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The Influence of Woven Geotextiles on Ponding Time and Overland Flow

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Abstract

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Nowadays, both synthetic and natural geotextiles are used to mitigate water erosion processes on hillslopes. Jute and coir are most suitable materials for the production of woven geotextiles. They are used for a variety of purposes – from natural fibre composite building materials to a soil protective agent. They were tested under laboratory conditions, without soil. This enabled us to focus on the reaction of the woven geotextiles to simulated rainfall. ECC 700 (coir), ECC 400 (coir), and ECJ 500 (jute) were tested. The Norton Ladder Rainfall Simulator was selected for spraying. Each simulated rainfall event lasted 15 min. An artificial hillslope with a gradient of 7.2 degrees was used. Jute absorbed water more effectively than both types of coir, and ECC 400 was more effective than ECC 700. The measured values were entered into the KINFIL hydrological model, which confirmed a positive impact of jute on delaying the ponding time and on reducing the total discharge. In practice, it can be suggested that jute prevents drying of the soil better than coir, and thus promotes better vegetation growth. The results also demonstrated that jute material is suitable for erosion control of hillslope surface for a short time (the time of the grass cover reinforcement), because it has good adhesion and reduces the total overland flow in an effective manner.

Keywords: hillslope; jute and coir materials; KINFIL hydrological model; Norton Ladder Rainfall Simulator

Of the present-day world environmental problems, only that of the rapid population growth is greater than soil erosion (Lang 2006). The most common type of erosion is water erosion, which makes hillsides unstable and also causes other geomorphological processes in the landscape. These processes affect mainly urban development (Rickson 1988) and also arable land, because there are many areas that lack the necessary vegetation cover to prevent erosion. For example, soil is without vegetation during landscaping, when houses, roads, and highways are being built, and when other construction work is being done in cities. Developers want rapid grassing and reforestation of these new areas to prevent soil erosion. Scientists are interested in various erosion control measures (Xu *et al*. 2006; Kovář *et al*. 2011; Prasuhn 2012). One of the fastest ways to protect soil and accelerate vegetation growth is by using geosynthetics. These materials have therefore become popular market leaders in this branch.

Two main groups of geosynthetics (ČSN EN ISO 10318-1:2015) are in frequent use in the Czech Republic: biodegradable (natural), and non-biodegradable (synthetic). The ČSN EN ISO 10318-1:2015 standard subdivides geosynthetics into the following product categories: geotextiles, geogrids, geonets, geomats, geocells, geostrips, geomembranes, and geocomposites. This issue is also regulated by other Czech standards, such as ČSN EN ISO 9862:2005, ČSN P ISO/TS 13434:2010, and ČSN EN 13252/A1:2015. Biodegradable and non-biodegradable geosynthetics are used for various purposes, e.g. for stabilizing river beds (Oberhagemann & Hossain 2011), or as a grassed waterway to stabilize a thalweg (Kašpar 2011;

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Rameš 2011). In addition, bags made of these geosynthetics are used to stabilize coastal areas against the waves of large lakes, dams, and seas (Yu *et al.* 2005; Saathoff *et al.* 2007; Corbella & Stretch 2012). In the landscape, biodegradable materials are encountered more often than non-biodegradable materials because of their advantages, such as adhesion to the ground and their limited lifetime (Langford & Coleman 1996; Sutherland & Ziegler 1996). Biodegradable materials also have a positive impact on the natural vegetation cover (Álvarez-Mozos *et al.* 2014), and are able to better conserve the soil against erosion caused by rainfall (surface sealing by kinetic energy) than non-biodegradable materials (Fohrer *et al.* 1999).

This study set out to investigate woven geotextiles made of coir and of jute. Although the geotextiles tested here are manufactured by very similar sewing methods, it was predicted that each selected material would have a different influence on ponding time and on overland flow. It could also be assumed that jute fibres absorb water better than coir.

MATERIAL AND METHODS

All laboratory experiments were performed in a laboratory of the Faculty of Environmental Sciences, Czech University of Life Sciences Prague. They were carried out using the Norton Ladder Rainfall Simulator, which was developed by Dr. D. Norton in USDA, Agricultural Research Service, National Soil Erosion Research Laboratory, West Lafayette, USA. The basic unit of the simulator was an aluminium frame 5 m in length, 0.76 m in width, and 0.25 m in depth. The frame included four VeeJet 80100 nozzles (Advanced Design and Machine, West Lafayette, USA), with an output of 14.75 l/min and pressure of 0.41 MPa. They were spaced 1.37 m apart, and performed an oscillatory motion around a horizontal axis. For this reason, the system supplied uniform rainfall over the surface. The height of the nozzles over a soil erosion trough was 2.4 m. The water jet was flat, parallel to the lengthways axis of the simulator (Figure 1). The nozzles formed artificial raindrops 2.3 mm in diameter, each raindrop having the same kinetic energy (Meyer & McCune 1958). The rain intensity of 23 mm/h was controlled by the frequency of the oscillatory motion. A computer was used for the overall setup (Meyer & Harmon 1979; Neibling *et al.* 1981). The measurements of the runoff out of the erosion trough were carried out by a mechanical tipping flow meter (device type, producer, town country). The number of tippings was recorded electronically.

A soil erosion trough with a gradient of 7.2 degrees and an experimental surface 1.05 m in width, 4.9 m in length, and 0.2 m in depth was chosen. It was covered by woven geotextiles of different mass per unit area. The specific weight was 700 g/m^2 (coir), 400 g/m^2 (coir), and 500 g/m^2 (jute). The combination of weight and material produced acronyms representing each of the geotextiles: ECC 700, ECC 400, and ECJ 500 (the numbers represented the weight per unit area, and the letters stood for the type of material). The size of the mesh was: ECC 700 – 7 × 11 mm, ECC 400 – 20 × 25 mm, and ECJ 500 – 10 × 30 mm (JUTA 2013).

Only the natural geotextiles were under investigation. It was therefore necessary to install them on an impervious surface. Polyethylene foil (PE foil), which served simultaneously as a control sample, was used for this purpose. This arrangement was made in order to ensure that the same infiltration conditions were set during all experiments. All the rainwater flowed away from the PE foil. This meant that the simulated rainfall was equal to the total runoff from the foil.

In order to maintain the same conditions for each test, each geotextile was sprayed with a 15-min rainfall 23 mm/h in intensity before the first test. This first simulation was not measured. Then there was a 30-min break, which was followed by subsequent 15-min simulations with an intensity of 23 mm/h. These were measured (the time by a stopwatch, and the discharges by a tipping flow metre). This method was used for all woven geotextiles. Thirteen measurements were performed for each type. A total of fifty-two measurements were made.

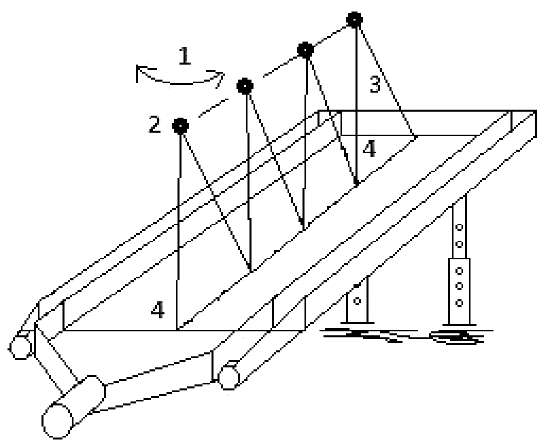

Figure 1. The scheme of rainfall simulation (1 – oscillation; 2 – nozzles; 3 – flat water jet; 4 – soil erosion trough)

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Table 1. Differences between the woven geotextiles tested and the control sample

	Ponding time				Overland flow			
	Control	ECC 700	ECC 400	ECJ 500	Control	ECC 700	ECC 400	ECJ 500
Control	–	19.512#	19.539#	19.588#	–	16.780#	19.637#	19.581#
ECC 700	**9.999×10^{-6}**	–	18.881#	18.927#	**4.198×10^{-5}**	–	16.768#	19.164#
ECC 400	**9.855×10^{-6}**	**1.391×10^{-5}**	–	16.597#	**9.363×10^{-6}**	**4.225×10^{-5}**	–	13.596#
ECJ 500	**9.607×10^{-6}**	**1.358×10^{-5}**	**4.622×10^{-5}**	–	**9.642×10^{-6}**	**1.199×10^{-5}**	**2.266×10^{-4}**	–

#Kruskal-Wallis chi-squared; *P*-values (significant at $P < 0.05$) in bold

A statistical analysis of the data was performed in R 3.2.1 software (https://www.r-project.org/). The normality test results showed that most of the observed indicators did not have a normal distribution. A nonparametric Kruskal-Wallis (KW) test was therefore selected to detect whether there were any significant differences between individual variables in ponding time and overland flow. In cases when the null hypothesis was rejected, a post-hoc test was used to show the differences between the tested pairs.

The following null hypotheses were tested:

(a) The type of woven geotextile has no influence on ponding time (H_0: $P \geq \alpha$; $\alpha = 0.05$).

(b) The type of woven geotextile has no influence on the amount of total overland flow (H_0: $P \geq \alpha$; $\alpha = 0.05$).

Afterwards, the data were entered into the KINFIL rainfall-runoff model (Kovář 1992). The suitability of this model for use has been proved several times (Kovář & Hrádek 1994; Kořínek & Kovář 2013). The KINFIL model has been described by Kovář and Vaššová (2011). The KINFIL model results were always values of effective rain and of discharges within a specific time unit. KINFIL was used to clarify our conclusions about ponding time and overland flow.

RESULTS

The results present positive effects of natural geotextiles on ponding time (KW: $\chi^2 = 47.538$, df = 3, $P = 2.67 \times 10^{-10}$) and also on the amount of overland flow (KW: $\chi^2 = 45.477$, df = 3, $P = 7.327 \times 10^{-10}$). Both tested variables evinced better results for jute than for both coir materials, but between the coirs, ECC 400 performed better than ECC 700 (Table 1). Table 2 summarizes the descriptive statistical parameters, in

Table 2. Values of statistical parameters

	N	Mean	Median	SD	SE	95% confidence interval for mean		Min	Max
						lower bound	upper bound		
Ponding time (s)									
PE Foil	13	9.615	10.000	0.506	0.140	9.309	9.921	9.000	10.000
ECC 700	13	68.615	69.000	3.228	0.895	66.664	70.566	61.000	72.000
ECC 400	13	77.692	78.000	1.974	0.548	76.499	78.885	74.000	80.000
ECJ 500	13	82.308	83.000	2.016	0.559	81.090	83.526	80.000	85.000
Total	52	59.558	73.000	29.611	4.106	51.314	67.802	9.000	85.000
Overland flow (l/s)									
PE Foil	13	0.0315	0.0317	0.0003	0.0001	0.0314	0.0317	0.0312	0.0318
ECC 700	13	0.0303	0.0299	0.0006	0.0002	0.0300	0.0307	0.0293	0.0312
ECC 400	13	0.0287	0.0287	0.0007	0.0002	0.0283	0.0291	0.0275	0.0299
ECJ 500	13	0.0270	0.0268	0.0010	0.0003	0.0264	0.0276	0.0257	0.0287
Total	52	0.0294	0.0296	0.0019	0.0003	0.0289	0.0299	0.0257	0.0318

SD – standard deviation; SE – standard error

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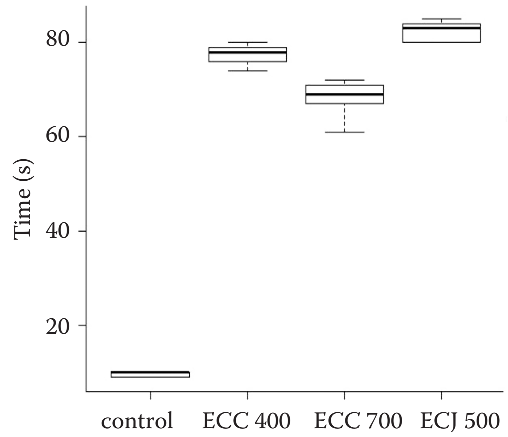

Figure 2. Boxplots of ponding time of different geotextiles

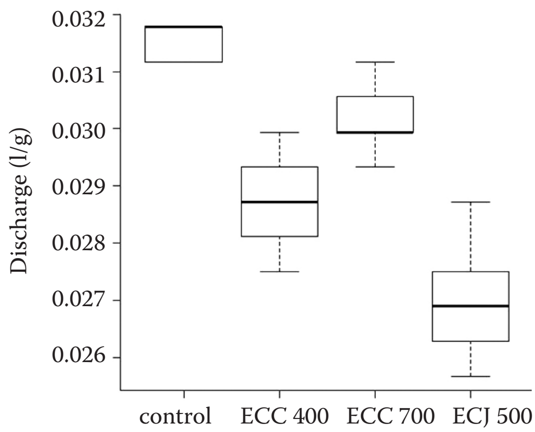

Figure 3. Boxplots of overland flow of different geotextiles

which jute (ECJ 500) has higher values for ponding time and lower values for overland flow than the tested geotextiles made of coir (ECC 700, ECC 400).

Figure 2 shows that the ponding time was highest for ECJ 500 and lowest for ECC 700. The amount of overland flow was influenced only by the woven geotextile, and not by the PE foil. The results are shown in Figure 3. More water was absorbed by jute fibres than by coir, and the discharge values for jute were the lowest. ECC 700 absorbed the least water. In some cases, its discharge reached the values for the control sample (PE foil). In this case, the rainfall was equal to the total runoff. The discharges for ECC 400 lay between the values for ECJ 500 and ECC 700.

The effect of jute and coir on overland flow and on ponding time could be deduced from the simulation results provided by the KINFIL model. Figure 4 presents the KINFIL hydrographs for both tested materials. The simulations showed that the beginning of overland flow could be slowed down to a greater extent by jute than by coir. The difference was less than 2 min for the conditions of our experiment.

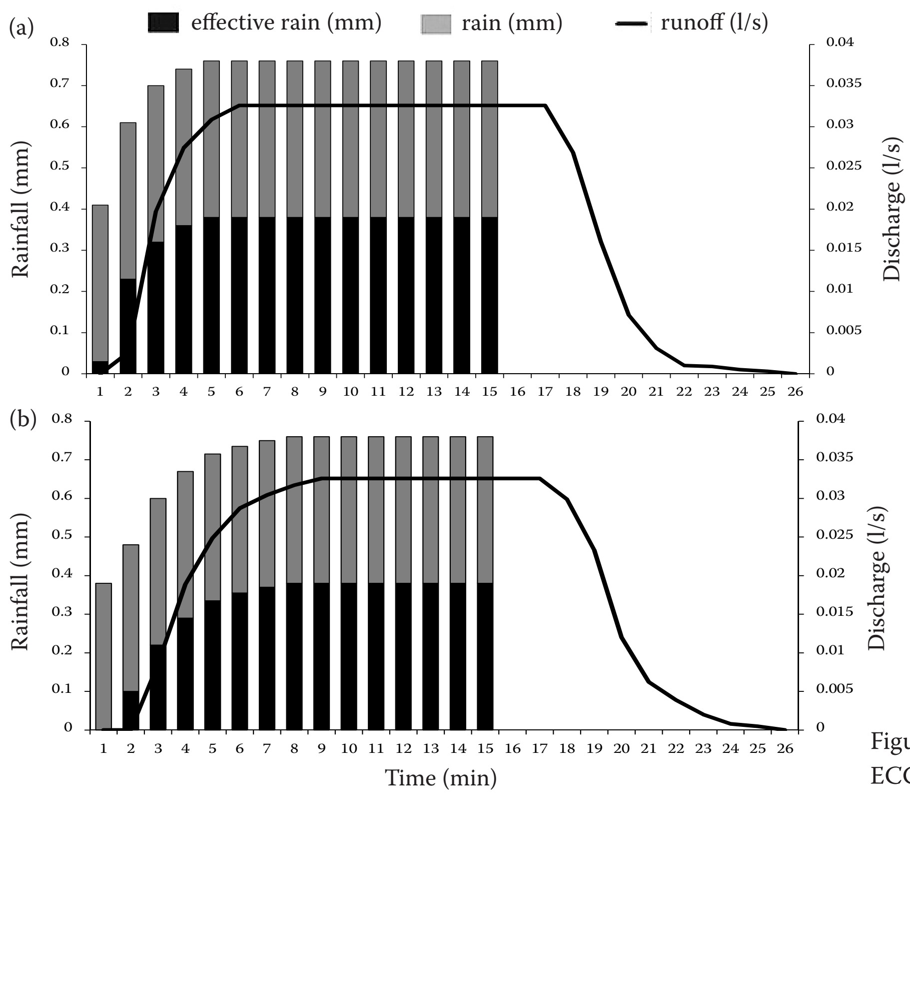

Figure 4. Hydrograph of geotextiles ECC 700 (a) and ECJ 500 (b)

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The course of the discharge curve also supported this claim. For example, the discharge curve for ECJ 500 was slower, both at the beginning and at the end, than the curve for ECC 700.

DISCUSSION

All tested woven geotextiles absorbed water better than the PE foil, and were able to adapt easily to underlying soil surfaces (Bhatia *et al*. 2010). ECC 700 had the worst ponding time and overland flow values, and was not able to reduce the overland flow. The values for ECC 400 and for ECC 700 were similar to each other, but they were both inferior to the values for ECJ 500. The differences between these geotextiles were caused mainly by the absorptiveness of the material.

The absorptiveness of the jute fibre was very good, as has been confirmed by Mitchell *et al*. (2003). Coir absorbs water less well than jute, but its fibre is strong and has a longer lifespan (Morgan & Rickson 1995; Lekha 2004). Jute fibre is softer, and lacks resistance to pressure, tension, and biodegradation (Defoirdt *et al*. 2010). However, for the purposes of ponding time, jute was able to delay the onset of overland flow by about 1.5 min in this simulation.

The mesh of ECC 400 was the largest in size, so it contained the least material. If the results were influenced only by the size of the mesh and by the amount of material, ECC 400 would be the worst for all parameters. However, this was not the case. For example, it could be caused by the quality of coir yarn (quality of fibres or sewing methods). Another reason could be the use of a large amount of batching oil, which reduces wetting ability of materials. We conclude that the difference was caused not by the size of the mesh, but by the different type of material (jute/coir).

The KINFIL model confirmed the suitability of jute for our purposes, as it reduced the impact of rainfall on the surface. It reduced not only the effective rainfall, but also the total discharge.

In our study, no soil was used. We first wanted to test the woven geotextiles, and to see how they react to rainfall. Future research will be conducted under natural conditions and will focus on the direct interaction between geotextiles and soil erosion caused by rainfall.

CONCLUSION

This paper has demonstrated the impact of ECC 400, ECC 700, and ECJ 500 woven geotextiles on ponding time and on overland flow without the influence of soil. The differences between the values of the observed parameters were statistically significant. The woven geotextile itself was able to absorb water, and it thereby influenced the ponding time and the overland flow. Jute reacted to rainfall better than coir. This fact was observed in all measured characteristics. On the basis of an analysis of other variables in the KINFIL model it can be stated that jute increased the ponding time and delayed the onset of overland flow significantly in comparison with coir. The results presented here lead to the recommendation that, for the parameters considered in our study, it is more suitable to use jute to increase ponding time and delay overland flow on hillslopes.

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References

Álvarez-Mozos J., Abad E., Goñi M., Giménez R., Campo M.A., Díez J., Casalí J., Arive M., Diego I. (2014): Evaluation of erosion control geotextiles on steep slopes. Part 2: Influence on the establishment and growth of vegetation. Catena, 121: 195–203.

Bhatia S., Rao G., Smith J. (2010): International Practices and Guidance: Natural-Fibre Rolled Erosion Control Products. Scour and Erosion, San Francisco: 231–240.

Corbella S., Stretch D.D. (2012): Geotextile sand filled containers as coastal defence: South African experience. Geotextiles and Geomembranes, 35: 120–130.

Defoirdt N., Biswas S., De Vriese L., Tran L.Q.N., Van Acker J., Ahsan Q., Gorbatikh L., Van Vuure A.W., Verpoest I. (2010): Assessment of the tensile properties of coir, bamboo and jute fibre. Composites Part A: Applied Science and Manufacturing, 41: 588–595.

Fohrer N., Berkenhagen J., Hecker J.M., Rudolf A. (1999): Changing soil and surface conditions during rainfall: Single rainstorm/subsequent rainstorms. Catena, 37: 355–375.

JUTA (2013): JUTENON EC – Technical Data. Dvůr Králové nad Labem, JUTA, a.s. (in Czech)

Kašpar M. (2011): Types of geotextiles and their function in building structures. Magazín GEOmail, GEOMAT. Available at: http://www.geomat.cz/chci-vedet-vic/dokumenty-ke-stazeni/ (accessed May 2014). (in Czech)

Kořínek J., Kovář P. (2013): Evaluation of the hydraulic parameters of the KINFIL model for surface runoff modelling, case study Třebsín. Vodní hospodářství, 63: 231–234.

doi: 10.17221/4/2016-SWR

Kovář P. (1992): Possibilities of design floods assessment using model KINFIL. Journal of Hydrology and Hydromechanics, 40: 197–220.

Kovář P., Hrádek F. (1994): Design flood determination on small catchments using the KINFIL model. In: Seuna P., Gustard A., Arnell N.W., Cole G.A. (eds): FRIEND: Flow Regimes from International Experimental and Network Data. IAHS Publication No. 221, Wallingford, IHAS: 307–313.

Kovář P., Vaššová D. (2011): The KINFIL Model Manual. Prague, CULS. (in Czech)

Kovář P., Vaššová D., Hrabalíková M. (2011): Mitigation of surface runoff and erosion impacts on catchment by stone hedgerows. Soil and Water Research, 6: 153–164.

Lang S.S. (2006): Slow, insidious soil erosion threatens human health and welfare as well as the environment, Cornell study asserts. Chronicle online, Cornell University. Available at: http://www.news.cornell.edu/stories/march06/soil.erosion.threat.ssl.html (accessed Jan 2015).

Langford R.L., Coleman M.J. (1996): Biodegradable erosion control blankets prove effective on Iowa wildlife refuge. In: Proc. 17th Int. Conf. Erosion Control Association, Seattle, Feb 27–Mar 1, 1996: 13–20.

Lekha K.R. (2004): Field instrumentation and monitoring of soil erosion in coir geotextile stabilised slopes – A case study. Geotextiles and Geomembranes, 22: 399–413.

Meyer L.D., McCune D.L. (1958): Rainfall simulator for runoff plots. Agricultural Engineering, 39: 644–648.

Meyer L.D., Harmon W.C. (1979): Multiple-intensity rainfall simulator for erosion research on row sideslopes. Transactions of the ASAE, 22: 0100–0103.

Mitchell D.J., Barton A.P., Fullen M.A., Hocking T.J., Zhi W.B., Yi Z. (2003): Field studies of the effects of jute geotextiles on runoff and erosion in Shropshire, UK. Soil Use and Management, 19: 182–184.

Morgan R.P.C., Rickson R.J. (1995): Slope Stabilization and Erosion Control: A Bioengineering Approach. Cranfield, E&FN Spon.

Neibling W.H., Foster Q.R., Nattermann R.A., Nowling J.D., Holbert P.V. (1981): Laboratory and field testing of a programmable plot size rainfall simulator. In: Erosion and Sediment Transport Measurement, Proceedings of the Florence Symposium, June 22–26, 1981. IAHS Publication No. 133, Wallingford, IHAS: 405–414.

Oberhagemann K., Hossain M. (2011): Geotextile bag revetments for large rivers in Bangladesh. Geotextiles and Geomembranes, 29: 402–414.

Prasuhn V. (2012): On-farm Effects of Tillage and Crops on Soil Erosion Measured over 10 Years in Switzerland. Zurich, Research Station Agroscope Reckenholz-Tänikon ART.

Rameš M. (2011): Ecotextiles as a natural solution for protecting surfaces against weeds and erosion. Magazín GEOmail, GEOMAT. Available at: http://www.geomat.cz/chci-vedet-vic/dokumenty-ke-stazeni/ (accessed May 2014). (in Czech)

Rickson R.J. (1988): The use of geotextiles in soil erosion control: comparison of performance on two soils. In: Rimwanich S. (ed.): Proc.5th Int. Soil Conservation Conf. Land Conservation for Future Generations, Bangkok, Jan 18–29, 1988: 961–970.

Saathoff F., Oumeraci H., Restall S. (2007): Australian and German experiences on the use of geotextile containers. Geotextiles and Geomembranes, 25: 251–263.

Sutherland R.A., Ziegler A.D. (1996): Geotextile effectiveness in reducing interrill runoff and sediment flux. In: Proc. 17th Int. Conf. Erosion Control Association, Seattle, Feb 27–Mar 1, 1996: 393–406.

Xu X., Zhang K., Kong Y., Chen J., Ju B. (2006): Effectiveness of Erosion Control Measures along the Qinghai–Tibet Highway, Tibetan Plateau, China. Transportation Research Part D: Transport and Environment, 11: 302–309.

Yu Y., Zhang B., Zhang J.M. (2005): Action mechanism of geotextile-reinforced cushion under breakwater on soft ground. Ocean Engineering, 32: 1679–1708.

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