextile performed roughly in line with the single-layer and the double-layer abaca geo-envelope configurations.

Table 7. One-way single factor analysis of variance

Source of Variation	SS	df	MS	F	P-value	F-crit
Between groups	0.01116	3	0.00372	9.85020	0.00064	3.23887
Within groups	0.00604	16	0.00038			
Total	0.01720	19				

Table 8. Post-hoc analysis (Pairwise Bonferroni-corrected t-Test)

Group 1	Group 2			
	1-Layer Abaca	2-Layer Abaca	3-Layer Abaca	1-Layer Commercial
1-Layer Abaca		0.01466	0.00197	0.98181
2-Layer Abaca			0.04739	0.05729
3-Layer Abaca				0.00493
1-Layer Commercial				

3.2 SEM Results

The SEM images in Figure 4 show that the abaca fiber geotextile effectively impeded the migration of sandy and fine soils into the drainpipe. This was most clearly shown in the third image, wherein soil particles can be seen adhering to the surface of the fibers. Additionally, even with suspended particles present, void spaces were still visible within the nonwoven matrix, suggesting the fabric's continued drainage potential.

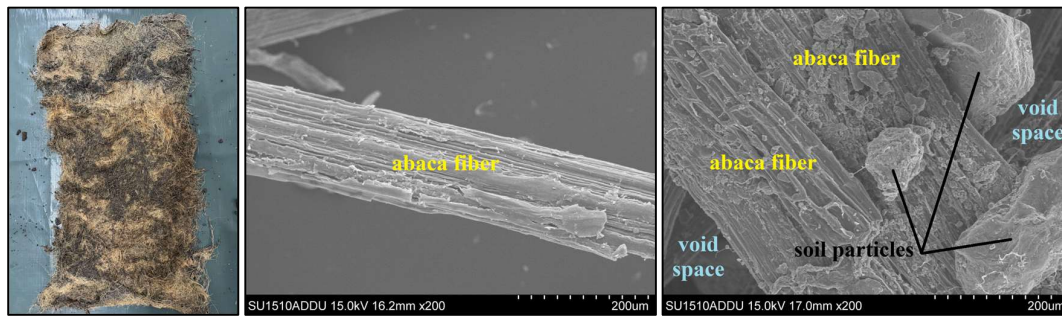


Figure 4. From left to right: abaca geotextile after soil tank testing, SEM (200x magnification) image before soil tank testing, and SEM (200x magnification) image after soil tank testing

4. Conclusions and Recommendations

Overall, the study highlighted the potential of abaca-based nonwoven geotextiles as sustainable geo-envelopes for subsurface drainage systems. It was found that the single-layer abaca geo-envelope's drainage performance was in line with that of their commercial, synthetic counterparts. Most notably, the calculated drainage intensity of the 3-layer abaca geo-envelope was even 0.3% higher than that of the single-layer commercial option. In addition, qualitative microscopic analysis suggested that the sustainable alternative effectively prevented clogging while maintaining ample pore space for water to flow.

It is therefore recommended that future research on sustainable geo-envelopes be focused on one or more of the following: long-term durability and performance, fabrication process optimization, and scaling and automation. Since the study spanned a relatively short period, the fabric's continued efficiency was not evaluated; therefore, long-term data are needed. Moreover, the abaca geotextile was fabricated by hand, which may not have been optimal for the microstructure of the fabric, introducing a potential room for improvement. Finally, since the study yielded promising results for abaca-based, nonwoven geo-envelopes, mass, automated production may also be a future research area.

References

- [1] Yang R, Wang C, Yang Y, Harrison M T, Zhou M and Liu K 2024 Implications of soil waterlogging for crop quality: A meta-analysis *European Journal of Agronomy* **161**
- [2] Manik S M N, Pengilley G, Dean G, Field B, Shabala S and Zhou M 2019 Soil and crop management practices to minimize the impact of waterlogging on crop productivity *Front. Plant Sci.* **10**
- [3] Varela R P, Apdohan A and Balanay R 2022 Climate resilient agriculture and enhancing food production: Field experience from Agusan del Norte, Caraga Region, Philippines *Front. Sustain. Food Syst.*
- [4] Wang X, Zhang Y, Fan L and Shen J 2024 Salt Drainage Efficiency and Anti-Clogging Effects of Subsurface Pipes Wrapped with Geotextiles *Water (Switzerland)* **16**
- [5] Prambauer M, Wendeler C, Weitzenböck J and Burgstaller C 2019 Biodegradable geotextiles – An overview of existing and potential materials *Geotextiles and Geomembranes* **47** 48–59
- [6] Motaleb K Z M A, Ahad A, Laureckiene G and Milasius R 2021 Innovative banana fiber nonwoven reinforced polymer composites: Pre-and post-treatment effects on physical and mechanical properties *Polymers (Basel)*. **13**
- [7] Alcivar-Bastidas S, Petroche D M, Cornejo M H and Martinez-Echevarria M J 2024 Effect of aging process on mechanical performance of reinforced mortar with NaOH abaca fibers *Case Studies in Construction Materials* **20**
- [8] Tan W, Fu F, Wang F F, Li Y, Wang P and Zhang D 2022 The mechanical and ultraviolet aging properties of needle-punched nonwoven geotextiles made with recycled fibers *Journal of Industrial Textiles* **51** 8668S-8689S
- [9] Blair J C, Bell J R and Hicks R G 1981 Permeability Testing of Geotextiles *Transportation Research Record: Journal of the Transportation Research Board* 1–6
- [10] Dierickx W 1987 Nature of Synthetic Envelope Materials in Subsurface Drainage *Geotextiles and Geomembranes* **5** 141–51
- [11] Vlotman W F, Smedema L K and Rycroft D W 2020 *Modern Land Drainage* (CRC Press)
- [12] Stuyt L C P M, Dierickx W and Beltrán J M 2005 *Materials for subsurface land drainage systems Materials for subsurface land drainage systems* (FAO)
- [13] Ghane E, Dialameh B, AbdalAal Y and Ghane M 2022 Knitted-sock geotextile envelopes increase drain inflow in subsurface drainage systems *Agric. Water Manag.* **274**
- [14] Islam M N, Bell R W, Barrett-Lennard E G and Maniruzzaman M 2022 Shallow surface and subsurface drains alleviate waterlogging and salinity in a clay-textured soil and improve the yield of sunflower in the Ganges Delta *Agron. Sustain. Dev.*
- [15] Ghane E and Askar M H 2021 Predicting the effect of drain depth on profitability and hydrology of subsurface drainage systems across the eastern USA *Agric. Water Manag.* **258**
- [16] Dierickx W 1993 Research and developments in selecting subsurface drainage materials *Irrigation and Drainage Systems* **6** 291–310
- [17] Dierickx W 1999 Non-Ideal Drains *Agricultural Drainage*
- [18] Van Der Molen W H and Wesseling J 1991 A solution in closed form and a series solution to replace the tables for the thickness of the equivalent layer in Hooghoudt's drain spacing formula *Agric. Water Manag.* **19** 1–16