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1 **ACCEPTED**

2 **Effects of plant traits and their divergence on runoff and sediment**
3 **retention in herbaceous vegetation**

4
5
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13
14
15 **Key-words**

16 Aboveground functional traits; Plant-soil-runoff interactions; Sediment transport; Sediment
17 trapping and deposition; Soil erosion control

18
19
20 **Abstract**

21 Aims

22 Plant species diversity impacts ecosystem processes, but its effects on runoff and soil erosion
23 are not fully understood. Herbaceous vegetation control concentrated runoff and soil erosion
24 through the increase of hydraulic roughness which leads to sediment retention. This study aims

25 to investigate the effect of aboveground traits and their divergence (i.e., stem diameter and
26 density, and leaf area and density) on hydraulic roughness and sediment retention in plant
27 communities.

28 Methods

29 Runoff experimentations were performed, using a sediment input, on three mono-specific and
30 one multi-specific conditions composed of plant species with contrasting traits furthering
31 hydraulic roughness and sediment retention.

32 Results

33 No effect of trait diversity was found on the hydraulic roughness and sediment retention; which
34 would be explained by the absence of an optimal space use by the traits involved in the increase
35 of the hydraulic roughness. The dominant effect of the community-weighted traits in the plant
36 community drives the effects of the vegetation on the hydraulic roughness and sediment
37 retention.

38 Conclusion

39 This absence of positive effects of the trait diversity on hydraulic roughness and sediment
40 retention constitutes an important knowledge to model runoff and soil erosion processes and to
41 design herbaceous infrastructures for soil erosion control.

42

43

44 **Introduction**

45 Soil-plant interactions play a key role in the reduction of runoff and soil erosion (Styczen and
46 Morgan 1995). The effects of plant functional traits (i.e., ‘morpho-physio-phenological traits
47 which indirectly impact fitness via their effects on growth, reproduction and survival’ (Violle
48 et al. 2007)) in herbaceous vegetation have been studied on different processes generating and

49 favouring runoff and soil erosion (Morgan 2004; Hussein et al. 2007; Isselin-Nondedeu and
50 Bédécarrats 2007; Burylo et al. 2012; Stokes et al. 2014; Liu et al. 2016; Mekonnen et al. 2016).
51 In vegetation patches, notably under temperate climates, concentrated runoff and soil erosion
52 are mainly controlled by the hydraulic roughness of herbaceous vegetation (i.e. frictional
53 resistance of the vegetation in contact with the flow) which induces sediment retention by
54 slowing the flow velocity (Meyer et al. 1995; Akram et al. 2014). More the flow velocity will
55 be reduced, more the quantity of sediments which will be retained by the vegetation will
56 comprise a wider variety of particle sizes, and especially smaller particles (Haan et al. 1994;
57 Syversen and Borch 2005). This indirect effect of the plant traits on the fractions of sediment
58 particles retained constitutes an important feature to understand the vegetation effects on soil
59 erosion, notably regarding the environmental consequences as the smaller sediment particles
60 are the most impacting ones regarding pollutant dispersion and water quality degradation
61 (Syversen and Borch 2005; Liu et al. 2008; Lambrechts et al. 2014). The effects of functional
62 traits on hydraulic roughness and sediment retention have been studied over the past decades,
63 showing the effects of aboveground biomass, projected stem area (i.e. stem area towards the
64 flow direction), stem density and diameter as well as leaf area and density (Burylo et al. 2012;
65 Zhu et al. 2015; Mekonnen et al. 2016; Kervroëdan et al. 2018). Some of these traits are found
66 negatively correlated (e.g. leaf area and density), implying that trait diversity and divergence
67 could have a better impact on hydraulic roughness and sediment retention by exerting
68 complementary effects of the traits (Kervroëdan et al. 2018). Positive effects of the trait
69 aggregation, due to trait divergence – or functional diversity – are driven by the
70 complementarity of the traits which leads to a better space occupation inducing greater effects
71 of the community structure and distribution on soil erosion reduction (Zhu et al. 2015). On the
72 other hand, when no effects of the trait diversity are observed, it is the community-weighted
73 traits (i.e. the mean of the trait values in the plant community) that are leading the effects on

74 the hydraulic roughness and sediment retention (Erktan et al. 2013; Zhu et al. 2015). As for
75 several other ecosystem processes, plant species diversity integrating contrasting plant
76 functional traits can influence the processes involved in soil erosion (Naeem et al. 1994; Tilman
77 2001a; Martin et al. 2010; Zhu et al. 2015). The mechanisms driving the effects of plant species
78 diversity on ecosystem processes can follow two non-exclusive hypotheses (Loreau 2000;
79 Garnier et al. 2016). The selection hypothesis stipulates that one or more dominant species in
80 the community would increase the overall productivity and efficiency of the community. On
81 the other hand, the complementarity hypothesis specifies that plant species diversity effects on
82 ecosystem processes result from a more complete space and resource uses by the trait
83 divergence composing the plant community (Loreau and Hector 2001; Fargione et al. 2007).
84 The relationships between plant trait diversity and soil erosion processes have been studied,
85 mostly focussing on the effects of non-herbaceous plant roots on soil stabilisation and
86 vegetation patch pattern impact on erosion rates (Gyssels et al. 2005; Bautista et al. 2007; Pohl
87 et al. 2009; Martin et al. 2010; Berendse et al. 2015; Hou et al. 2016). However, the effects of
88 trait diversity on sediment retention are not well known and can be contrasting (Martin et al.
89 2010; Erktan et al. 2013; Zhu et al. 2015; Hou et al. 2016). Studies focussing on the effects of
90 functional diversity on sediment retention and erosion rates showed controversial effects on the
91 functional diversity (i.e., ‘the value, range, and relative abundance of plant functional traits in
92 a given ecosystem’ (Tilman 2001b; Díaz et al. 2007)) (Erktan et al. 2013; Zhu et al. 2015).
93 Influenced by neighbouring, the interspecific differences in functional traits among diverse
94 plant communities have been found to impact positively soil erosion reduction (Zhu et al. 2015).
95 These debated results stress the need to deepen the knowledge on the effects of the trait diversity
96 in herbaceous vegetation on concentrated runoff and soil erosion to increase hydraulic
97 roughness and sediment retention.

98 This trait-based plant-soil study aimed to examine the effects of the traits and their divergence
99 on the hydraulic roughness and sediment retention by characterising the quantity of retained
100 sediments and their sizes. We hypothesised that the aggregation of contrasting traits involved
101 in the increase of the hydraulic roughness would induce a better aboveground space use and a
102 better sediment retention. The traits and their divergence, which would have a greater effect on
103 the hydraulic roughness, would lead to a wider variety of the size of the retained sediments by
104 the multi-specific plant communities.

105

106

107 **Materials and methods**

108 **Plant material**

109 Three herbaceous species presenting contrasting aboveground morphological traits furthering
110 the hydraulic roughness were selected from a list of 76 potential candidate species of indigenous
111 plants from north-west Europe. This list was obtained by applying six criteria to the 3500
112 spermatophyte species of north-west Europe (Lambinon et al. 2012) based on the identified
113 functional types influencing runoff and soil erosion in this phytogeographical territory
114 (Kervroëdan et al. 2018): (1) the Raunkiaer's life-form categories "herbaceous chamaephytes",
115 "hemicryptophytes" and "geophytes" which select perennial herbaceous species with an
116 effective soil cover all year; (2) the presence of biomass during winter, when soil erosion is
117 observed at its highest in north-west Europe (Boardman and Poesen 2006), either dry (i.e., non-
118 caespitose hemicryptophytes and geophytes) or fresh (i.e., herbaceous chamaephytes and
119 caespitose hemicryptophytes); (3) the presence of stolon or rhizomes which ensure a lateral
120 spreading growth pattern forming a homogenous cover and burying tolerance towards sediment
121 deposition; (4) a vegetative height ≥ 20 cm to avoid any submergence of the vegetation by the
122 water flow and ensure the efficiency towards concentrated flows (Dillaha et al. 1989), as the

123 water maximal level is 20 cm in north-west European catchments; (5) a broad ecological niche
124 which guarantee the plants development within a wide gradient of soil conditions and (6) the
125 non-invasiveness of the plants which select non-weed species and avoid the plant spreading
126 into agricultural fields.

127 To restrict the competition for light, the species were chosen considering their vegetative height
128 range with a minimal height comprised between 40 and 70 cm. The species *Carex pendula*
129 Huds., *Tanacetum vulgare* L. and *Festuca arundinacea* Schreb. were tested under three
130 monospecific and one multi-specific communities (Fig. 1), each condition comprising three
131 replicates. Only one multi-specific condition (comprising the three species) was tested as the
132 aim of this study was to examine the effect of the trait diversity on the hydraulic roughness and
133 sediment retention using contrasting traits. The multi-specific communities were composed of
134 the three species and presented a high functional diversity, with a functional divergence (FDis,
135 with a range between 0 and 1) of 0.88 (± 0.04) (Villéger et al. 2008).

136

137 **Experimental site design**

138 The plots were implanted at the bottom edge of a loamy field cultivated with winter wheat
139 located in the municipality of Drosay, Normandy, France (Fig 2.A). The soil, defined as
140 Luvisol, was characterised by 12.5% ($\pm 0.66\%$) clay, 64.3% ($\pm 0.84\%$) silt and 23.2% ($\pm 0.64\%$)
141 sand with a pH of 5.3 (± 0.1), 2.1% ($\pm 0.19\%$) of organic matter content and a crusting index of
142 1.8 (± 0.08).

143 In October 2016, one year *prior* experiments, the plants were planted in 1m² plots with a density
144 of 53 young plants.m⁻² (Fig. 1). The multi-specific plots were planted with the same proportion
145 of each species and the young plants were placed so young plants of the same species would
146 not be next to each other. A control condition, with no vegetation, was also tested with three
147 replicates to compare the effects of the traits between each species. Each of the 15 plots was

148 randomly distributed along a 50m strip and 2m were left between each plot to allow movement
149 and limit plant spreading in the next plot (Fig. 2.B).

150

151 **Hydraulic measurements**

152 A runoff simulator (Fig. 3) generating a flow at set discharges in controlled conditions was used
153 to performed the experiments in October and November 2017 (Richet et al. 2017; Kervroëdan
154 et al. 2018). The simulator was composed of three parts, two Venturi channels with ultrasound
155 probes measuring the water level in the channels (± 1.26 mm) on both ends of a channel where
156 measurements were performed. The central channel was a 5.2 m by 0.90 m stainless steel
157 channel with a 1.2 m bottomless part where the vegetation was located. The channel slope was
158 measured for each plot using an automatic rotating laser (Geo Fennel EL 515plus) and was
159 adjusted to 4.90% ($\pm 0.13\%$), using wooden planks to ensure stability during experiments. The
160 backwater levels in front of the plots were measured using six spacers placed upstream the
161 plants. The closest spacer from the plants was 13 cm away, the next two were spaced by 25 cm,
162 the forth spacer was 50 cm away from the third and the last two were spaced by 75 cm. Each
163 spacer was levelled and their elevations were measured and used as elevation-known baselines
164 for the water level measurements.

165 The hydraulic parameters which were measured during the experiments were the flow discharge
166 and the water levels in the backwater area. The discharge used for the experiments was 3.6 L.s^{-1}
167 m^{-1} ($\pm 0.06 \text{ L.s}^{-1}.\text{m}^{-1}$), and was continuously monitored using the upstream and downstream
168 flowmeters. The water level measurements were carried out when the upstream and
169 downstream discharges were equivalent. The perpendicular distance between the bottom of the
170 spacer and the top of the water flow was measured with an aluminium ruler. Ten water level
171 measurements were done on each spacer, every 10 cm along the spacer from one channel edge

172 to the other. All the water level determinations were undertaken using clear water flows (Table
173 1).

174 The unit stream power (USP, $\text{m}\cdot\text{s}^{-1}$) was used to characterise the hydraulic roughness (Yang
175 1972; Govers 1992). Often used as a sediment transport capacity index, it defines the energy
176 dissipation of the flow, per unit of time and per unit of weight, and depends on the mean flow
177 velocity (V , $\text{m}\cdot\text{s}^{-1}$) and the slope (S , $\text{m}\cdot\text{m}^{-1}$) (Govers 1992):

$$178 \quad USP = VS \quad (1)$$

179 The USP was calculated based on the water levels measured on the closest spacer to the
180 vegetation. The USP is negatively related to the hydraulic roughness: the lower it is, the higher
181 the hydraulic roughness will be.

182

183 **Sediment retention**

184 In June 2017, soil in the experimental site was taken off, sifted at 2 mm and stored until October
185 2017. *Prior* the experiments, the sediments were dried at 40°C for 72h and stored in sealed
186 containers. After conducting the water level measurements, sediments were integrated into the
187 flow in order to characterise the trait diversity effect on sediment retention capacity. The
188 sediment concentration was at $11 \text{ g}\cdot\text{L}^{-1}$ ($\pm 0.36 \text{ g}\cdot\text{L}^{-1}$) at a discharge of $3.6 \text{ L}\cdot\text{s}^{-1}\cdot\text{m}^{-1}$ ($\pm 0.09 \text{ L}\cdot\text{s}^{-1}\cdot\text{m}^{-1}$).
189 $^1\cdot\text{m}^{-1}$). The sediment concentration and discharge used were chosen in order to analyse the
190 effects of traits and their divergence in plant communities on frequent erosional episodes (e.g.
191 annually) observed in the upper parts of catchments located in the European loess belt. Indeed,
192 the sediment concentration of $11 \text{ g}\cdot\text{L}^{-1}$ represents more than 75% of the sediment concentrations
193 measured in small catchments and in the upper parts of the catchments in the European loess
194 belt (Van Dijk et al. 1996; Cerdan et al. 2002; Le Bissonnais et al. 2004; Delmas et al. 2012;
195 Richet et al. 2017).

196 The experiment lasted 3 min of sediment input and was followed by 30 sec of clear water to
197 allow the last sediments to be transported. The extra 30 sec of clear water did not significantly
198 influence the sediment particles detachment and their transport in the flow downstream the
199 vegetation (Supplementary material). In order to estimate the quantity of sediment passing
200 through the vegetation, a 250 ml flow sample was taken every 15 sec, from the sediment input
201 to the end of the experiment. After the test run, the sediments deposited in the channel were
202 collected. All the sampled sediments were oven-dried at 105°C for 48h and weighted. The
203 quantity of trapped sediments in the vegetation was estimated from calculation. Particle
204 granulometry was analysed using a LS 13 320 Beckman Coulter particle sizing analyser for the
205 sediments deposited in the channel (upstream) and the ones downstream the vegetation.

206 The total sediment quantity downstream the vegetation was calculated using a sequential
207 calculation method, from each sample collected. The quantity trapped within the vegetation
208 (S_{within}) was estimated as followed:

$$209 \quad S_{\text{within}} = S_{\text{input}} - (S_{\text{upstream}} + S_{\text{downstream}}) \quad (2)$$

210 where S_{input} is the total quantity of sediments integrated into the flow, S_{upstream} is the quantity
211 deposited in the channel and $S_{\text{downstream}}$ the quantity which passed through the vegetation.

212 The sediment retention capacity represented the quantity of sediments upstream and within
213 the vegetation:

$$214 \quad S_{\text{retention}} = S_{\text{upstream}} + S_{\text{within}} \quad (3)$$

215

216 **Leaf and stem trait measurements**

217 Six aboveground plant morphological traits (stem – density, diameter, projected area; leaf –
218 density, area and specific area), known to influence the hydraulic roughness and sediment
219 retention (Kervroëdan et al. 2018), were measured on three levels along the stem: between 0
220 and 5 cm, 0 and 10 cm and 0 and 20 cm. Sampling collection, samples conservation and

221 analyses methods were conducted following the standardised guidelines from (Pérez-
222 Harguindeguy et al. 2013). The leaves were collected in sealed bags with moist tissue until
223 measurements were performed and then, dried at 70°C for 72h. The traits were all measured
224 within one quadrat (10 by 10 cm) per monospecific community plot and one quadrat per species
225 within the multi-specific community plots, due to the homogeneous plant cover within the plots.
226 The leaf density (leaves.m⁻²) was measured for each level along the stems by counting fresh
227 and dry leaves. The leaf area (mm²) and specific area (mm².mg⁻¹) were determined using six
228 representative leaves, scanned at 600dpi resolution, and the images were analysed using Gimp
229 2.8. Pseudoculms for sedges species (Cyperaceae) and tillers for grass species were counted
230 with the stems to measure the stem density (stems.m⁻²). The stem diameter (mm) was measured
231 for each level on three representative stems and was used to calculate the projected stem area
232 (mm²), using the rectangle area formula. The aboveground biomass (g) was estimated by
233 collecting a 50 x 50 cm quadrat in each plot and dried during 72h at 70°C. The species biomass
234 in the multi-specific plots were separated in order to determine the biomass productivity of each
235 species.

236 Moreover, a density-weighted trait was calculated for each trait by multiplying the (1) leaf traits
237 with the leaf density and (2) stem traits with the stem density; which corresponded to the density
238 value of the traits and were dissociated from the traits with a “D” at the front of the trait
239 appellations.

240

241 **Characterisation of the trait diversity effects on the hydraulic roughness and sediment** 242 **retention**

243 All multi-specific plots were planted with an equal abundance of each species, although these
244 abundances changed through the year to experiments. The abundance (%) of each species was
245 estimated for each multi-specific plot.

246 The community-weighted traits (CWT) were calculated for each trait in the multi-specific plots
247 by weighting each trait with the species abundance (Díaz et al. 2007; Violle et al. 2007):

$$248 \quad CWT_i = \sum_{k=1}^{n_i} A_{k,i} T_{k,i} \quad (5)$$

249 with CWT_i being the community-weighted value of the trait in the community i , $A_{k,i}$ and $T_{k,i}$
250 being, respectively, the relative abundance and the trait value of the species k in the community
251 i and n_i being the number of species in the community i .

252 The complementarity effect on the traits was determined using the land equivalent ratio (LER);
253 which is the relative area required for monoculture to grow with the same productivity as when
254 the species are in mixture (Mead and Willey 1980). The LER was calculated for each species
255 trait in the multi-specific plots as follows:

$$256 \quad LER = pLER_A + pLER_B = \frac{T_{A,multi-specific}}{T_{A,monospecific}} + \frac{T_{B,multi-specific}}{T_{B,monospecific}} \quad (4)$$

257 with $pLER_A$ and $pLER_B$ being the partial LERs for the species A and B; $T_{A,multi-specific}$ and
258 $T_{B,multi-specific}$ being the trait values of the species A and B in the multi-specific conditions; and
259 $T_{A,monospecific}$ and $T_{B,monospecific}$ being the trait values of the species A and B in their respective
260 monospecific conditions. If $LER > 1$, the multi-specific condition presents an advantage for the
261 trait value compared when the species is in monospecific condition. In the contrary, if $LER <$
262 1 , there is a detrimental effect on the trait of the multi-specific condition compare to the
263 monospecific. The $pLER$ allows to indicate competitive effects between the species, within the
264 multi-specific condition, using $pLER < (1/n)$ or $pLER > (1/n)$ as an indices, with n the species
265 number (Mead and Willey 1980; Hector 1998; Darch et al. 2018).

266

267 **Data analyses**

268 Comparison analyses highlighting the differences between the community-weighted traits of
269 each tested condition were carried out using ANOVA and Tukey post-hoc tests on the
270 community- weighted trait values of the three monospecific and the multi-specific conditions.

271 The effects of each vegetated condition in comparison to the control condition on the unit
272 stream power and sediment retention were tested using Kruskal-Wallis and Dunn's tests.
273 Comparative analyses using Mann-Whitney tests were performed on the USP and the sediments
274 (quantities and granulometries) data, gathered under "monospecific" and "multi-specific"
275 categories, in order to identify if there was a complementarity or a selection effect of the trait
276 diversity on these processes.

277 To identify differences between the communities, ANOVA and Kruskal-Wallis analyses were
278 computed accordingly to the normality of the data on the USP, the sediments (quantities and
279 granulometries) and the LER data. The analyses' respective post-hoc tests Tukey and Dunn's
280 were also performed. As the aim of the analyses was to understand the effects of the trait
281 diversity on the tested variables, control data were excluded. All the statistical analyses were
282 carried out using the "Stats" and "dunn.test" packages in the statistical software R (version
283 3.3.2).

284

285

286 **Results**

287 **The traits in the monospecific conditions and their effects on the unit stream power and** 288 **sediment retention**

289 The comparison analyses of the trait values between each monospecific condition emphasised
290 the contrasting leaf densities found between each species (Table 2). *C. pendula* presented
291 significantly lower CW density-weighted projected stem area and CW density-weighted stem
292 diameter with *F. arundinacea* and no difference with *T. vulgare* for the cited traits. The CW
293 density-weighted leaf area of *C. pendula* was not different with *F. arundinacea* and larger than
294 *T. vulgare*'s. The CW leaf area of *C. pendula* presented a significant difference with the leaf
295 area of *F. arundinacea* and *T. vulgare*. Regarding the effects on the unit stream power and

296 sediment retention, the analyses showed no significant differences between the control and *T.*
297 *vulgare*, while *C. pendula* and *F. arundinacea* had significant lower unit stream power and
298 higher quantity of retained sediments than the control. *C. pendula* had higher hydraulic
299 roughness (thus, a lower unit stream power) and quantity of sediments retained than *T. vulgare*.
300

301 **Effects of the trait diversity on the community-weighted traits involved in the increase of** 302 **the hydraulic roughness and sediment retention**

303 The comparison analyses between the CW traits in the monospecific and the multi-specific
304 conditions showed (1) a higher CW leaf area in the *C. pendula* monoculture than in the multi-
305 specific condition; (2) more important CW leaf densities (0 – 5cm, 0 – 10cm and 0 – 20cm) in
306 the multi-specific condition than in the *T. vulgare* monoculture; and (3) more important CW
307 density-weighted leaf areas densities (0 – 5cm, 0 – 10cm and 0 – 20cm) in the multi-specific
308 condition than in the *T. vulgare* monoculture (Table 2). Regarding the LER, the biomass
309 productivity and the leaf density (0 – 5 cm; 0 – 10 cm and 0 – 20 cm) were higher in the multi-
310 specific communities, with a LER > 1 (Table 3). The density-weighted projected stem area (0
311 – 5 cm) and density-weighted stem diameter (0 – 5 cm) did not show differences between
312 monospecific and multi-specific communities, with a LER = 1. Higher traits values were found
313 for *F. arundinacea*, *C. pendula* (only the leaf area, the specific leaf area and the leaf density (0
314 – 5 cm, 0 – 10 cm and 0 – 20 cm)) and *T. vulgare* (only the leaf density (0 – 5 cm, 0 – 10 cm
315 and 0 – 20 cm)) in the multi-specific communities, with partial LER > 0.33. The biomass
316 productivity was favoured in the multi-specific condition for *F. arundinacea* and *T. vulgare*
317 (LER > 0.33) but was not higher for *C. pendula*.

318

319 **Trait diversity effects on the unit stream power, the sediment retention and the quantity** 320 **of each size category of sediment particle retained**

321 When averaging the three monospecific conditions under the category “monospecific”, the
322 comparison analysis of the unit steam power showed no significant difference between the
323 monospecific and the multi-specific conditions. There were no differences between the mean
324 of the monospecific and the multi-specific conditions for the sediment quantities upstream,
325 within and downstream the vegetation. Similar results were also found for the sediment particle
326 sizes.

327 The comparison analysis between each condition regarding the unit stream power showed that
328 *T. vulgare* had a significantly lower hydraulic roughness than *C. pendula* and the multi-specific
329 condition (Fig. 4). Regarding the sediment retention (quantities upstream and within the
330 vegetation), the results showed differences between the multi-specific condition and *T. vulgare*,
331 which was also different from *C. pendula* (Fig. 5.A). When focussing on the size categories of
332 the sediment particles retained by the vegetation, the multi-specific condition was not different
333 from the monospecific conditions for each category; while *C. pendula* had a bigger amount of
334 each size category than *T. vulgare* (Fig. 5.A). *F. arundinacea* did not present any difference
335 with any of the other conditions for each sediment size fraction (Fig. 5.A). The quantity of
336 particles between 100 and 2000 μm showed no difference between each condition. The quantity
337 of sediments downstream the vegetation was significantly higher for *T. vulgare* than for *C.*
338 *pendula* and the multi-specific conditions (Fig. 5.B). The quantity of particles between 50 and
339 100 μm and between 100 and 2000 μm was smaller for the multi-specific and *C. pendula* than
340 for *T. vulgare* (Fig. 5.B).

341

342

343 **Discussion**

344 The aboveground traits of a vegetation constitute the main drivers for generating hydraulic
345 roughness and sediment retention in an herbaceous community. The density-weighted leaf area

346 (product of the leaf area and the leaf density) influenced the hydraulic roughness and the
347 sediment retention in the present study, highlighted by the lower values of this trait in the *T.*
348 *vulgare* condition which showed the lowest hydraulic roughness and sediment retention. The
349 density-weighted leaf area has been emphasised as a main trait influencing the hydraulic
350 roughness, especially when combined with an important density-weighted stem diameter in
351 herbaceous vegetation (Kervroëdan et al. 2018). This strong relationship between the density-
352 weighted leaf area and the hydraulic roughness and sediment retention strengthen the
353 hypothesis observed in the literature that vegetation composed of species with a good trade-off
354 between leaf density and leaf area (i.e. presenting an important density of long leaves), such as
355 graminoid species, would present a greater impact on the hydraulic roughness and a higher
356 efficiency to retain sediments (Morgan 2004; Isselin-Nondedeu and Bédécarrats 2007). Better
357 effects of the traits of graminoid species were also highlighted in the present study with a higher
358 hydraulic roughness and sediment retention for *C. pendula* and *F. arundinacea* (with 84% and
359 76.2% of the sediments retained, respectively) than *T. vulgare* (with 69.7% of the sediments
360 being retained). The hypothesis that vegetation composed of traits inducing a high efficiency
361 in sediment retention would present a wider diversity of sediment particle sizes was also
362 emphasised in the graminoid conditions due to their higher density-weighted leaf area,
363 especially for *C. pendula*. The effects of herbaceous vegetation, notably graminoid species, on
364 sediment retention regarding the particle size fractions have been studied over the past decades,
365 especially in the concern of pollutants dispersion with the finer particles (Meyer et al. 1995;
366 Syversen and Borch 2005; Liu et al. 2008; Lambrechts et al. 2014). It has been shown that the
367 coarser particles tend to deposit upstream the vegetation while finer one deposit within or pass
368 through the vegetation. In our study, most of the particles coarser than 50 μm were retained by
369 all the conditions tested with vegetation while there was a decrease of the retention efficiency
370 for finer particle sizes, which is the same pattern found in the literature (Meyer et al. 1995;

371 Syversen and Borch 2005). This was especially observed for *T. vulgare* (for particles <2 µm)
372 which presented significantly lower density-weighted leaf areas and thus, a lower hydraulic
373 roughness.

374 The effects of the trait diversity on runoff and soil erosion processes have been emphasised,
375 with contentious results (Pohl et al. 2009; Martin et al. 2010; Erktan et al. 2013; Berendse et al.
376 2015; Zhu et al. 2015). In this study, we focussed on the effects of the aggregation of contrasting
377 traits involved in the increase of the hydraulic roughness and sediment retention which are
378 negatively associated. We hypothesised that the aggregation of these contrasting traits would
379 present a complementary effect on the hydraulic roughness and sediment retention, as well as
380 would induce a greater quantity of sediment particle sizes retained by the vegetation. However,
381 while the trait diversity should have led to a greater hydraulic roughness, the results showed no
382 significant increase in hydraulic roughness nor sediment retention for the multi-specific
383 communities. Indeed, the complementarity hypothesis stipulates that the trait divergence in
384 plant communities influences ecosystem processes and leads to a more complete space and
385 resources use (Loreau and Hector 2001). This absence of complementarity effects could not be
386 explained by the biomass productivity of the plant community, as for a greater productivity in
387 the multi-specific condition there was no greater effects on the hydraulic roughness nor on the
388 sediment retention, emphasising that biomass productivity was not a major factor to increase
389 sediment retention. The absence of differences between the mean of the monospecific and the
390 multi-specific communities indicated a dominant effect of the traits of specific species in the
391 community on runoff and sediment transport capacity (Grime 1998; Lorentzen et al. 2008).
392 This dominance effect would be led by the traits of *F. arundinacea* and *C. pendula* and more
393 specifically by their CW density-weighted leaf area, emphasising the greater effect of
394 graminoid species. These results on dominance effects of the community-weighted traits are
395 not in accordance with the complementarity effects of plant species diversity found on runoff,

396 soil erosion and soil aggregation capacity in other studies (Pohl et al. 2009; Martin et al. 2010;
397 Zhang et al. 2015). However, these studies focussed on non-herbaceous spontaneous plant
398 communities of mountainous or semi-arid environments, which usually comprise different (e.g.
399 more intense) runoff and erosion episodes and adapted spontaneous vegetation towards these
400 processes (Guerrero-Campo and Montserrat-Martí 2000). These opposing results could be
401 explained by idiosyncratic effects (i.e. contrasting effects of the plant species diversity),
402 impacted by species-traits and soil-plant interactions (Loreau 2000). The idiosyncratic effects
403 could be influenced by the species combination and structure in the community (Parsons et al.
404 1996; Loreau 2000; Erktan et al. 2013), which is consistent with results showing the decrease
405 of soil erosion resistance with the disappearance of species in the community (Berendse et al.
406 2015). Moreover, an increasing proportion of species with larger stems diameters would create
407 preferential flow paths and further runoff intensity, which would impact the effect of the trait
408 diversity on the hydraulic roughness and sediment retention (Parsons et al. 1996; Erktan et al.
409 2013). This hypothesis is consistent with our results, showing the negative influence on the unit
410 stream power of the traits of *T. vulgare* by reducing the hydraulic roughness and sediment
411 retention within the multi-specific conditions, due to its larger stem diameters than the two
412 other tested species. Negative effects of species with large stem diameters were also highlighted
413 in the literature, highlighting their influence over the water path within the vegetation and the
414 overall neutral effect of trait diversity (Erktan et al. 2013). This postulate coincides with the
415 traits' effects found regarding the size of the sediment particles upstream the vegetation, as the
416 preferential flow paths induced by the presence of larger stems would accelerate the flow
417 velocity at the path's scale and further the transport of sediment particles. Indeed, while a wider
418 variety of sediment particle sizes was expected within the retained sediments by the multi-
419 specific condition, there was no significant difference between the monospecific and the multi-
420 specific conditions for each particle size category. To understand the idiosyncratic effects on

421 hydraulic roughness and sediment retention, perspective is to examine the effects of trait
422 diversity on hydraulic roughness and sediment retention by using a wide gradient of functional
423 diversity, with a variation in the abundance of the traits involved in hydraulic roughness
424 increase, to unravel the relationship between trait diversity and sediment retention.

425

426

427 **Conclusions**

428 This trait-based ecohydrology study allowed to further the understanding of the effect of trait
429 diversity on runoff and soil erosion processes. The results emphasised that there was not a better
430 effect of trait diversity on the hydraulic roughness and sediment retention, as well as on the
431 quantity of sediment fractions. The absence of negative effects on sediment retention suggests
432 that multi-specific communities can be used to mitigate soil erosion and can be recommended
433 because plant species and functional diversity could offer other ecosystem processes and
434 services. Perspective is to examine the effects of functional diversity on several main ecosystem
435 processes in herbaceous hedges created to mitigate soil erosion, to design multi-functional
436 ecosystems.

437

438

439 **Authors' Contributions**

440 Léa Kervroëdan, Michel-Pierre Faucon and Romain Armand conceived the objectives and
441 designed the methodology; Léa Kervroëdan and Mathieu Saunier collected the data; Léa
442 Kervroëdan analysed the data; Léa Kervroëdan and Michel-Pierre Faucon led the writing of the
443 manuscript. All authors contributed critically to the drafts and gave final approval for
444 publication.

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597 **Fig. 1 Experimental plots with three monospecific and one multi-specific communities.**

598 The photos from October 2016 were taken just after the plantation and the ones from September
599 2017 were taken a month *prior* experiment.

600

601 **Fig. 2 Experimental site. A – Location of the experimental site in Drosay, France and B**
602 **– Arrangement of the plots within the experimental area.**

603

604 **Fig. 3 Runoff simulator used for the experiments.**

605

606 **Fig. 4 Differences between each community for the unit stream power.** The bars represent
607 the mean \pm standard error. The letters represent the significant differences between each
608 condition according to Tukey post-hoc tests. The significance level “ns” means not significant.

609

610 **Fig. 5 Differences between each community for (A) the sediment quantities for each**
611 **particle size category upstream the vegetation and (B) the sediment quantities for each**
612 **particle size category downstream the vegetation.** The error bars represent the mean \pm
613 standard error. The letters represent the significant differences between each condition
614 according to the Tukey post-hoc tests, for each sediment size fraction. The significance level
615 “ns” means not significant. The uppercase letters in bold represent the differences between each
616 condition in the overall sediment quantities, according to the Tukey post-hoc tests.