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1 **Higher runoff and soil detachment in rubber tree plantations**
2 **compared to annual cultivation is mitigated by ground cover in steep**
3 **mountainous Thailand**

4 Margot Neyret^{*1}, Henri Robain¹, Anneke de Rouw¹, Jean-Louis Janeau¹, Thibaut Durand³,
5 Juraiporn Kaewthip², Karn Trisophon² & Christian Valentin¹

6
7 ¹ Institute of Ecology and Environmental Sciences (IEES-Paris), IRD, SU, CNRS, INRA, Paris
8 Diderot, Paris Est Créteil; Bondy, France

9 ² Land Development Department, Regional office 6, Chiang Mai, Thailand

10 ³ School of Computing Science, Simon Fraser University, Burnaby, Canada

11

12 * Corresponding author: Margot Neyret (margot.neyret@senckenberg.de)

13

14 **Abstract**

15 Due to high rainfall erosivity and rapid land-use changes, South-East Asia is one of the hot
16 spots of soil degradation worldwide. In recent decades, several studies showed that the
17 expansion of rubber tree (RT) plantations into previously forested areas has caused a major
18 increase in soil erosion. However, the effects of cropland conversion to RT plantations on
19 surface runoff and soil detachment are still unclear. Here we show that mature RT plantations
20 considerably increase runoff and soil detachment compared to annual crops or young RT
21 plantations with intercrop, mostly due to the absence of understory.

22 Monitoring 1 m² microplots over four years in mountainous Northern Thailand, we found
23 that runoff and detachment increased with time since the onset of the rainy season and with
24 rainfall height, but more so in mature RT plantations than in young RT plantations and maize.
25 This led to much higher annual soil detachment in mature RT plantations (5.7 kg/m² on
26 average) than in maize and young RT plantations with intercrop (0.36 kg/m²). We identified
27 two main factors explaining this difference: first, rubber tree leaf litter, although abundant,

28 seemed ineffective in reducing runoff at the end of the rainy season. Secondly, the cover by
29 low-growing plants in mature rubber tree plantation was usually sparse and provided little
30 protection. In particular we showed that increasing the cover by low-growing plants from quasi-
31 null cover to >31 % cover decreased runoff coefficient by 32 %.

32 Our results demonstrate that afforestation by RT, at least under current management
33 practices and on steep slopes, is overall detrimental to soil conservation but that its effects
34 could be mitigated by the adoption of less intense weeding practices.

35 **1. Introduction**

36 In 2012, the UN Rio+20 conference on sustainable development acknowledged the
37 importance of soil protection and sustainable land management (United Nations, 2012).
38 Following this recognition, the Sustainable Development Goals (SDG) pledged to "protect,
39 restore and promote sustainable use of terrestrial ecosystems [...] and halt and reverse land
40 degradation and halt biodiversity loss" (SDG 15). Maintaining soil functionality and resilience is
41 a major element of several sustainable development global challenges: food and water security,
42 climate change mitigation, ecosystem service provision, biodiversity protection, and energy
43 sustainability (Koch *et al.*, 2013; McBratney, Field & Koch, 2014).

44 Southeast Asia is doubly exposed to land degradation, due to extreme meteorological
45 conditions and to rapid land-use changes (Van Lynden & Oldeman, 1997; Borrelli *et al.*, 2017;
46 Panagos *et al.*, 2017). Oldeman (1991) classified all South-East Asia as having medium to high
47 land degradation rates due to water erosion, especially due to adverse meteorological
48 conditions. For example, the Global Rainfall Erosivity Database classifies the area as one of the
49 regions with the highest rainfall erosivity (> 7400 MJ ha⁻¹ yr⁻¹, Panagos *et al.* (2017)), and some
50 models predict that climate change will cause a continued increase in rainfall erosivity
51 (Plangoen & Udmale, 2017). Besides, in 2012, the GLASOD (Global Assessment of Human-
52 Induced Soil Degradation, Oldeman *et al.* (1991)) estimated that 18% of Asian lands had been
53 degraded by humans (ISRIC 2012). More recently, Borrelli *et al.* (2017) predicted a 5% yearly
54 increase of soil erosion rates in most of South East Asia due to very high rates of land-use
55 change. In the area, deforestation (among the highest rates in the world, Zhao *et al.* (2006);
56 Sodhi *et al.*, (2010)) and the intensification of agriculture exacerbated environmental
57 degradation, especially in mountainous areas with steep slopes. In the uplands of Northern
58 Thailand, where subsistence agriculture was previously dominant, government incentives

59 started in the 1970s to encourage the transition to more intensive and market-oriented
60 agriculture (Fox & Vogler, 2005). The intensification and the expansion of cash crops into
61 previously forested areas led to intense environmental degradation (Wangpakapattanawong *et al.*
62 *et al.*, 2016) increasing surface runoff and sedimentation (Mohammad & Adam, 2010) as well as
63 soil organic carbon losses (Häring *et al.* 2014). Maize and cassava cultivation systems were
64 found to be particularly prone to erosion (Valentin *et al.*, 2008). Thus, more recently, national
65 and international organisations and programmes such as UNCCD and REDD+ encouraged the
66 replacement of annual cash crops by perennial cash crops, such as teak or rubber tree (RT). The
67 objective was to increase farmers' income and to expand tree cover in mountainous areas. The
68 replanting of trees in degraded areas was expected to restore favourable soil conditions and
69 water resources. Yet the effect of perennial monoculture expansion is far from consensual.
70 While natural forest regrowth decreases overland flow and soil erosion, the replacement of
71 annual crops by teak plantations in Laos led to a sharp increase of soil detachment and
72 overland flow (Lacombe *et al.*, 2017; Ribolzi *et al.*, 2017; Patin *et al.*, 2018). Other ecosystem
73 services, such as carbon storage or support for biodiversity are also lower in tree plantations
74 compared to natural forests (Hall *et al.*, 2012). Most studies investigating the impacts of RT
75 plantations on soil compared the plantations to forests or other tree plantations (Noguchi *et al.*,
76 2003; Li *et al.*, 2012; Liu *et al.*, 2015; Nurulita *et al.*, 2016). Yet, many plantations are planted on
77 previously arable lands (Holt *et al.*, 2016): an adequate estimation of RT impact on soil erosivity
78 should thus include annual as well as perennial crops.

79 Erosion processes must be measured and analysed at different scales. At the largest scale,
80 variations in rivers flows, sediment loads and sediment redeposition can provide information
81 about regional erosion processes. At the catchment scale, processes include water partitioning
82 into overland and underground flow; the detachment and redeposition of sediments
83 downslope; and runoff connectivity and redistribution by topographical features such as gullies
84 or terraces. The catchment scale is particularly appropriate for tackling long-term issues, for
85 instance regarding the impacts of land-use changes on erosion processes (Valentin *et al.*, 2008).

86 In this four-year study located in Northern Thailand, we investigated the combined effects of
87 rainfall, soil surface conditions, ground cover and land use (maize, young RT plantations with
88 intercrop, and mature RT plantations). We used 1 m² erosion microplots (Janeau *et al.*, 2003)
89 which is a relevant scale for investigating very local, fine-scale processes of soil particle
90 detachment and water infiltration (e.g. Lacombe *et al.* (2018)) and their relation to local soil
91 surface characteristics. It provides key information about the erosion potential of a particular

92 field or land use. We characterised soil surface by quantifying the proportions of crusts, free
93 gravels and aggregates as well as soil cover by weeds and crops (Casenave & Valentin, 1992).
94 The dynamics of soil cover by low-growing plants were quantified using weekly standardised
95 pictures. We hypothesised that the main factors affecting runoff and detachment would be the
96 presence of a high canopy associated with discontinuous ground cover; and thus that mature
97 RT plantations (high trees and sparse understorey) would cause higher runoff and detachment
98 than young RT plantations (with intercrop) and maize, unless ground cover by living plants was
99 high. We aimed i) to quantify runoff and soil detachment on an annual and monthly basis (2015
100 experiment) in the different land uses; ii) to quantify the different runoff and soil detachment
101 responses of the different land uses to rainfall (2016 experiment) and iii) to quantify the effect
102 of ground cover by low-growing plants on runoff in mature RT plantations (2017-2018
103 experiment).

104 **2. Material and methods**

105 **2.1. Study sites**

106 Study sites were located in Huai Lang, Chiang Rai province, northern Thailand (100°27'E,
107 20°00'N). Soils belonged to Alfisols with clay to clay-loam texture. A detailed soil description is
108 provided in Table S1. The local climate is typical of tropical mountainous regions. It is
109 characterised by the succession of a dry season (December to April) and a rainy season (May to
110 November), which accounts for most of the annual rainfall. The meteorological station installed
111 for the study showed that total annual rainfall was approximately 1600 mm/year with a high
112 inter-annual variability of 200 mm/yr. Mean annual temperature was 24.2 °C with a low inter-
113 annual variability of 0.4 °C but a high amplitude between maximum and minimum daily values,
114 43.5 °C and 4.8 °C respectively. The total annual potential evapotranspiration was
115 approximately 900 mm with an inter-annual variability of 30 mm. All studied plots were
116 deforested more than 20 years ago. In 2000, they were all already intensely cultivated with
117 open-field crops and the first RT plantations were planted in 2003.

118 **2.2. Location of erosion microplots**

119 In March 2015, microplots were installed in a maize field (M), a young rubber tree plantation
120 with maize intercrop (YR) and a mature RT plantation either within the RT rows (OR_s , where
121 canopy is usually dense and rainfall interception is high) or between the rows (OR_i , with usually

122 sparser canopy and lower interception). The owner of this mature plantation reported no
123 herbicide application. Three replicates were installed for each situation. M and YR were located
124 on different soil types than OR (Table 1, Table S1). To control for this potential bias, in 2016,
125 during the dry season, the microplots were moved to fields with similar land uses and the soil
126 types were switched compared to 2015. These new locations were also located closer to the
127 automatic meteorological station presented hereafter, allowing the use of high-resolution
128 rainfall kinetic energy data provided by the station. The baseline weed management in this new
129 plantation was two applications of glyphosate each year. In 2017 and 2018, we redistributed
130 the microplots in the two RT plantations studied in 2015 (OR₁) and 2016 (OR₂), thus in both soil
131 types. All microplots were located between tree rows. In each plantation, half the microplots
132 were treated with herbicides twice a year, while herbicides were excluded from the other half.
133 The effect of the treatment was not investigated *per se* but rather through its effect on weeds,
134 and more generally on cover by low-growing plants.

135 At the start of the experiment, all young RT were approximately 4 years old and mature
136 trees approximately 13 years old. Information on RT height and girth and plantation
137 management is provided in Table 1.

138 **2.3. Meteorological monitoring**

139 An automatic weather station (Campbell BWS200) has been installed since March 2015 in
140 the middle of a small flat grassland located at an elevation of 535 m AMSL. Meteorological
141 parameters were measured on a one-minute basis: temperature and air relative humidity with
142 CS215 Sensor; and rainfall with a tipping bucket rain gauge adjusted to tip once for each 0.2
143 mm of rain (Campbell ARG100).

144 The starting and ending time of an individual rain event was determined by a delay of at
145 least 20 min between two bucket tips. For each rain event, we calculated the EI₃₀ and R indices
146 established by Renard *et al.* (1997) to describe rainfall aggressiveness, as established within the
147 Revised Universal Soil Loss Equation (Table S2). We also used two manual cumulative rain
148 gauges located in open areas close to M and YR fields (for the 2015 experiment) and to OR₁
149 (2015 and 2017-2018 experiments).

150 **2.4. Runoff and soil detachment monitoring**

151 Erosion microplots were 1 m² metallic frames, driven into the soil to a 10 cm depth to avoid
152 any influence of hypodermic lateral flow. They have been widely used in studies of soil

153 detachment in South-East Asia (Janeau *et al.*, 2003; Pierret *et al.*, 2007; Podwojewski *et al.*,
154 2008; Patin *et al.*, 2018). Their installation was realised carefully to avoid any disturbance of the
155 soil surface along the frame or preferential infiltration along the sides of the frame. This
156 allowed us to start monitoring just after installation, from mid-May 2015 onwards.

157 65 L buckets, located downward each microplot, allowed to collect the part of the rainfall
158 which runs over the soil surface (overland flow), as well as the transported soil particles
159 detached by splash erosion or by the velocity of the overland flow. The total volume of the
160 overland flow was calculated from the measurement of water height in the collecting bucket.
161 The concentration of soil particles was measured on a 300 mL aliquot, which was filtered and
162 dry-weighted at the Land Development Department laboratory in Chiang Mai, Thailand. The
163 maximum frequency of overland flow sampling was once a day. The events occurring within
164 this period were pooled as indicated in Table S2. For these cumulated rain events we
165 calculated:

- 166 • Cumulated rainfall height, cumulated kinetic energy and maximum EI₃₀ as
167 described in Table S2;
- 168 • Runoff coefficient, ratio between runoff volume collected for 1 m² (L/m² and hence
169 mm) divided by rainfall height (mm);
- 170 • Soil detachment (g/m²) as the product of sediment concentration in the collected
171 samples (g/L) by runoff volume (L/m²).

172 The adjustments in the protocol, made to fit with the specific objective of the experiment
173 in each year, are described in Table S3. In particular, as we found large differences in 2015
174 between rainfall measured at the automatic weather station and at manual rain gauges, in
175 2016 we moved the plots closer to the station to be able to use rainfall kinetic energy and
176 EI₃₀ calculated with the records of the automatic weather station. Besides, while in 2015 the
177 objective was to measure precisely soil detachment on a monthly or annual basis, in the
178 following years we focused on event-scale analyses with a slightly different methodology for
179 soil detachment measurements (Table S3).

180 **2.5. Soil surface conditions**

181 We visually estimated the proportion of each soil surface type for each microplot from two
182 direct observations a year using the method proposed by Casenave and Valentin (1992) (Janeau
183 *et al.* 2003; Chaplot *et al.* 2005, Podwojewski *et al.* 2008b; Patin *et al.*, 2012; Patin *et al.* 2018).

184 The assessment, both accurate and reproducible when applied by the same expert (Malam Issa
185 *et al.* 2011), identified:

- 186 • Free aggregates (Fag) not anchored to the soil surface, and readily detached by
187 gently brushing the soil surface;
- 188 • Crusts resulting from the slaking of aggregates and the sealing of soil surface
189 pores, including erosion crusts (ERO), gravel crusts (G) and structural crusts (ST);
- 190 • Litter and plant fragments lying directly on the soil surface.

191 In 2016, the same expert also analysed a series of detailed pictures (instead of direct
192 observation) to estimate the same parameters at the end of the rainy season.

193 **Soil cover by low living plants**

194 In 2017 and 2018, in addition to soil surface type estimations, we took weekly standardised
195 pictures of soil cover for each microplot, which corresponded to approximately 1 200 pictures
196 in total. All images were corrected for perspective deformation using the GIMP software. We
197 conducted precise segmentation using FIJI (Fiji Is Just Image J) plugin Weka Segmentation on
198 350 soil cover images from both rubber tree plantations and other land uses, to account for
199 different soil and light conditions. The images were annotated at a pixel level and each pixel
200 was associated to one label (living plants, litter and bare soil). Annotating images at a pixel level
201 is time consuming, and takes between 5 to 15 minutes per image. We thus used a computer
202 vision approach to annotate the remaining images. We used the 350 labelled images to learn a
203 segmentation network, and then used the learned model to automatically predict the label of
204 each pixel (Figure S1 and supplementary methods). The segmented images were finally
205 analysed to measure the proportion of soil surface covered by living plants. The litter cover was
206 poorly distinguished from bare soil and was not used in the analysis. We then calculated the
207 proportion of plant cover at the date of each runoff measurement by interpolation. Separate
208 interpolations were fitted for five periods corresponding to each herbicide sprayings (January-
209 June 2017, June-August 2017, August 2017-June 2018, June-September 2018, and September –
210 December 2018).

211

212 **2.6. Data processing**

213 We completed all data analyses using the R software (R Core Team, 2018).

214 **Corrections for biased data**

215 In mature rubber tree plantations, some rain events with very high intensity or rainfall
216 height could not be correctly recorded, for two main reasons. Firstly, the maximum possible
217 runoff volume recorded corresponded to the volume of the buckets, i.e. approximately 50 L.
218 Some exceptional events (e.g. with rainfall height > 100mm) created runoff larger than this
219 volume, but the records had an artificial threshold of 50 L/m². Besides, some very intense
220 events created concentrated runoff coming from an upslope section of unknown area, which
221 entered over the frame of the microplots and led to overestimations of detachment and
222 runoff. We considered that runoff and detachment were likely biased if the runoff volume
223 reached the volume threshold (> 50 L), or if the runoff coefficient was higher than 2 (runoff
224 coefficient slightly higher than one is possible if there is some concentrated throughfall from
225 the canopy). These “biased” measurements represented between 0.5% and 3.5% of the total
226 number of runoff and detachment data, depending on the year. To correct these
227 measurements, we re-estimated them based on mixed models with square-root
228 transformed runoff (or detachment) as the response. For runoff, the explanatory variables
229 were meteorological variables (rainfall height, API, cumulated kinetic energy, and maximum
230 EI₃₀) and their interactions with the year and plot. For soil detachment, available only in 2015
231 and 2016, the explanatory variables were runoff volume, API, cumulated kinetic energy, and
232 maximum EI₃₀ and their interactions with year. The models also included the microplot as a
233 random effect. We fitted the models for all non-biased data and conducted stepwise model
234 selection based on AIC. The final models had an R² of 67% (69 % when including random
235 effects) for runoff volume and 83% (85% when including random effects) for soil
236 detachment. The missing runoff and detachment measurements were then predicted from
237 these models (function *predict*) and integrated into all following analyses.

238 **Data analyses**

239 We investigated the variation of monthly runoff coefficients using mixed linear models (R
240 package LMER) with month and land use as fixed effects and microplot identity as the random
241 effect to take into account the repeated measurements within each microplot. We conducted
242 pairwise comparisons using the EMMEANS package and we corrected p-values for multiple
243 testing using the Tukey method. To investigate the relations between runoff and soil
244 detachment and meteorological variables, we discarded “small” events with rainfall height
245 under 2 mm. Fixed effects were rainfall characteristics (e.g. rainfall height) or date, and random
246 effects were the microplots. Surface runoff and soil detachment were non-normal and with

247 heterogeneous variance. We thus performed model-specific box-cox transformations:

$$248 \quad y' = \begin{cases} \frac{y^\lambda - 1}{\lambda} & \text{if } \lambda \neq 0 \\ \ln(y) & \text{if } \lambda = 0 \end{cases}$$

249 With y the runoff or soil detachment, y' the transformed variable, and λ the optimised box-
250 cox parameter (function *boxCox*, R package *CAR*). We then performed stepwise model selection
251 based on AIC (function *step*, R package *LMERTEST*). Because maximum EI_{30} was highly correlated
252 with rainfall height, we present only results for rainfall height, which is the most common
253 rainfall variable used in erosion models. The date was coded as day number since January 1st.

254 To test the relationship between soil surface characteristics and runoff in the different land
255 uses during the different stages of the rainy season, we first calculated early (until August 14th)
256 and late (from August 15th) semi-annual runoff coefficients. We then conducted mixed model
257 analyses of the semi-annual runoff coefficient with soil crusting per microplot in each stage of
258 the rainy season. We also tested the effect of ground cover by low-growing plants on runoff
259 volume (square-root-transformed for ensuring normalisation of the residuals) of individual rain
260 events during the rainy season 2017 and 2018 (May-November) in a mixed model with rainfall
261 height (square-root transformed), soil cover and plantation (OR_1 or OR_2) as fixed effects. In both
262 cases, microplots were included as random effects.

263 **3. Results**

264 **3.1. Meteorological conditions**

265 Annual rainfall varied from 1 270 mm in 2015 (measured from March onwards) to 1 836 mm
266 in 2017. It was intermediate in 2016 (1 539 mm) and 2018 (1 447 mm). The rainy season was
267 clearly bimodal in 2015 and 2018, with rainfall peaks in April-May and August, but less so in
268 2016 and 2017, with a large rainfall peak in August and a smaller one in May-June (Figure 1a).
269 The monthly erosivity factor R (10^2 kJ mm/m²/h, corresponding to the monthly sum of EI_{30}
270 divided by 100, Renard *et al.* (1997)) peaked in April and August 2015 and June and August
271 2016, July and August 2017 and August and October 2018 (Figure 1b). Rainfall events larger
272 than 25 mm were particularly numerous in 2017 (Table 2).

273 **3.2. Effect of land use and rainfall on runoff and soil detachment (2015-2016)**

274 Yearly runoff and soil detachment for each microplot are summarised in Table 2.

275 In M (and YR respectively), annual runoff coefficient was 7.7% (median for the three M
276 microplots; resp. 8.1% in YR) in 2015 and 6.1% (resp. 7.8%) in 2016. Monthly runoff coefficients
277 in 2015 in M and YR were the lowest in M microplots in June (2.7 %) and peaked at 22% in M
278 microplots in October (Figure 2a), when monthly rainfall height was low but rainfall erosivity
279 density still high (Figure 1). In 2016, monthly runoff coefficients remained stable throughout
280 the rainy season, around 6% (Figure 2b). Median annual soil detachment was 0.43 kg/m² in M
281 (resp. 0.31 kg m⁻² in YR) in 2015 and 0.36 kg/m² (resp. 0.26 kg/m²) in 2016: it remained
282 relatively low throughout the rainy season in 2015 (Figure 2c).

283 In mature rubber tree plantations, annual runoff coefficient was highly variable. It ranged
284 from 24% (median of the three OR_s microplots in 2015) to 51% (OR_{1,h} in 2017). Both 2015 and
285 2016 considered, there was no significant difference in monthly runoff coefficient between OR_i
286 and OR_s ($P > 0.3$). In both years, monthly runoff coefficient ranged between 4.4 % (June) and
287 65.6 % (September) in OR_i, and between 4.7 % (May 2016) and 65 % (September 2016, Figure
288 2a,b). It was low at the beginning of the rainy season (until August) and was significantly higher
289 afterwards ($P < 10^{-6}$). From June onwards in 2016, runoff coefficient in OR_i and OR_s was always
290 higher than in M or YR and increased steadily over the rainy season. Annual soil detachment
291 varied from 3.1 kg/m² (OR_i in 2015) to 7.9 kg/m² (OR_s in 2016). It was significantly higher in the
292 late rainy season ($P = 0.003$), with no difference between OR_i and OR_s. All rain events in 2015
293 and 2016 combined, runoff and soil detachment for individual rain events were also
294 significantly higher in OR_i and OR_s than in M and YR (Figure 3).

295 We investigated the relationships between rainfall height and runoff and detachment only in
296 2016, when detailed data from the weather station was available. Both runoff and soil
297 detachment (boxcox-transformed) significantly increased with rainfall and date in all land uses,
298 but with larger slopes coefficients in OR_i and OR_s than in M and YR ($P < 10^{-3}$, Figure 3). This was
299 also the case for other descriptors of rainfall, such as maximum EI_{30} (data not shown).

300 Besides, log-transformed soil detachment increased linearly with log-transformed runoff ($P <$
301 10^{-6}); with a steeper slope in OR_i and OR_s (slope coefficient confidence interval: $1.93 \text{ g L}^{-1} \pm 0.05$
302 g/L) than in YR and M (slope coefficient confidence interval: $1.20 \text{ g L}^{-1} \pm 0.9 \text{ g/L}$; interaction: $P <$
303 10^{-12} ; R^2 for fixed and random effects: 84 %; Figure 4).

304 **3.3. Effect of soil crusting and ground-level plant cover on runoff**

305 In both 2015 and 2016 in M and YR, structural crust covered most of the ground surface
306 except at the end of the rainy season 2016, when free aggregates were particularly abundant in

307 M (Figure 5). Runoff coefficient was not affected by the amount of crop residues (Figure S2, $P >$
308 0.05) but slightly increased with the proportion of crusts ($P = 0.046$), in both the early and late
309 rainy season. However, the soil was rarely bare but covered by weeds or by the crop (Figure 6),
310 therefore a high interception by vegetation occurred during the rainy season.

311 Rubber leaf litter covered a significant part of all microplots in RT plantations, while the rest
312 of the soil was mostly structural crust (Figure 5). Runoff coefficient between 2015 and 2018
313 significantly increased with soil crusting and decreased with crop residues at the beginning of
314 the rainy season in OR plantations (May to Mid-August, Figure S2, $P = < 1 \cdot 10^{-2}$). Contrarily to M
315 and YR plots, herbicide application in late July 2016 in OR_i and OR_s had lasting effects,
316 maintaining a quasi-null living plant cover until the end of the rainy season and corresponded
317 to a leap in runoff coefficients (Figure 6 and see runoff leap in August on Figure 2b). Focusing
318 more specifically on ground cover by low-growing plants in 2017 and 2018 we found that it was
319 often relatively sparse, with one third of the ground cover estimates under 2.9% (low cover),
320 one third between 2.9 and 31% (medium cover), and one third over 31% (high cover). When
321 controlling for rainfall height and for the plot, low ground cover generated significantly higher
322 runoff coefficient ($34\% \pm 4\%$) compared to medium ($28\% \pm 4\%$) or high ($23\% \pm 4\%$) soil cover (P
323 < 0.05). Besides, runoff (square-root transformed) increased with rainfall height (square-root
324 transformed) with a larger slope coefficient when ground cover was low than when it was high
325 (Figure 7). Runoff was also usually higher ($P = 6 \cdot 10^{-4}$), and increased more strongly with rainfall
326 ($P = 1 \cdot 10^{-4}$), in plot OR_2 compared to OR_1 .

327 **4. Discussion**

328 **4.1. Erosion monitoring on steep slopes**

329 It is common in soil erosion studies to discard small rainy events as insignificant (generally
330 less than 0.5 inch, i.e. 12.7 mm, (Wischmeier & Smith, 1978; Renard *et al.*, 1997)) and focus on
331 medium to large events to quantify erosion. We found that indeed, medium and large events
332 accounted for a large part of the runoff and erosion. These large events are the most visible for
333 farmers and public authorities as they can cause gullies, floods or even landslides. On the
334 contrary, small events tend to be overlooked because they have little individual impact.
335 However, we found that events under 25 mm, the most numerous, added up to on average
336 34% of annual rainfall. All years and land uses together, they accounted on average for 20 % of
337 total runoff and 15 % of total detachment. This last figure was probably underestimated

338 because from 2016 onwards we did not measure detachment for events generating runoff < 2 L
339 m⁻². Such results are likely to depend on the context of a given event: for instance, a small
340 event occurring when the soil is still saturated from previous rainfalls is likely to produce
341 relatively high runoff. Besides, small events mobilise particles, which will then be more easily
342 displaced by later events (especially on steep slopes such as the fields investigated here) thus
343 contributing to high detachment during large rain events. Thus, overlooking the cumulative
344 effect of small events could introduce significant underestimations of soil loss assessments.

345 **4.2. Afforestation by RT plantations increases runoff and soil detachment**

346 Maize is widely recognised as a very erosion-prone crop in South-East Asia (Valentin *et al.*,
347 2008). Detachment rates observed under maize in this study were slightly lower than those
348 usually reported in the region (e.g. 6 t/ha/year in Patin *et al.* (2018)), possibly due to relatively
349 high cover by weeds in our study plots and to the absence of mechanical soil preparation.
350 However, we found that in both 2015 and 2016, and despite variations in soil types and
351 meteorological conditions, runoff and soil detachment were consistently higher under OR than
352 M or YR with annual soil detachment rates in OR_i and OR_s on average 10 times (in 2015) and 23
353 times (in 2016) higher than in M and YR.

354 The extent of the difference between OR and M/year was lower in 2015 than in 2016, which
355 can be related both to soil and climatic factors. Firstly, a later monsoon in 2016 with higher
356 rainfall and erosivity at the end of the rainy season (when RT leaf litter had partly disappeared
357 but weeds protected soil surface in M and YR) can explain the stronger effect of land use on
358 runoff in 2016 than in 2015. Secondly, there might be an impact of soil variability: the two soil
359 series found in the area are quite similar, both Haplustalfs characterised by moderate runoff
360 and permeability (Moormann *et al.*, 1966). Nevertheless, Ultic Haplustalfs (M and YR in 2015;
361 OR_i and OR_s in 2016) are thinner soils often truncated by erosion; in such case initially deep
362 clayey horizon can reach shallow position. The effect of soil type on runoff was confirmed in
363 2017 and 2018, where the more clayey soils observed for OR₂ (same plantation as in 2016)
364 generated higher runoff for similar rainfall than the more loamy soils observed for OR₁ (same
365 plantation as in 2015). We changed soil series-land use pairing between the 2015 and 2016 and
366 obtained similar results: the annual runoff and soil detachment observed at 1m² scale were
367 systematically higher for OR_i and OR_s than for M or YR. Thus, while direct comparison between
368 2015 and 2016 is not possible, the higher rates of runoff and detachment for OR_i and OR_s
369 compared to M and YR are consistent; and the possible soil- or weather-related variation in

370 sensitivity to erosion did not exceed nor compensate land-use effects.

371 The higher rates of soil detachment and runoff for OR_i and OR_s were combined with notable
372 soil surface degradation. In 2016, the a_1 coefficients of the linear regressions ($Y=a_0+a_1*X$)
373 between runoff or detachment and rainfall were higher for OR_i and OR_s than for M or YR.
374 Runoff coefficient and soil detachment rates also increased with time along the rainy season
375 with larger a_1 slope coefficient for OR_i and OR_s than for M and YR. This could be explained by
376 higher soil moisture in the late rainy season under mature RT. However, we also found larger a_1
377 coefficients for the regression of detachment versus runoff for OR_i and OR_s than for M and YR.
378 All these elements suggest a gradual decay of soil cohesion and infiltration capacities during the
379 rainy season in mature RT plantations, and overall a higher susceptibility of RT plantations to
380 soil detachment. It is thus important to quantify the resilience of these soil characteristics and
381 to investigate physical (e.g. drying, cracking) or biological (earthworm activity, plant growth)
382 factors that may contribute to the regeneration of both infiltration and cohesion for such
383 degraded soils.

384 **4.3. Factors affecting runoff and detachment in RT plantation**

385 Other recent studies suggested a strongly negative impact on soil erosion of afforestation by
386 tree plantations without convenient understorey management. The transition from open
387 environments to teak plantations caused a large increase of overland flow and soil detachment
388 (Ribolzi *et al.*, 2017) and mature RT are known to be quite prone to erosion (Lacombe *et al.*,
389 2018). The combination of three main factors, i.e. the presence of a high canopy, ground cover
390 by litter, and the low ground cover by living plants, can explain these high erosion rates.

391 **Canopy effect**

392 Even though the size of the leaves of RT and teak trees are very different, both canopies
393 concentrate raindrops, and hence increase their kinetic energy (Liu *et al.*, 2016b; Lacombe *et al.*,
394 2018). In particular, the tree canopy is usually dense close to the tree lines, but sparser
395 between rows, resulting in increased kinetic energy close to the trees. Microplots within tree
396 rows (OR_s) were also located closer to the trees, thus more prone to disturbance from
397 trampling and tapping operations. Thus, we expected higher runoff and detachment within RT
398 rows (OR_s) than between rows (OR_i). However, we did not observe higher soil detachment or
399 runoff under OR_s. This was possibly due to high local variability in the response of individual
400 microplots, as well as in the proportion of cover by leaf litter.

401 **Soil surface: residues and soil crusting**

402 While higher cover by residues under mature RT plantations compared to M or young RT
403 was expected to provide better protection against soil crusting and to decrease runoff
404 (Podwojewski *et al.*, 2008; Patin *et al.*, 2012, 2018), we found that on the contrary runoff and
405 detachment were overall higher under mature RT plantations. This apparent paradox suggests
406 that it is not possible to directly compare the effects of different types of crop residues. Indeed,
407 rubber leaves are waxy (Prüm *et al.*, 2013) and form a tight tiling on the soil surface. Although
408 this cover is still likely to effectively protect the soil from falling raindrops, it might be less
409 effective in controlling surface runoff than (for instance) maize residues, especially in steep
410 areas.

411 When considering only RT plantations, runoff significantly increased with soil crusting and
412 decreased with crop residues cover at the beginning of the rainy season. It was not possible to
413 precisely distinguish between the effect of residues and crust: due to the method of evaluation
414 of soil surface characteristics, a lower crust cover might be due either to actual “uncrusted”
415 surface or to the presence of abundant litter partly covering the crusts. Soil covered by residues
416 is, though, usually less crusted due to direct protection against splash effect and to the
417 presence of microorganisms improving soil structure. Crop residues also slow down runoff,
418 limiting further detachment and favouring redeposition of soil particles. For instance, on gentle
419 slopes, Liu *et al.* (2015) showed that in the early rainy season, runoff and soil detachment were
420 much lower in control RT plantations (>70% litter cover) than in RT plantations with litter
421 removal. However, the dynamics of litter cover under RT are quite specific. In most forests of
422 the area, trees shed leaves continuously ensuring permanent cover. Conversely, defoliation in
423 RT plantations occurs over two weeks in February-March and is rapidly followed by leaf flush.
424 Thus, in our study plots, soil cover by leaves was high at the beginning and middle of the rainy
425 season (>75%); but leaves were progressively destroyed by microorganisms, insects (termites,
426 ants...) or abiotic processes (fragmentation, displacement...). This might explain why the
427 relationship between residues and runoff was not significant in the late rainy season, as the
428 partly decomposed leaves failed to effectively protect soil surface and the proportion of bare
429 soil (on average 45% of the surface) was sufficient to cause surface crusting and high
430 detachment. This supports previous findings by Liu *et al.* (2017) who showed that rubber litter
431 was efficient in controlling runoff and soil detachment only when it covered >70% of the soil
432 surface – hence at the onset of the rainy season.

433 **Ground cover by living plants**

434 Soil cover by plants or leaves is known to decrease splash erosion (Liu *et al.*, 2016a; Lacombe
435 *et al.*, 2018) and to increase infiltration rates. In 2016, while ground cover by weeds was
436 relatively important in M and YR, it was very low in OR_i and OR_s and quasi null from August
437 onwards. Very low ground-level plant biomass in this area has been reported elsewhere (e.g.
438 Neyret *et al.*, 2018) and is probably due to low light availability under the canopy and to a low
439 resilience of the system after herbicide application (part of the usual management process of
440 RT plantation owners in the area). Low ground cover by plants was thus a major factor of high
441 runoff and detachment rates in mature RT plantations.

442 Our estimations of soil cover, available with an extremely high temporal resolution, allowed
443 us to quantify precisely this effect on a rain event basis. We showed that increased cover by
444 ground-level plants significantly reduced soil vulnerability to large rain events. Above 30% of
445 soil cover by ground-level plants, runoff was strongly decreased, suggesting high infiltration
446 capacities. Besides, ground-level plants not only slow down runoff but can also act as sediment
447 traps. Even though soil detachment was not measured for this last experiment, data from
448 previous years showed that detachment increased exponentially with runoff volume. It is thus
449 likely that the effect of soil cover by ground-level plants would be even stronger on soil
450 detachment than on runoff.

451 **4.4. Soil detachment rates in tree plantations of tropical mountainous regions**

452 While high runoff and soil detachment in mature RT plantations are supported by the
453 literature, the amount of runoff and soil detachment we found in this study was higher than
454 previously reported. Our estimation of annual soil detachment in mature RT plantations ranged
455 from 2.8 kg/m²/year to 8.6 kg/m²/year in 2015 and 2016, which was relatively high compared
456 to previous results. At the catchment scale, Ribolzi *et al.* (2017) found a raise of soil loss from 98
457 to 609 t/km²/year in a Laotian mountainous catchment, after conversion from upland rice to
458 teak plantations. On a larger scale, and using a generic soil erosion model, Borrelli *et al.* (2017)
459 estimated erosion rates ranging between 0 and 1 t/ha/year (i.e. 0.1 kg/m²/year) in
460 mountainous Northern Thailand. Nevertheless, it is not possible to directly compare soil
461 detachment measured at the 1m² scale with gross soil loss measured at the catchment or
462 regional scale. Indeed, depending on the rainfall and topographical characteristics, a large part
463 of the sediment is redistributed shortly after detachment. Using 1m² microplots on similarly
464 steep slopes (40-55% on average) and under similar meteorological conditions, Patin *et al.*,

465 (2018) also found lower annual soil detachment under upland rice or maize (resp. 604 ± 86
466 $\text{g/m}^2/\text{year}$ and $796 \pm 83 \text{ g/m}^2/\text{year}$) than under mature teak tree ($2\,948 \pm 523 \text{ g/m}^2/\text{year}$), and
467 this last figure was significantly lower than our data.

468 We consider that the high soil detachment rates observed in this study result from a
469 combination of management practices and topographical characteristics. Indeed, Liu et al.
470 (2015) found that in RT plantations of SW China, bare soil and soil covered with leaf litter
471 produced soil detachment of $4\,700$ and $1\,900 \text{ g/m}^2/\text{year}$, respectively, on gentle slopes. While a
472 steeper slope may decrease soil erosion on bare soils and in open field conditions (Janeau *et al.*,
473 2003; Ribolzi *et al.*, 2011), in this case we think that combined with clear-weeding it favours the
474 exposition of bare soil by partially washing away RT leaves. It has also been observed that the
475 proportion of bare soil under trees increased with slope in both temperate and tropical areas
476 (C. Valentin, personal communication).

477 **Conclusion**

478 Afforestation by RT is currently ongoing in various marginal areas of Southeast Asia. We
479 showed that in mountainous areas, far from promoting soil conservation, this transition
480 increased soil susceptibility to erosion. Particularly high soil detachment under mature RT
481 plantations, either intra- or inter-rows, was related to high proportions of bare soil, especially
482 at the end of the rainy season with little or no understorey and largely degraded litter. Yet we
483 showed that these very high erosion rates could be mitigated by the adoption of less intense
484 weeding practices, encouraging the growth of understorey in RT plantations. We propose three
485 main research axes to work towards better protection of soils in mountainous areas. i.,
486 investigating farmers' motivations and practices in understorey management, in order to
487 identify new sets of agroforestry practices more favourable to soil protection and involving less
488 intense weeding. ii., further understanding of climatic parameters influencing soil detachment
489 and runoff is needed to identify high-risk periods and areas; in this regard, large-scale modelling
490 should always be supported by extensive field measurements. Specifically addressing these
491 erosion hot moments and hot spots may reduce efficiently gross erosion rates by focusing soil
492 conservation efforts on the most erosive periods and on lightly degraded areas, to avoid the
493 expansion of strongly degraded areas and compensate their detrimental outputs. And iii.,
494 additional analyses of the relationships between plant cover and soil erosion processes are
495 needed, especially regarding plant traits that are most appropriate to mitigate erosion. These
496 three axes will shed light on better solutions for striking a balance between soil conservation

497 and farmers' income.

498

499 **Data accessibility**

500 Code and data will be made available online (GitHub and Zenodo) upon acceptance.

501

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510

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619 List of Figures

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621 monthly records started in March 2015.

622 Figure 2 Monthly variations of surface runoff coefficient in 2015 (a), in 2016 (b) and soil detachment in 2015 (c) in maize
623 fields (M), young RT plantations with intercrop (YR), and mature RT plantations inter (OR_i) and within (OR_s) tree rows.
624 Different letters indicated differences significant at 5% within each month.

625 Figure 3 Runoff and soil detachment variations with land use, rainfall height and time since the onset of the rainy season in
626 2016 in maize fields (M), young RT plantations with intercrop (YR), and mature RT plantations inter (OR_i) and within (OR_s)
627 tree rows. Runoff and detachment were transformed using model-specific box-cox transformations, which λ parameter is
628 indicated in each subfigure.

629 Figure 4 Increase of log-transformed soil detachment with log-transformed surface runoff for all individual events
630 causing detachment in 2016 in maize fields (M), young RT plantations with intercrop (YR), and mature RT plantations inter
631 (OR_i) and within (OR_s) tree rows. The effects of log-transformed runoff ($P < 10^{-12}$) and land use ($P < 10^{-12}$) were significant.
632 The slope coefficient in OR_i and OR_s (confidence interval: 1.70 g L^{-1} to 1.95 g L^{-1}) was significantly higher than in YR and M
633 (confidence interval: 1.05 g L^{-1} to 1.52 g L^{-1} ; interaction: $P < 10^{-7}$). R^2 for fixed and random effects was 85 %.

634 Figure 5 Variations of soil surface type during the 4 years of experiment in a. maize fields (M), young RT plantations
635 with intercrop (YR), and mature RT plantations inter (OR_i) and within (OR_s) tree rows and b. the two studied RT plantations,
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637 Figure 6 Evolution of soil cover between May and November, 2016 in maize fields (M), young RT plantations with
638 intercrop (YR), and mature RT plantations inter (OR_i) and within (OR_s) tree rows. Symbols indicate actions realised during
639 the considered month.

640 Figure 7 Effect of rainfall height (mm, square-root transformed) and soil cover by ground-level plants, as assessed from
641 photographs, on runoff (mm, square-root transformed). Each point represents the runoff for one rain event in one
642 microplot, between May and November, in 2017 and 2018. Microplot identity and month were included as random
643 effects. Coloured areas represent the confidence intervals, based on marginal effects (i.e. after controlling for the plot).
644 Proportion of cover $P = 1.10^{-6}$, Rainfall $P < 10^{-12}$, Plot $P = 6.10^{-4}$. Interaction between the proportion of cover and rainfall:
645 $P = 1.10^{-8}$. Different letters indicate significant slope differences ($P < 0.05$).

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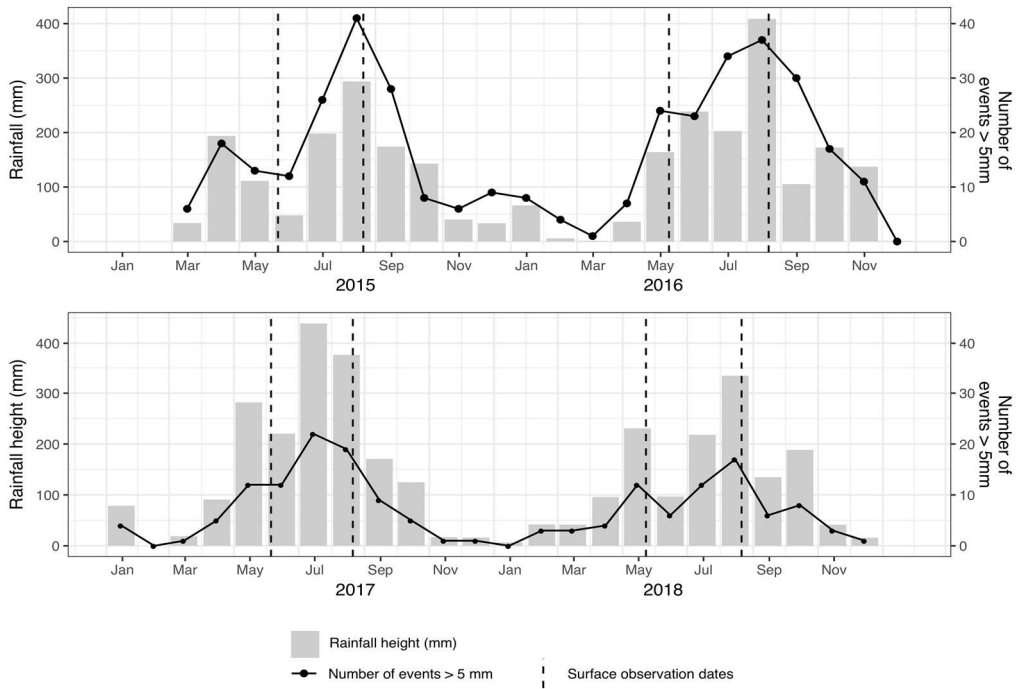
653 **List of tables**

654 **Table 1** Plot characteristics in maize fields (M), young RT plantations with intercrop (YR), and mature RT plantations
655 inter (OR_i) and within (OR_s) tree rows. Soil belonged to two soil series: Mollek (MI) and Wang saphung (Ws). Soil series
656 and textures were obtained from Jumpa (2012). Gly = glyphosate, Gra = gramoxone, Atr = Atrazine. Tree girth was
657 averaged over at least 25 trees, numbers preceded by “~” indicate too few measurements to provide a very precise
658 estimation.

659 **Table 2** Cumulative rainfall height separated by rain event size from 2015 to 2018 in maize fields (M), young RT
660 plantations with intercrop (YR), and mature RT plantations inter (OR_i) and within (OR_s) tree rows. In 2015, 2017 and 2018
661 results are presented separately for M/year and OR i/ORs (2015) and OR2/ OR4 (2017-2018) because of rainfall spatial
662 variability. Rainfall in 2015 was measured only from March onwards; for the following years it is measured from January
663 1st. For runoff and detachment data, each line shows the data for one individual microplot.

Figure 1: Seasonal variations of a. rainfall height (mm) and b. rainfall erosivity between 2015 and 2018. Note that monthly records started in March 2015.

a.



b.

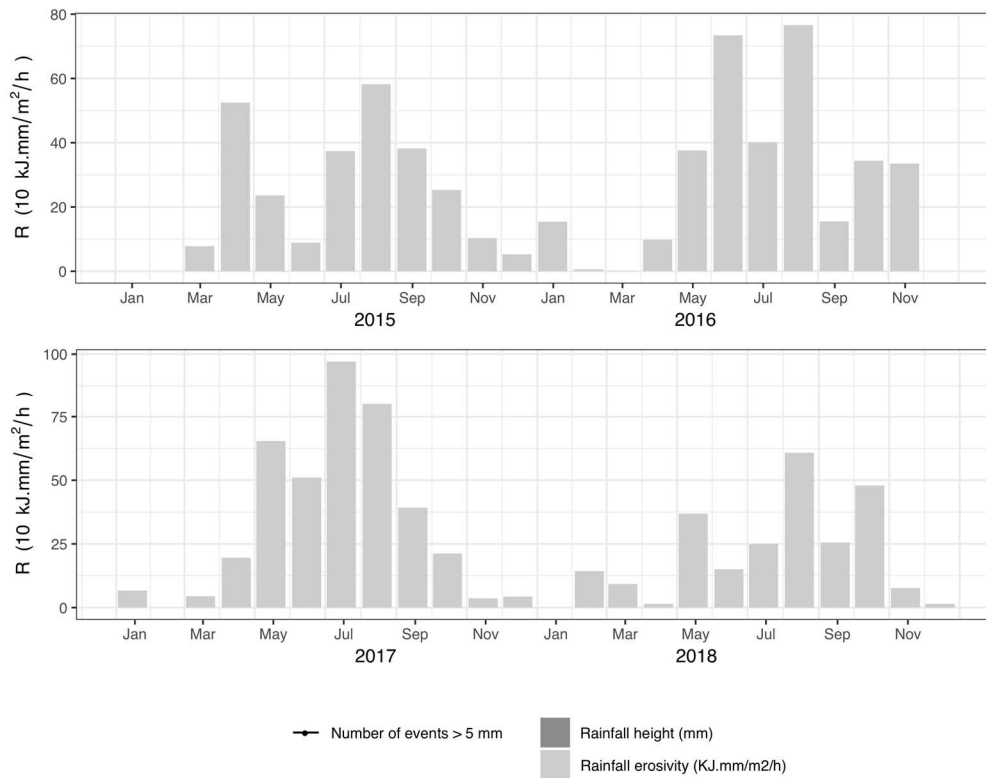


Figure 2 Monthly variations of surface runoff coefficient in 2015 (a), in 2016 (b) and soil detachment in 2015 (c) in maize fields (M), young RT plantations with intercrop (YR), and mature RT plantations inter (OR_i) and within (OR_s) tree rows. Different letters indicate differences significant at 5% within each month.

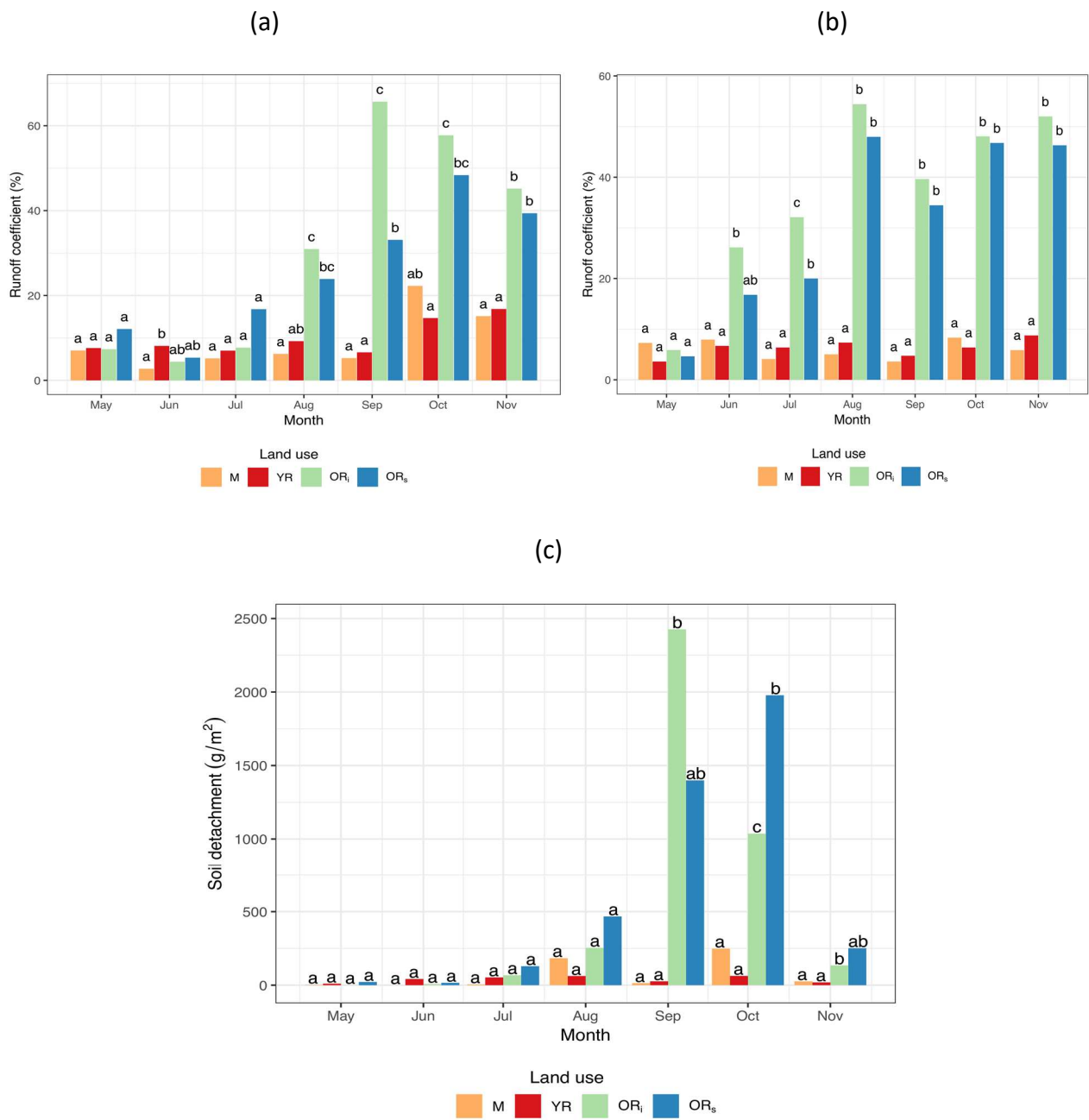
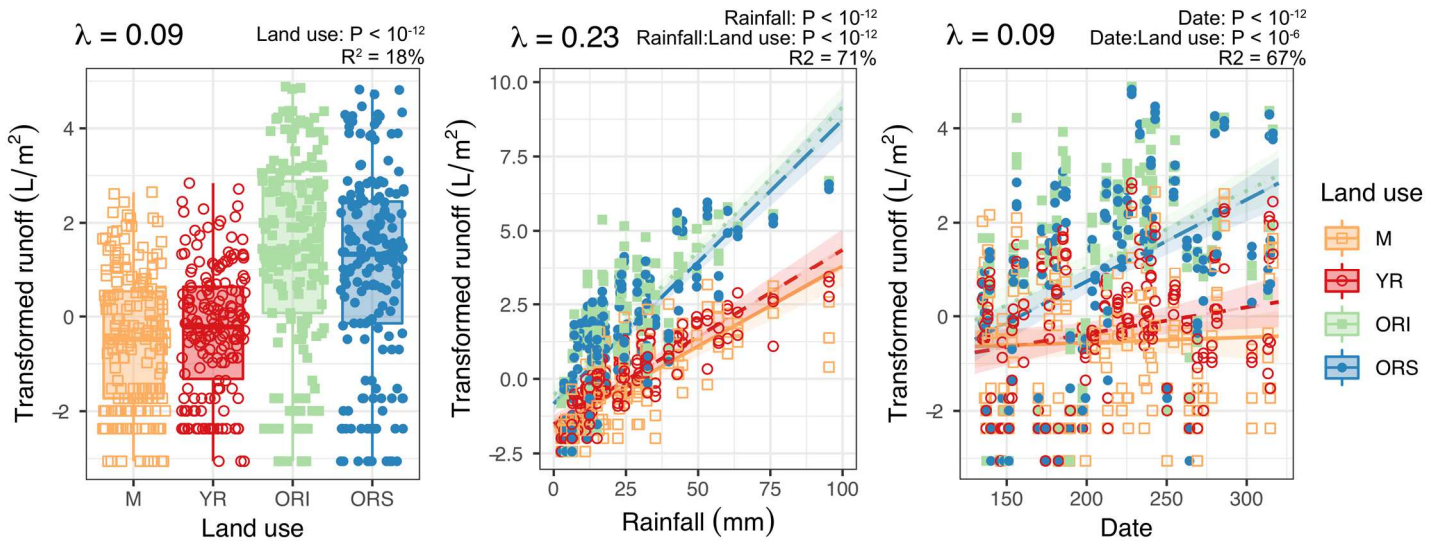


Figure 3 Runoff and soil detachment variations with land use, rainfall height and time since the onset of the rainy season in 2016 in maize fields (M), young RT plantations with intercrop (YR), and mature RT plantations inter (OR_i) and within (OR_s) tree rows. Runoff and detachment were transformed using model-specific box-cox transformations, which λ parameter is indicated in each subfigure.

(a) Runoff



(b) Detachment

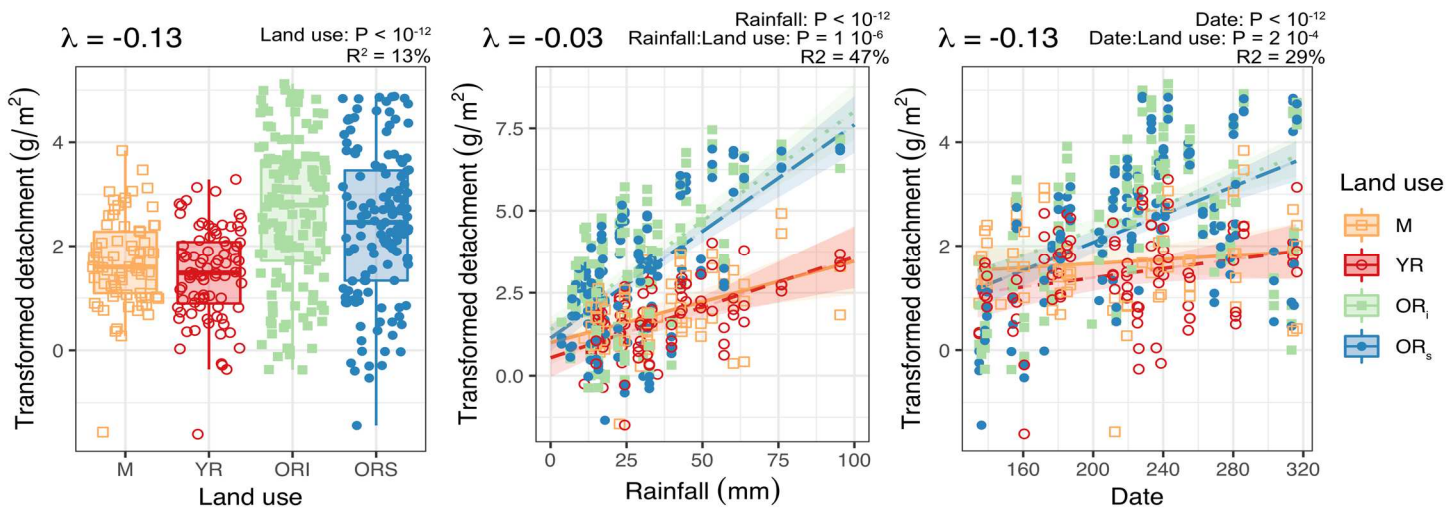


Figure 4 Increase of log-transformed soil detachment with log-transformed surface runoff for all individual events causing detachment in 2016 in maize fields (M), young RT plantations with intercrop (YR), and mature RT plantations inter (OR_i) and within (OR_s) tree rows. The effects of log-transformed runoff ($P < 10^{-12}$) and land use ($P < 10^{-12}$) were significant. The slope coefficient in OR_i and OR_s (confidence interval: 1.70 g L^{-1} to 1.95 g L^{-1}) was significantly higher than in YR and M (confidence interval: 1.05 g L^{-1} to 1.52 g L^{-1} ; interaction: $P < 10^{-7}$). R^2 for fixed and random effects was 85 %.

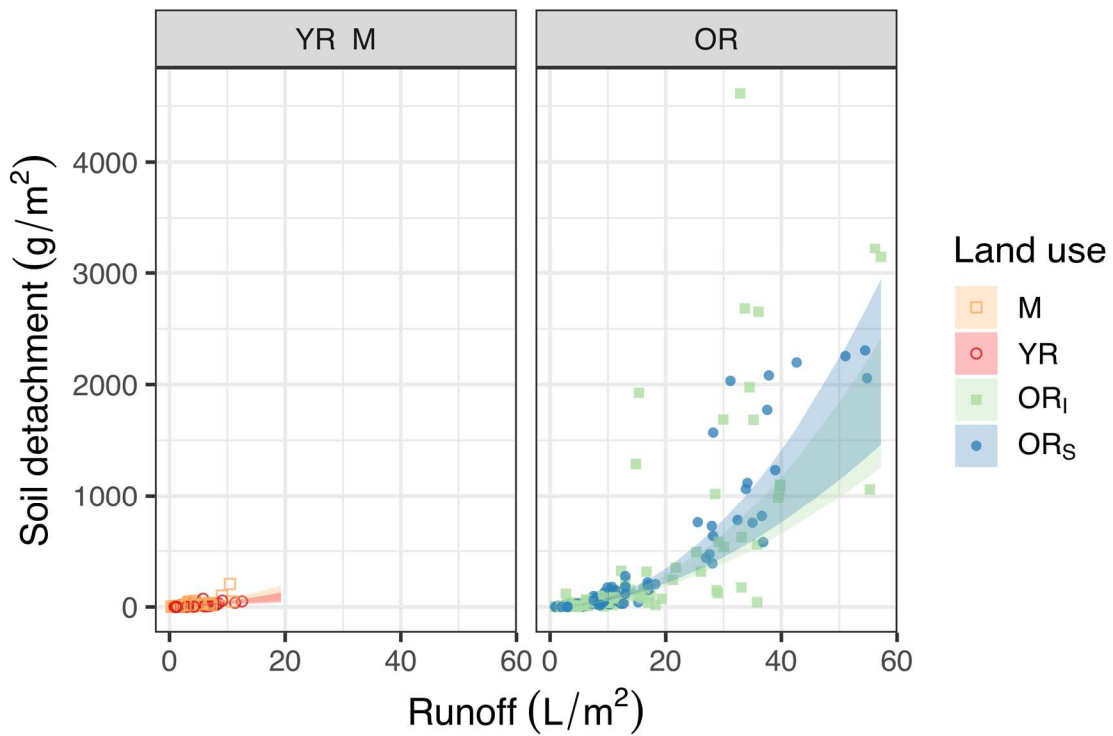


Figure 5 Variations of soil surface type during the 4 years of experiment in a. maize fields (M), young RT plantations with intercrop (YR), and mature RT plantations inter (OR_i) and within (OR_s) tree rows and b. the two studied RT plantations, with (OR_h) or without (OR_{nh}) herbicide application.

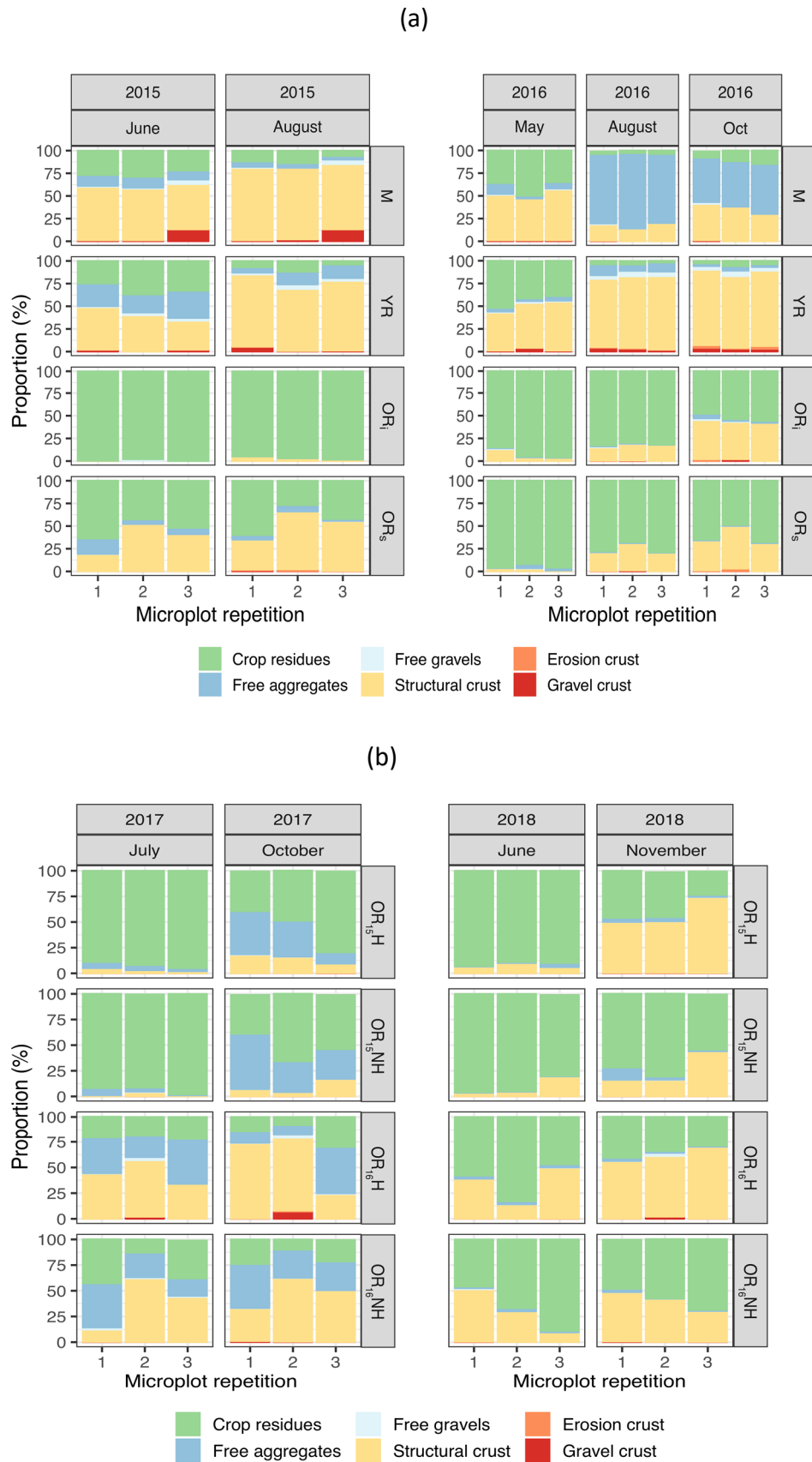
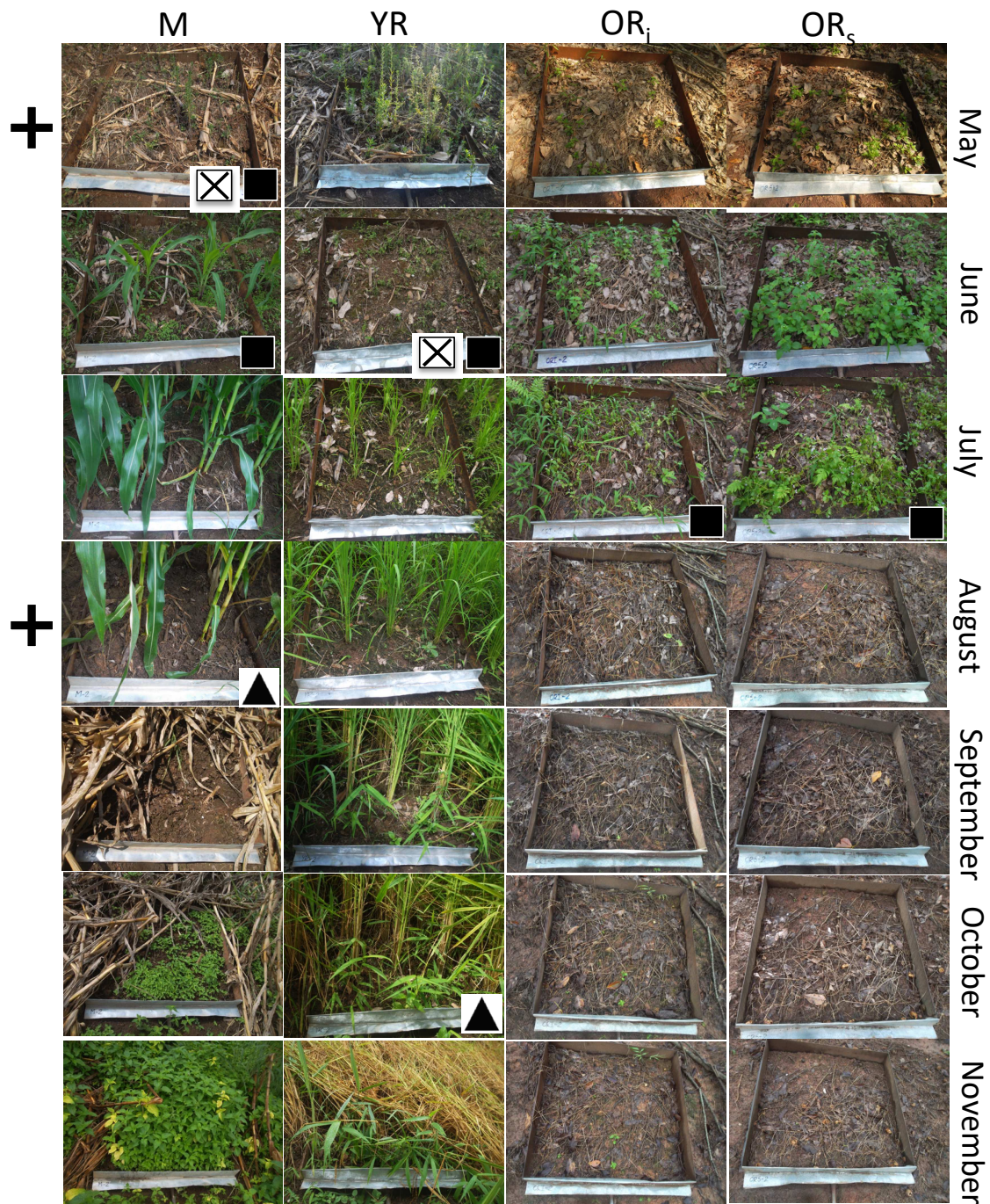


Figure 6 Evolution of soil cover between May and November, 2016 in maize fields (M), young RT plantations with intercrop (YR), and mature RT plantations inter (OR_i) and within (OR_s) tree rows. Symbols indicate actions realised during the considered month.



Herbicide spraying Harvest
 Sowing Observation

Figure 3 Effect of rainfall height (mm, square-root transformed) and soil cover by ground-level plants, as assessed from photographs, on runoff (mm, square-root transformed). Each point represents the runoff for one rain event in one microplot, between May and November, in 2017 and 2018. Microplot identity and month were included as random effects. Coloured areas represent the confidence intervals, based on marginal effects (i.e. after controlling for the plot). Proportion of cover $P = 1 \cdot 10^{-6}$, Rainfall $P < 10^{-12}$, Plot $P = 6 \cdot 10^{-4}$. Interaction between proportion of cover and rainfall: $P = 1 \cdot 10^{-8}$. Different letters indicate significant slope differences ($P < 0.05$).

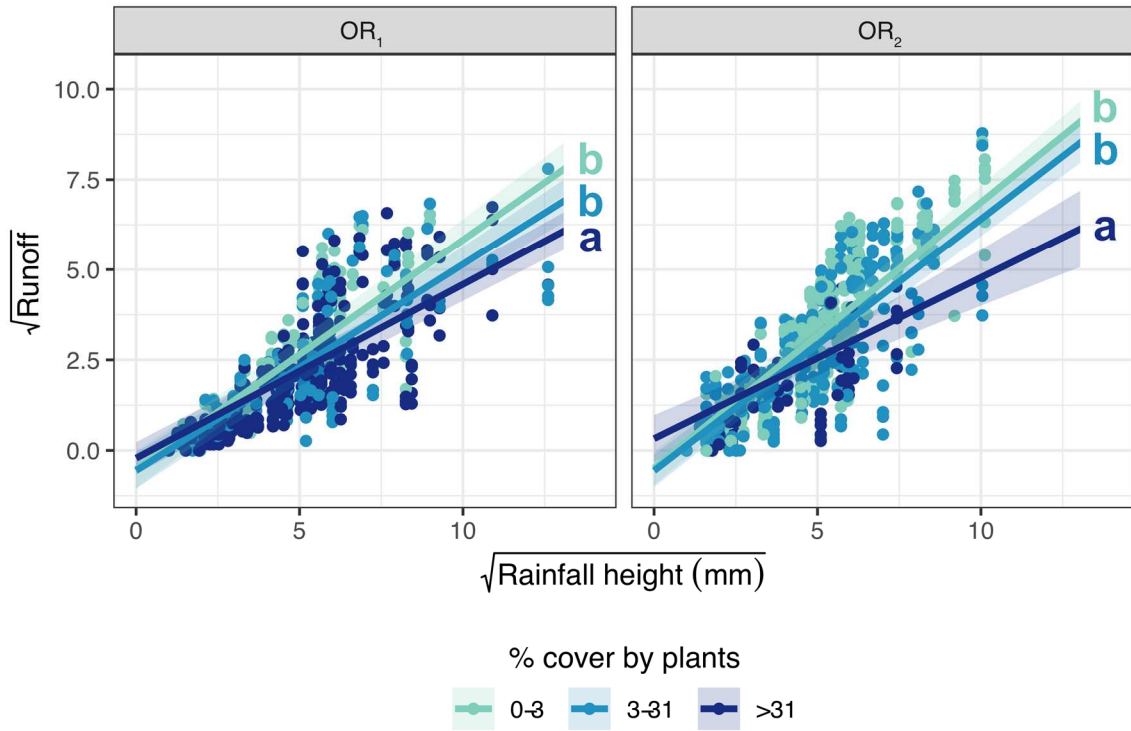


Table 1 Plot characteristics in maize fields (M), young RT plantations with intercrop (YR), and mature RT plantations inter (OR_i) and within (OR_s) tree rows. Soil belonged to two soil series: Moklek (Ml) and Wang saphung (Ws). Soil series and textures were obtained from Jumpa (2012). Gly = glyphosate, Gra = gramoxone, Atr = Atrazine. Tree girth was averaged over at least 25 trees, numbers preceded by “~” indicate too few measurements to provide a very precise estimation.

Year	Land use	Soil series	USDA soil texture	Tree girth (cm)	Tree planting grid (m)	Baseline herbicide application
2015	M	Ml	Clay	/	/	Gly (April), Gra (May)
	YR	Ml	Clay	~ 20	3 x 6.5	Gly (April)
	OR _i	Ws	Clay		3.5 x 7	None
	OR _s	Ws	Clay	48.9 +/- 6.1	3.5 x 7	None
2016	M	Ws	Loam	/	/	Gly + Atr (May), Gra (July)
	YR	Ws	Clay-loam to loam	20.0 +/- 5.2	3 x 6.5	Gly (April)
	OR _i	Ml	Clay to clay-loam		3.5 x 7	Gly (July, October)
	OR _s	Ml	Clay to clay-loam	~ 54	3.5 x 7	Gly (July, October)
2017-2018	OR ₁	Ws	Clay	56.1 +/- 5.8	3.5 x 7	None*
	OR ₂	Ml	Clay to clay-loam	58.8 +/- 10.4	3.5 x 7	Gly* (July, October)

* Baseline application. It was modified in half the plots in 2017 and 2018, resulting in half the plots receiving no herbicides and the other half receiving glyphosate in July and October in both plantations.

Table 2 Cumulative rainfall height separated by rain event size from 2015 to 2018 in maize fields (M), young RT plantations with intercrop (YR), and mature RT plantations inter (OR_i) and within (OR_s) tree rows. In 2015, 2017 and 2018 results are presented separately for M/year and OR_i/ORs (2015) and OR2/ OR4 (2017-2018) because of rainfall spatial variability. Rainfall in 2015 was measured only from March onwards; for the following years it is measured from January 1st. For runoff and detachment data, each line shows the data for one individual microplot.

Year	Land use	Rainfall (mm) & (number of events)				Runoff (L/m ²)				Soil detachment (g/m ²)			
		<25mm	25-50mm	>50mm	Total	<25mm	25-50mm	>50mm	Total	<25mm	25-50mm	>50mm	Total
2015	M					5	24	13	42	1	47	87	136
						10	60	26	95	5	735	143	883
		552 (80)	472 (14)	214 (3)	1238 (97)	18	65	40	123	11	250	173	434
	YR					28	57	38	122	60	249	157	466
						25	55	20	101	105	149	51	305
						12	32	13	58	9	89	9	107
	ORS					75	170	65	309	625	2973	492	4090
						79	165	81	325	409	3137	1799	5344
		583 (81)	490 (13)	221 (3)	1295 (97)	58	115	62	234	268	1846	1236	3350
	ORI					64	251	62	376	186	2230	367	2784
						97	283	43	423	709	4819	365	5894
						64	266	24	354	181	2348	569	3098
2016	M					18	19	28	65	17	79	267	364
						20	24	31	75	48	125	189	362
						38	42	36	116	92	134	137	363
	YR					24	31	41	97	41	86	202	330
						26	33	40	99	50	103	102	255
		634 (79)	499 (14)	406 (6)	1539 (99)	26	30	27	83	57	125	81	263
	ORI					122	163	233	518	606	1029	4841	6476
						199	201	216	616	1711	1811	4365	7887
						165	168	210	543	1487	1625	4812	7923
	ORS					135	152	209	496	975	1746	5900	8621
						101	119	178	398	743	1311	3743	5798
						139	167	203	508	1024	1858	4920	7803
2017	OR1,h					58	285	322	664				
						56	257	219	532				
		336 (35)	751 (23)	898 (11)	1985 (69)	57	260	273	590				
	OR1,nh					52	237	226	515				
						35	179	137	351				
						58	261	208	528				
	OR2,h					164	450	398	1013				
						156	455	344	955				
		391 (38)	781 (22)	702 (9)	1874 (69)	105	347	271	724				
	OR2,nh					85	290	188	564				
						155	414	373	943				
						95	371	291	757				
2018	OR1,h					77	208	101	385				
						81	230	104	414				
		541 (56)	681 (19)	409 (5)	1631 (80)	68	217	112	397				
	OR1,nh					35	127	43	204				
						47	127	42	215				
						52	158	61	271				
	OR2,h					171	318	162	651				
						95	301	137	533				
		493 (56)	637 (19)	297 (6)	1427 (81)	74	206	105	385				
	OR2,nh					62	192	97	351				
						78	242	130	450				
						86	186	108	381				