The effectiveness of jute and coir erosion control blankets in different field and laboratory conditions

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Abstract. A vegetation cover is found to be an ideal solution to most problems with erosion on steep slopes. Biodegradable geotextiles (GTX) have been proved to provide a sufficient protection against soil loss in the period before the vegetation reaches maturity. In this study, 500 g.m^{-2} jute (*J500*), 400 g.m^{-2} (*C400*), and 700 g.m^{-2} coir (*C700*) GTX were installed firstly on 9° slope in "no-infiltration" laboratory conditions, secondly on 27° slope in natural field conditions. The impact of GTX on runoff and soil loss was investigated to compare the performance of GTX in different conditions. Laboratory runoff ratio (percentage portion of control plot) equaled 78 %, 83 % and 91 % and peak discharge ratio equaled 83 %, 91 % and 97 % for *J500*, *C700* and *C400*, respectively. In the field, a runoff ratio of 31 %, 62 % and 79 % and peak discharge ratio of 37 %, 74 % and 87 % were recorded for *C700*, *J500* and *C400*, respectively. All tested GTX significantly decreased soil erosion. The highest soil loss reduction in the field was observed for *J500* (by 99.4%) followed by *C700* (by 97.9%) and *C400* (by 93.8%). Irrespective of slope gradient or experiment condition, *C400* provided lower runoff volume and peak discharge control than *J500* and *C700*. The performance ranking of *J500* and *C700* in the laboratory differed from the field, which may be explained by different slope gradient and also by the role of soil, which was not included in the laboratory experiment.

Key words: Soil loss, Steep slope, Runoff, Biological geotextiles, Rainfall simulator

1 Introduction

Land degradation causes high erosion rates as a consequence of agriculture, grazing, mining, forest fires or deforestation and this causes an economic, social and environmental damage (Cerdà, 1998, Cerdà et al., 2010, Erkossa et al., 2015, Keesstra et al., 2014, Lieskovský and Kenderessy, 2014, Moreno-Ramón et al., 2014, Stanchi et al., 2015). However, the largest erosion rates and the most degraded soils are usually found in areas affected by developments, infrastructures or urbanization (Cerdà, 2007, Pereira et al., 2015, Sadeghi et al., 2015, Seutloali and Beckedahl, 2015, Yuan et al., 2015).

Civil engineering projects often result in steep slopes with bare soil, which is highly vulnerable to soil erosion, caused either by impact energy of the rain drops or by surface runoff (Weggel and Rustom, 1992). Well-established, low-growing, dense vegetation cover is able to control soil loss by two or three orders of magnitude compared to bare soil condition (Keesstra et al., 2016, Ola et al., 2015, Rickson, 2006). The highest reduction of erosive runoff was recorded on permanently grassed plots (Álvarez-Mozos et al., 2014). However, the establishment of vegetation cover can be disrupted during early plant growth stages, leaving the slopes exposed to further erosion processes with negative consequences for slope stability (Rickson, 1988). Soils play a pivotal role in major global biogeochemical cycles (carbon, nutrient and water), while hosting the largest diversity of organisms on land. Because of this, soils deliver fundamental ecosystem services, and management to change a soil process in support of one ecosystem service can either provide co-benefits to other services or can result in trade-offs. Therefore, the need of protecting the soil is nonnegligible (Berendse et al., 2015, Brevik et al., 2012, Decock et al., 2015, Keesstra et al., 2012, Smith et al., 2015). This is the reason why there is a trend in the research to protect the soil with mulches, amendments and other erosion control measures (Álvarez-Mozos et al., 2014, Hu et al., 2015, Hueso-Gonzáles et al., 2014, Keesstra et al., 2016, Prosdocimi et al., 2016, Yazdanpanah et al., 201).

Biological/biodegradable geotextiles (GTX), made out of jute, coir, rice, straw etc., have often been proved to be an effective, sustainable and eco-friendly alternative to synthetic erosion control materials used for preventing soil erosion and subsequent slope degradation processes in the period before vegetation reaches maturity (Fullen et al., 2007, Khan and Binoy, 2012, Langford and Coleman, 1996, Morgan and Rickson, 1995, Ogbobe et al, 1998, Sutherland and Ziegler, 2007, etc.). The range of GTX is wide. Based on the ratio of GTX' cost versus effectiveness, the choice of an individual product occurs to be most convenient.

Many case studies evaluating the effect of jute and coir GTX on slopes have been carried out across the world, but the reported effectiveness of GTX varies (Giménez-Morera et al., 2010) (see Table 1). Therefore, the results cannot be generalized (Cantón et al., 2011, Rickson, 2005). Furthermore, because of various site conditions, it is difficult to determine the extent to which the soil loss reduction was caused by GTX themselves and not by other factors (vegetation cover etc.) (Fifield, 1992, Toy and Hardley, 1987).

This paper presents a study, in which the effectiveness of three jute and coir fibre rolled erosion control systems (see Table 2), that are commercially available and widely applied world-wide, was tested under both laboratory and field conditions. No product with dense coverage (non-woven) was included, as it is not as effective in reducing runoff (Luo et al., 2013) and can produce even more runoff than bare soil (Davies et al., 2006, Mitchell et al., 2003).

Unlike in other previous laboratory studies, the impact of GTX was examined on "no-soil" subgrade, to omit one of the most variable factors affecting soil erosion – soil itself (Smets et al., 2011) – and to assess the effectiveness based on nothing but GTX' properties. Due to the infiltration process, soil supports the erosion control effect of GTX providing less water for overland flow (Beven, 2011). Assuming that soil would affect all GTX equally in the field, the laboratory records of surface runoff volume (L) and peak discharges ($L.s^{-1}$) reduction should proportionally match the data from field experiments. Concerning the shear stress of overland flow, the character of surface runoff volume and velocity reduction in the laboratory should reflect soil loss reduction in the field as well (Harmon and Doe, 2001, Morgan and Rickson, 1995, Thompson, 2001).

The objective of this experiment was to test the impact of biodegradable erosion control GTX on surface runoff on a slope exposed to simulated rainfall under laboratory and field conditions; to rank the effectiveness of GTX in runoff reduction; to compare the runoff data trends under laboratory conditions (where soil subgrade and infiltration process were excluded) with data trends under different field conditions (including soil subgrade and different slope gradient).

2 Materials and methods

2.1 Laboratory experiment

Laboratory experiments were conducted in the rainfall simulation laboratory at the Czech University of Life Sciences Prague, using a Norton ladder-type rainfall simulator. Rainfall simulations are being used since the 30's by scientists to study soil erosion by water and soil hydrology. They are one of the most used and most successful tools used in different disciplines, such as agronomy, hydrology and geomorphology (Cerdà, 1998, Martínez-Murillo et al., 2013, Rodrigo Comino et al., 2015, 2016, Iserloh et al., 2013a, 2013b). In this study, the Norton simulator uses four Veejet 80100 nozzles, with water pressure of 0.04 MPa, height of 1.9 m and target area of 4.9 m × 1.05 m. The main rainfall characteristics are given in Table 3. A slope gradient of 9° was used for the experiment. An impermeable plastic film spread over the test bed was used as a control. The tested GTX were then laid onto the plastic film to simulate no-infiltration conditions during the simulation (see Fig. 1). All treatments were exposed to rainfall of 1.75 $mm.min^{-1}$ intensity and 15 min duration. Ten rainfall simulations were carried out on each treatment (control, *J500*, *C400*, *C700*). To provide constant starting conditions, a 15-minute rainfall of 1.75 $mm.min^{-1}$ intensity was applied before each simulation. In a rainfall event, runoff initiation time t_i [s] was recorded, runoff was collected by a mechanical toggle flow-meter with electronic recording of time for each toggle and total runoff volume at time = 15 min R_{15} [L] and peak discharge Q [$L.s^{-1}$] was measured. An outline of laboratory experiments is given in Table 4.

2.2 Field experiment

The field simulations were carried out on the south slope of the Rokycany–Pilsen rail corridor near the village of Klabava (49°44'56.938"N, 13°32'17.887"E) in the Pilsen Region, Czech Republic. According to Quitt's classification, Klabava falls into a moderately warm region with mean annual air temperature 8°C and mean annual precipitation 550 mm (Tolasz, 2007). The experimental slope was formed by a 1:2 (27°) cut. The stabilized unmade ground was covered by a gravelly loamy soil layer of 0.3 m thickness, 1.40 $g.cm^{-3}$ bulk density and 47 % porosity. A particle size analysis was performed, using hydrometer method (SIST-TS CEN ISO/TS, 17892-4:2004, 2004). The soil texture was classified using the system of the United States Department of Agriculture. The tested soil was classified as gravelly loam (24 % clay, 40 % silt, 36 % sand). Percentage of gravel (> 2 mm) was 26 %. Estimated organic matter content of soil was 3.5 %. The loss-on-ignition method (heated destruction of all organic matter) was used for the calculation of the organic matter content in the soil (ASTM, 2000, Schumacher, 2002, Nelson and Sommers, 1982).

Four rectangular plots (one control and three for the GTX treatments), each covering an area of 1.8 m × 8.5 m, were outlined by iron barriers on each side and a triangular collecting trough at the bottom (see Fig. 2), afterwards erosion control nets were installed. A bare soil plot was used as control.

The rainfall was simulated by 4 FullJet nozzles, with water pressure of 0.03 MPa and height 2.4 m above the plots. Rainfall application did not differ significantly among treatments (a=0.05). Three replications of each treatment were carried out at overall mean intensity of 1.33 ± 2 $mm.min^{-1}$. (a 10-year return period at the study site). To provide constant starting conditions, a 15-minute rainfall of 1.33 $mm.min^{-1}$ intensity was applied before each simulation. For an outline of field experiment see Table 4.

For operational reasons, it was necessary to spread the simulations over a period of two days. The measurements were therefore carried out under slightly different moisture conditions. The control treatment was measured on the first day with initial volumetric soil moisture content being 20.7 %. The geotextile treatments were measured the following day with initial volumetric soil moisture content being 13.1 % (an average value of nine records – three for each plot; the individual values did not differ significantly). The volumetric soil moisture content was determined using the gravimetric method (e.g. Kutílek and Nielsen, 1994) from undisturbed soil samples (100 cm^3) that were collected in the top soil. In the rainfall event, runoff initiation time t_i [s] was recorded, runoff was collected by a mechanical toggle flow meter with electronic recording of time for each toggle and the total runoff volume [L] and discharge [$L.s^{-1}$] were measured. After the rainfall event, sediment concentration [$g.L^{-1}$] of the runoff was determined by oven-drying five collected runoff samples at 105°C for 48 h and subsequent weighing of the samples, and sediment load (soil loss SL) [g] was calculated by multiplying the mean sediment concentration by total runoff volume.

2.3 Data analysis

All analyses were performed using Excel 2010 and R Statistical Software. One-way analysis of means was used to test whether the differences in laboratory values of time to runoff initiation t_i [s], runoff [L] at time t=15 min (R_{15}) and peak discharge Q [$L.s^{-1}$] are caused by sampling variation, at significance level 0.05. Welch Two Sample t-test, not assuming equal variances, was used to compare mean values of t_i, R_{15} and Q for each treatment. The null hypothesis was defined as follows: The true difference in means is equal to zero.

In order to compare runoff (and soil loss) rates from field and laboratory plots, runoff ratios RR_{15} (Eq. 1), peak discharge ratios QR (Eq. 2) and soil loss ratios SLR (Eq. 3) were calculated and expressed as a portion of control [%]:

$$RR_{15} = \frac{R_{15\,geotextile}}{R_{15\,control}} \times 100\ , \tag{1}$$

$$QR = \frac{Q_{geotextile}}{Q_{control}} \times 100\ , \tag{2}$$

$$SLR = \frac{SL_{geotextile}}{SL_{control}} \times 100\ , \tag{3}$$

Ratios were calculated from mean values of variables.

3 Results

Statistical description of results of peak discharge Q ($L.s^{-1}$) is shown in Table 5. Runoff R_{15} data were analysed analogically.

Mean time to runoff initiation of the simulated rainfall in the laboratory was 16.3 s (standard deviation $\sigma = 0.46$ s) for control, 21.3 s ($\sigma = 0.46$ s) for *J500*, 21.1 s ($\sigma = 1.30$ s) for *C400* and 25.8 s ($\sigma = 1.54$ s) for *C700*. The results of a one-way analysis of mean values of runoff t_i (F = 28.484, num df = 2.000, denom df = 14.076, p-value = 1.127×10^{-5}, equal variance of datasets are not assumed) indicate that the differences in mean values of measured geotextile samples are not caused by sampling variation, at significance level 0.05. The null hypothesis "The true difference in means of time to runoff initiation is equal to zero" was rejected (by Welch Two Sample t-test, not assuming equal variances) for all comparisons except *C700* vs *C400* at significance level 0.05 (see Table 7).

Mean runoff R_{15} in the laboratory was 130.9 L ($\sigma = 0.30$ L) for control, 102.2 L ($\sigma = 5.21$ L) for *J500*, 118.6 L ($\sigma = 1.43$ L) for *C400* and 109.0 L ($\sigma = 1.79$ L) for *C700*. The results of a one-way analysis of mean values of runoff R_{15} (F = 100.414, num df = 2.000, denom df = 16. 201, p-value = 7.432×10^{-10}, equal variance of datasets are not assumed) indicate that the differences in mean values of measured geotextile samples are not caused by sampling variation, at significance level 0.05. The null hypothesis "The true difference in means of runoff is equal to zero" was rejected for all comparisons (see Table 7).

The results of a one-way analysis of mean values of peak discharge *Q* (F = 52.051, num df = 2.000, denom df = 13.494, p-value = 4.53×10^{-7}, equal variance of datasets are not assumed) indicate that the differences in mean values of measured geotextile samples are not caused by sampling variation, at significance level 0.05. The null hypothesis "The true difference in means of peak discharge is equal to zero" was rejected for all comparisons (see Table 7).

In short, all GTX samples significantly delayed the runoff initiation in comparison with control. Jute *J500* was proved to be significantly more effective than both coir GTX. No statistically significant difference in time to runoff initiation was found between coir GTX *C400* and *C700*. Mean values of runoff and discharge are significantly different for all tested GTX. All GTX significantly reduced runoff and peak discharge with jute net *J500* being the most effective under laboratory conditions. The results of the rainfall simulation experiments in the laboratory are shown in Fig. 3 and Fig. 4.

Mean time to runoff initiation of the simulated rainfall in the field was 295 s (792 s, 50 s and 44 s for first, second and third rainfall event) for control, 120 s (-, 120 s, 120 s) for *J500*, 268 s (-, 280 s, 255 s) for *C400* and 325 s (-, 405 s, 245 s) for *C700*. For *J500*, *C400* and *C700* no runoff was produced during the first rainfall event.

In general, control plots tended to produce highest runoff volume (L) and discharge (L.s-1). Concerning the time of runoff initiation, runoff was most quickly produced at the control plot, followed by coir *C400*, jute *J500* and coir *C700* in the laboratory. In the field, *J500* treated plots produced runoff faster than *C700*.

The order control – *C400* – *J500* – *C700* matches the impact of GTX on runoff volume and discharge for the first rainfall event in the laboratory. For next replications, an obviously decreasing trend of R_{15} and *Q* for *J500* was recorded, showing jute GTX to be the most effective. Other GTX seemed to provide slightly increasing trends (Fig. 3, 4).

Table 6 shows a comparison of runoff (RR_{15}) and peak discharge (QR) ratios for both laboratory and field conditions. In the laboratory, the greatest decrease in RR_{15} was recorded by the *J500* jute net (RR_{15} = 78 %) in comparison with control (100 %). The order of effectiveness of each treatment in the laboratory was identical for both runoff volume and peak discharge: 1. *J500*, 2. *C700* and 3. *C400*.

Different effectiveness ranking was observed in the field. The highest reductions of runoff volume and peak discharge were observed for coir *C700* (RR_{15} = 31 %, QR = 37 %) followed by jute *J500* (RR_{15} = 62 %, QR = 74 %).

Results of soil loss ratio from the field experiment are also given in Table 6. All GTX provided a great reduction of soil loss with jute *J500* being the most effective followed by coir *C700* and *C400*.

4 Discussion

4. 1 Time to runoff initiation

In general, control plots (bare soil/impermeable plastic film without GTX) have a significantly faster response to rainfall than GTX-treated plots (also reported by Cerdà et al., 2009). The performance of GTX seems to be highly influenced by the infiltration rate as the surface runoff was initiated after less than 30 s on impermeable subgrade (laboratory experiment) and after two-six minutes on soil (field experiment). The very short time to runoff initiation means that any thunderstorm will contribute to runoff and soil loss on sloping bare soil (Cerdà et al., 2009). The high bulk density of the soil (1.40 $g.cm^{-3}$) (frequently present on slopes created during civil engineering projects) can be the explanation for the fast runoff initiation, and the large runoff volumes and sediment available are due to raindrop impact on bare soils (Cerdà and Jurgensen, 2008).

The results of laboratory-based rainfall simulations indicated that the GTX significantly delayed the time to runoff initiation. Similar results were obtained by Shao et al. (2014) or Sutherland and Ziegler (2007). According to mean values, *C700* performed better than *J500*. When studying the results of individual replications, *J500* reached the peak discharge earlier than *C700*, but the discharge values remain lower than for *C700*. Time of runoff initiation was longer for *C700*, but higher peak discharge values were observed. Better performance of jute *J500* compared to both coir GTX was probably caused by lower water absorbing capacity and lower flexibility of coir GTX, due to which the GTX did not lay directly on the subgrade, allowing water to flow over a smoother surface under GTX. Same observation was previously reported also by Rickson (2006). In the literature, significant differences between GTX-covered and control (bare soil) plots were both confirmed (Sutherland and Ziegler, 2007) and not proved (Rickson, 2000). Possible explanation could be the different infiltration capacity of used soil subgrade. Rickson (2000) used more permeable sandy loam, while Sutherland et Ziegler (2007) used clay (see Table 1), therefore it seems that the smoother and less permeable the subgrade, the higher is the delay in the GTX' effect, as the low infiltration capacity of subgrade provides higher volume of surface runoff.

4. 2 Runoff volume reduction

Results of laboratory simulations showed a significant decrease in runoff volume [L] from GTX-treated plots. Similar results were reached by Khan and Binoy (2012), Shao et al. (2014) or Sutherland and Ziegler, 2007 (see Table 1). On contrary, some studies (both field and laboratory) concluded, that GTX increase the runoff volume (Álvarez.Mozos et al., 2014, Giménez-Morera et al., 2010, Kertézs et al., 2007). The increase might be caused by a dense cover of GTX (Mitchel et al., 2003) or high slope gradient when water can flow through the GTX fibers without infiltration into the soil (Álvarez-Mozos et al., 2014). In this study, the runoff control effect of GTX was supported by the infiltration process leading to higher runoff reduction in the field in comparison to laboratory, despite higher slope gradient (27°).

Authors presumed, that due to the infiltration process, soil would support the erosion control effect of GTX providing less water for overland flow (Beven, 2011). Assuming that soil would affect all GTX equally in the field, the laboratory records of surface runoff volume (L) and peak discharges ($L.s^{-1}$) reduction should proportionally match the data from field experiments. However, the GTX effectiveness ranking in the laboratory significantly differed from the field data. In the laboratory the runoff ratios of 78 %, 83 % and 91 % were recorded for jute J500, coir C700 and coir C400, respectively. In the field, the runoff ratios were the following: 62 %, 31 % and 79 % for the same order of GTX (see Table 6). Coir GTX C700 performed significantly higher runoff reduction than jute J500 in the field. The same result were reported by Álvares-Mozos et al. (2014) from a 60° slope, while on 45° slope jute performed better than coir. If more replications were carried out in the field, a different trend possibly might be found, because a decreasing trend of runoff volume is obvious for jute *J500* under laboratory "no-soil" conditions, while coir *C700* shows an increasing trend (see Fig. 3). Similar behaviour was observed in the field, where the runoff ratio of 66 % and 59 % (first and second replication) was observed for *J500* and 24 % and 38 % for *C700*. More replications in the field would prove whether the decreasing trend for jute and increasing trend for coir would continue in the field alike during the laboratory experiment.

Higher runoff reduction of *C700* might also be explained by its slightly higher loop size in comparison with *J500* (see Table 2). In theory, *C700* might provide more space for rainfall water to fall directly to the soil surface and then infiltrate, which would lead to lower surface runoff volume. While on jute-treated plot the rainfall water was initially absorbed by the fibers and then brought down through them due to gravity.

4. 3 Soil loss reduction

According to laboratory test, jute *J500* seemed to have the highest impact on peak discharge and runoff velocity. Therefore, lower shear stress might be assumed for jute *J500* (Thompson, 2001) than for coir GTX which would lead to lower erosion rate in the field. This was confirmed both in the field experiment of this study and in the work of Rickson (2000, 2006). All GTX significantly reduced soil loss (see Table 6). Despite much higher runoff volume of jute-treated plot, SLR equaled to 0.6 % for jute *J500*, followed by coir *C700* with SLR = 2.1 %. The performance of jute and coir *C700* may be considered to be comparable as the little difference might have been caused by soil loss measurement error.

Álvarez-Mozos et al. (2014) reported similar behaviour of jute and coir GTX. In their study, jute performed better runoff reduction but higher soil loss than coir on 45° slope. On 60° slope the situation was reversed, jute showed worse runoff reduction but better erosion control than coir. Authors explain this by the theory that on gentle or moderate slopes, biological GTX might absorb rainfall water and slow runoff generation, whereas on steep slopes water can slip through the geotextile fibers and create superficial flow paths without infiltrating into the soil. This factor seems to be more crucial for jute than coir due to its higher water absorbing capacity (Gosh, 2014). In this study, the runoff control effect of GTX varied under different slope gradients even when lower values (9° and 27°) were used. It is interesting that differences in performance were recorded for slope ranges which do not overlap (9° vs 27°and 45° vs 60°). A threshold value of slope gradient, at which GTX' behaviour changes, needs to be established. Potentially, if the field and laboratory experiments were both carried out on slope gradient either below or above this threshold, the match between datasets would be reached.

The rigidity of GTX fibers may play an important role too, as the smoother structure of jute GTX probably provides better condition for water flow through fibers in comparison with the tougher coir fibers.

Furthermore, the contact between GTX and soil plays a very important role (Midha and Suresh Kumar, 2013). It seems to decrease as the slope gradient and GTX material rigidity increases (Chen et al., 2011, Midha and Suresh Kumar, 2013). This may apply also for this study – jute probably absorbed more rainfall water into its fibers and thanks to gravity this water was brought down through the fibers, causing almost no erosion. In spite of being provided by the same supplier, coir *C700* was visually observed to have slightly higher cover in the field (manufacturing variability). This might lead to higher retention of rainfall water, but because of lower contact with the soil due to its rigidity, the erosion rate of plot with coir was higher than for jute. Other explanation might be that due to the structure of fibers, water flows slower through coir than through jute. Additionally, coir fibers create higher obstacles for overland flow due to is larger diameter and also the clogging of spaces among fibers. Therefore, at coir *C700* plot the water runoff was lower but the sediment content was higher Further investigation of the interactions between eroded soil particles and GTX fibers during rainfall events would be valuable to test this theory. According to this experiment, it seems that slope gradient is not the only factor determining GTX performance. Soil characteristics and GTX-soil interface need to be considered along with the slope gradient.

The field experiment was carried out on a steeper slope (27°) than the laboratory experiment (9°). Authors proceeded to compare these two datasets because, according to some studies, GTX effectiveness increases with the slope gradient (Morgan et al. 2005). This fact was partly confirmed by Álvarez-Mozos et al. (2014), who examined the impact of GTX on runoff volume and soil loss on 45° and 60° slope. On 45° slope the soil loss was reduced by 69 % and 90 % by jute and coir, respectively. On 60° slope, the reduction was 60 % for jute and 56 % for coir. Again, different behaviour (performance ranking) was recorded with changing slope which makes the need of finding slope gradient threshold values beyond which the performance of GTX changes. In this study it is not possible to determine whether the soil erosion control performance increased in the field as "no-soil" conditions were used in the laboratory. Furthermore, without any other field records from lower slope gradient and same soil conditions to be compared with, it would be highly complicated to separate erosion control effect of GTX from the impact of soil infiltration on soil loss in the field. Also lower rainfall intensity applied in the field for operational reasons, might slightly modify the results. But for a pilot research on whether the performance ranking of GTX is the same in the field and in the laboratory, this deviation might be acceptable. For further research more consistent conditions definitely would be required, but the data presented here can shed more light on the behaviour of GTX under different site conditions.

5 Conclusion

Jute and coir geotextiles tested in this study can significantly delay the initiation of surface runoff under the simulated rainfall, when compared to control plots (bare soil in the field, impermeable plastic film in the laboratory) without GTX. Control plots tended to produce significantly higher runoff volume [L], discharge [L.s-1] and soil loss [g.] than GTX-treated plots.

In the laboratory, jute *J500* showed increasing trend of runoff control, unlike coir GTX, the performance of which gradually decreased. Further investigation is needed to prove whether this behavior appears also in the field.

Regardless the conditions (slope, laboratory vs field), coir *C400* showed to be less effective than jute *J500* and *C700*. The runoff control performance of jute *J500* and coir *C700* significantly differed between the "no-soil" laboratory and field conditions, but all GTX provided a great reduction of soil loss with jute *J500* being the most effective followed by coir *C700* and *C400*. The theory that soil would influence the performance of all GTX equally (same effectiveness ranking in the laboratory as in the field) was not confirmed, which makes the need of finding slope gradient threshold values beyond which the performance of GTX changes. Influence of the slope gradient and soil-GTX contact on runoff and soil loss reduction still need to be investigated in detail. Another experimental testing of GTX effectiveness using different slope gradient and soil subgrade is suggested by authors.

6 Author contribution

J. Kalibová designed the experiments and carried them out together with J. Petrů. L. Jačka performed laboratory and statistical analyses. J Kalibová prepared the manuscript with contributions from all co-authors.

7 Data availability

The data are publicly accessible.

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Table 1

Overview of studies investigating the impact of *J500* jute (500 g.m^{-2}) and *C400*, *C700* coir (400 g.m^{-2}; 700 g.m^{-2}) geotextiles on surface runoff and soil erosion by water since 2000[*].

Author	GTX type	Soil type (sand - silt - clay; %)	Slope [°]	Simulated rainfall intensity [mm h^{-1}]	control sample cover type	runoff reduction [% of control]	Soil loss reduction [% of control]	Lab./ Field [L/F]
Álvarez-Mozos et al. (2014)	*J500*	silty clay loam (13.8 - 53.9 - 32.3)	45°	max. 31.2	hydroseeded soil	**266**	31	F
	J500	silty clay loam (13.8 - 53.9 - 32.3)	60°	max. 31.3	hydroseeded soil	**238**	40	F
Shao et al. (2014)	*J500*	mixed substrate	40°	50	bare substrate	37.9	0.3	L
Khan et Binoy (2012)	*J500*	sandy	33°	122	bare soil	83	10	L
Jakab et al. (2012)	*J500*	silty loam (23 - 70 - 7)	8.5°	max. 38.7	bare soil	47, 74, **119**	20	F
Kertész et al. (2007)	*J500*	silty loam	11°	max. 83	bare soil	30 - **250**	7 - **306**	F
Sutherland and Ziegler (2007)	*C700*	clay (24 - 34 - 42)	5.5°	35	bare soil	84	0.4	F
	C400	clay (24 - 34 - 42)	5.5°	35	bare soil	90	8	F
Rickson (2006)	*J500*	sandy loam	10°	72	bare soil	**102**	15	L
	C700	sandy loam	10°	72	bare soil	**106**	51	L
Sutherland and Ziegler (2006)	*J500,* *C700*	clay-dominated oxisol	5.5°	35, 114	bare soil	91 **- 104**	17	F
Lekha (2004)	*C700*	sandy loam	26°	NA[**]	seeded bare soil	NA[**]	0.4 - 21.9	F
Mitchel et al. (2003)	*J500*	loamy sand	15°	NA[**]	bare soil	35	1	F
Rickson (2000)	*J500*	sandy loam	10°	35	bare soil	90	14	L
	C700	sandy loam	10°	35	bare soil	97	25	L
	J500	sandy loam (68.1 - 22.1 - 9.8)	10°	95	bare soil	90	23	L
	C700	sandy loam (68.1 - 22.1 - 9.8)	10°	95	bare soil	102	23	L

[*] For studies carried out before the year 2000, see the papers of Bhattacharyya et al. (2010) or Ingold and Thompson (1986).

[**] NA = not available

Table 2

Main characteristics of three tested biological GTX.

Treatment	1 - Jute net	2 - Coir net	3 - Coir net
Marking	*J500*	*C400*	*C700*
Material	100% jute fiber	100% coir fiber	100% coir fiber
Description	open weave biodegradable jute geotextile in a grid structure	open weave biodegradable coir geotextile in a grid structure	open weave biodegradable jute geotextile in a grid structure
Mass per area (g.m^{-2})	500	400	700
Mesh size (mm × mm)	15 × 15	35 × 35	20 × 20
Thickness (mm)	2	7	8
Open area (%)	60	65	50
Working life (years)	1 - 2	3 - 4	3 - 7
Average price (EUR/m^2)*	0.61 – 0.96	0.89 – 1.29	1.29 – 2.09

* Data obtained from several GTX suppliers.

Table 3

Main laboratory rainfall characteristics measures by Laser Precipitation Monitor.

Mean intensity I [mm.h^{-1}]	Time-specific kinetic energy KE_R [J.m^{-2}.h^{-1}]	Volume-specific kinetic energy KE [J .m^{-2}.mm^{-1}]	Median volumetric drop diameter d_{50} [mm]	Christiansen Uniformity CU [%]
105	1269	12	0.44	79

Table 4

An outline of laboratory and field experiments testing the impact of biological GTX on surface runoff and soil loss.

	Laboratory experiments	Field experiments
Substrate type	impermeable plastic film	gravelly loam
Slope (°)	9	27
Rainfall intensity (mm.h^{-1})	105	80
Experiment duration (min)	15	15
Cover type	*J500, C400, C700*	*J500, C400, C700*
Control cover	impermeable plastic film	bare gravelly loam
Replications	10	3
Total number of experiments	40	12

Table 5

Statistical description of peak discharge for 500 g.m^{-2} jute net (*J500*), 400 g.m^{-2} coir net (*C400*), and 700 g.m^{-2} coir net (*C700*); laboratory experiments.

Parameters	Units	Control	*J500*	*C400*	*C700*
Arithmetic mean	L.s^{-1}	0.151	0.126	0.146	0.137
Standard deviation	L.s^{-1}	0.0005	0.0076	0.0025	0.0015
Median	L.s^{-1}	0.151	0.126	0.145	0.138
Minimum	L.s^{-1}	0.150	0.117	0.143	0.135
Maximum	L.s^{-1}	0.150	0.140	0.150	0.139
Range	L.s^{-1}	0.001	0.023	0.007	0.004
Coefficient of variation	%	0.004	0.058	0.017	0.011
Cl mean 0.95*	L.s^{-1}	0.0004	0.0056	0.0019	0.0011

*The confidence interval of the mean calculated at the 0.95 significance level.

Table 6

Mean runoff ratios RR_{15} [%], peak discharge ratios QR [%] and soil loss SLR [%] ratios of jute 500 g.m^{-2} (*J500*), coir 400 g.m^{-2} (*C400*) and coir 700 g.m^{-2} (*C700*) GTX, compared to control treatments under field and laboratory conditions.

	mean runoff ratio RR_{15} [%]				mean peak discharge ratio QR [%]				mean soil loss ratio SLR [%]			
	control	*J500*	*C400*	*C700*	control	*J500*	*C400*	*C700*	control	*J500*	*C400*	*C700*
lab.	100	78	91	83	100	83	97	91	100	-	-	-
field	100	62	79	31	100	74	87	37	100	0.6	6.2	2.1

Table 7
Parameters (*t-value*, degree of freedom *df* and *p-value*) of the Welch Two Sample t-test; significance level 0.05.

	runoff t_i			runoff R_{15}			peak discharge Q		
	t-value	*df*	*p-value*	*t-value*	*df*	*p-value*	*t-value*	*df*	*p-value*
control×J500	-16.53	10.42	8.18×10^{-9}	16.49	9.06	4.57×10^{-8}	9.98	8.08	8.00×10^{-6}
control×C400	-10.45	11.20	4.07×10^{-7}	25.28	9.79	3.02×10^{-10}	5.85	8.74	2.72×10^{-4}
control×C700	-23.15	18.00	7.63×10^{-15}	36.22	9.51	1.65×10^{-11}	26.10	10.07	1.40×10^{-10}
J500×C700	7.64	10.42	1.38×10^{-5}	-3.70	11.09	0.0034	-4.37	8.64	0.002
J500×C400	6.49	17.17	5.31×10^{-6}	-9.11	10.34	2.93×10^{-6}	-7.57	9.80	2.15×10^{-5}
C700×C400	-0.44	11.20	**0.672**	-7.57	9.80	2.15×10^{-5}	9.01	13.01	5.90×10^{-7}

Figure 1

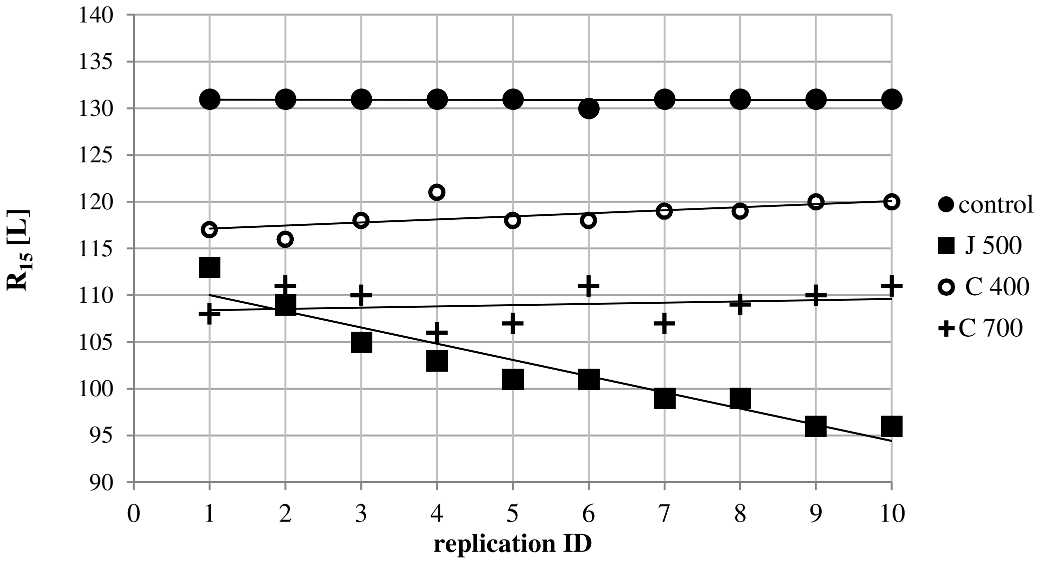
Norton Ladder Rainfall Simulator above test beds with mechanical toggle flow metres. *C400* coir erosion control net spread in the test bed**.**

Figure 2

Experimental slope in the field (Rokycany, Czech Republic). Rainfall simulation on bare soil (control sample) in progress. Note: the iron collecting trough at the bottom of the plot is hidden below the eroded material as the figure was taken during the rainfall simulation.

Figure 3

Surface runoff volume at time = 15 minutes, R_{15} (L); linear trend-lines included; laboratory conditions. For the data see supplementary Table S1.



Colour version:

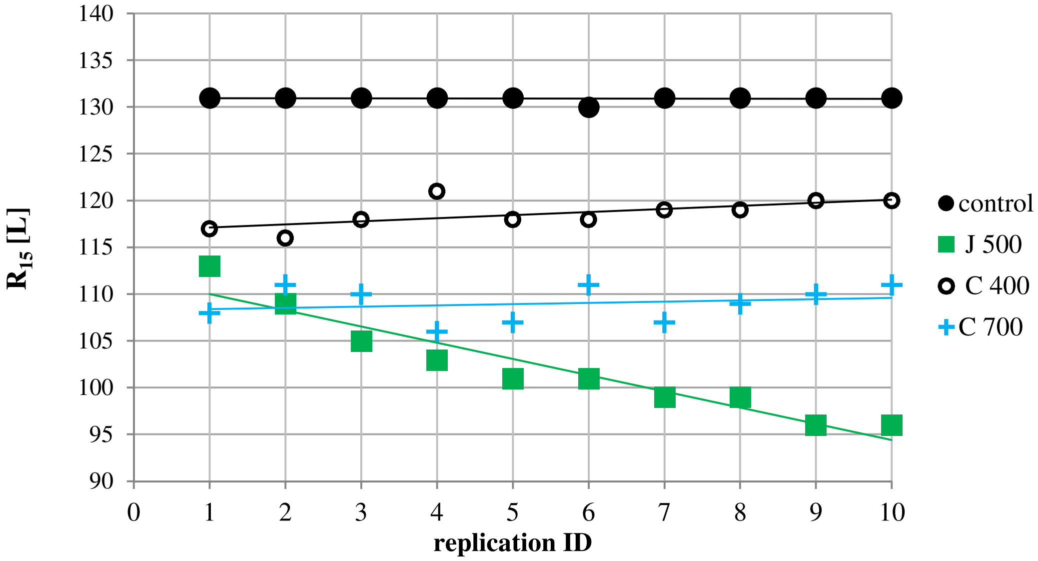
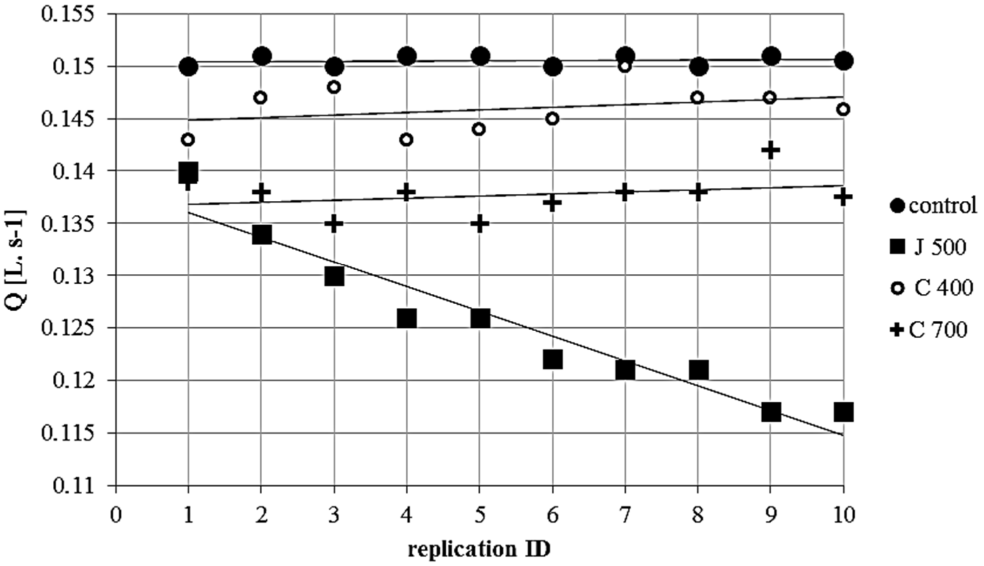


Figure 4
Peak discharge at outlet section, Q (L.s-1); linear trend-lines included; laboratory conditions. For the data see supplementary Table S2.



Colour version: