Margot Neyret

Ecological changes along the transition from annual crops to rubber plantations in Northern Thailand

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Encadrants: Henri Robain & Anneke de Rouw

IRD
Institut de recherche
pour le développement

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Contents

1 Introduction

Economic development in South-East Asia led to a rapid agricultural transition from sub-sistance to cash and exportation crops. In mountainous areas of Northern Thailand, rubber tree (*Hevea brasiliensis*) plantations have been encouraged as a mean to raise farmers' income and to restore degraded lands (Trébuil et al. 2006). However, rubber plantations are being planted in increasingly marginal areas which endangers their sustainability. The transition from swidden agriculture to tree plantations has raised important concerns about biodiversity (Rerkasem et al. 2009), but also regarding the depletion of carbon stocks and water ressources (de Blécourt et al. 2013; Fox et al. 2013; Fox et al. 2014; Warren-Thomas et al. 2015); besides, soil degradation and loss of fertility are serious problems in these areas very subjected to erosion (Paiboonvorachat et al. 2011; Janeau et al. 2003). Non-cultivated biodiversity has been shown to be a major component of biodiversity conservation as well as erosion control and soil stability (Jackson et al. 2007; Moonen et al. 2008; Navas 2012).

Thus, understanding of how weed communities respond to changing management practices and interact with erosion-related soil characteristics could provide relevant information for promoting both soil and biodiversity conservation in this area. But while the effects of landscape homogeneisation and agricultural intensification on weeds has been well described in Europe (Jose-Maria et al. 2011; Fried et al. 2012; de Mol et al. 2015; Petit et al. 2014) or other intensive areas (e.g. Argentine, (Puricelli et al. 2012; Scursoni et al. 2014)), fewer studies have described the evolution of weed communities in response to land-use change in South-East Asia (Rerkasem et al. 2009; Beukema et al. 2007; Gnanavelrajah et al. 2007). This study aims at investigating the relations between management practices, weed communities and soil physical properties. In this introduction I review the main roles of weeds in the agroecosystem, especially regarding soil protection. I will also describe previous findings regarding agricultural intensification's effects on weeds and current situation in South-East Asia.

1.1 The role of weeds in the agroecosystem

Various studies have shown that diverse plant communities in arable lands promote biodiversity at higher levels by providing food and habitats to arthropods and birds, especially for species specialist of cultivated areas (Marshall et al. 2003). Furthermore, a high plant diversity provides food sources during extended periods (Edesi et al. 2012) and promotes large and rich populations of pollinators necessary to the cultivation of arthropod-pollinated crops (Bàrberi et al. 2010). Weeds also play a role in the regulation of crop pests. They can provide habitat or food resources to harmful instects or disease vectors (Franke et al. 2009). Yet, they sometimes also limit pests' impact on crop by preventing them to complete their life cycle and by favouring arthropod diversity and pest regulation by their natural enemies (Bàrberi et al. 2010).

Plants also favor soil protection by enhancing its resistance and resilience. Soil resistance is defined as its capacity to maintain its functions, i.e. sustaining biological diversity, regulating water flow, detoxifying and storing nutrients (Herrick and Wander 1998 in Seybold et al. (1999)). Thus soil degradation can take many forms, such as a decrease in nutrient stocks, a compaction related to the loss of porosity, or the loss of soil itself. While relations between weeds and soil resistance have not been well described, plant cover has been shown to support soil fertility (Durán Zuazo et al. 2008) and to control erosion (Nearing et al. 2005; Durán Zuazo et al. 2008). Plants also participate to soil resilience - i.e. its ability to recover its functional and structural integrity after a degradation (Herrick and Wander 1998 in Seybold et al. (1999)) - such as supporting biological diversity and restoring surface conditions allowing infiltration. Biological activity is essential to most of the recovery mechanisms including nutrients cycling, detoxification, and structure stabilisation (Seybold et al. 1999). Thus plants enhance both the speed and extent of the recovery through litter accumulation and interactions with micro-organisms.

According to the ecological insurance hypothesis (Loreau et al. 2003), the diversity of the components within a system favors its stability and long-term resilience. Thus, the conservation of weeds biodiversity in a context of agricultural intensification might be a key element in maintaining or enhancing agroecosystems functionning by promoting soil conservation.

1.2   Impact of agricultural intensification on weeds communities

Most studies focusing on weeds' response to land-use changes have been conducted in Europe, where the homogenisation of agricultural landscapes and the intensification led to a drastic decrease in plant diversity (Foley et al. 2004; Matson et al. 1997; Kleijn et al. 2009). Similar results have been found in Asia (Zhao et al. 2006; van Vliet et al. 2012; Sodhi et al. 2010), and associated to major changes in ecosystem functioning (Barnes et al. 2014). These interactions between agricultural practices and weed communities, and their impact on the environment - such as soil conservation - emerge at various spatial (rhizosphere, field, landscape) and time (from days for rainfall events to millenia for soil formation) scales.
Studies of weed communities usually distinguish between abiotic factors and agricultural practices (Edesi et al. 2012; de Mol et al. 2015). Navas (2012) proposed to further distinguish local conditions (climate, soil) from crop abiotic factors (previous crop, fertilisation, weeding practices). For instance, Fried et al. (2008b) showed that French weed communities differ strongly depending on soil type, rainfall and longitude. But although climate is the first parameter affecting weeds communities, management also impacts strongly communities composition (de Mol et al. 2015), as has been shown for instance in soil seedbanks (Hosseini et al. 2014; De Rouw et al. 2014).

1.3 Agrarian transition and rubber tree expansion in Northern Thailand

Montainous South-East Asia, which covers Northern Thailand, parts of Cambodgia, Lao, Myanmar and Yunnan, is a hotspot of biodiversity. Is has been traditionnaly dominated by swidden agriculture favouring a high diversity of crops and non-cultivated plants (Rerkasem et al. 2009) as well as hydric and soil resources conservation (Fox et al. 2005). Yet in the past decades demographic growth caused increasing pressures on the environment (Rerkasem et al. 1995). Integration to the global market led to the expansion of cash crops and the increased use of chemicals (Riwthong et al. 2015), leading in Thailand to the raise of an agriculture mostly based on exportation (Trébuil et al. 2006).

In particular, national and international institutions have greatly encouraged the expansion of rubber plantations, even in sub-optimal environments such as Northern Thailand (Fox et al. 2013). While rubber was seen as a way to reforest degraded areas and to increase farmers' revenues, its social and environmental conseqences are not benign (Ahrends et al. 2015). Plantations often replaced secondary forests, leading to severe losses in animal and plant biodiversity (Warren-Thomas et al. 2015; Cotter et al. 2009; Beukema et al. 2007) and to the degradation of organic carbon stocks (de Blécourt et al. 2014). While these impacts are lessened when the area was previously cultivated, rubber monocultures in suboptimal areas have been shown to degrade soil quality, to disturb hydrological regimes and to modify local microclimates (Ahrends et al. 2015; Fox et al. 2014). Recent studies also suggest a strong reduction of soil biodiversity (Brauman et al. 2014) and an increase in erosion rates (Lestrelin et al. 2012; Valentin et al. 2008), at least in the early stage of the plantations.

1.4 Scope of the study

This study investigates weed communities and soil characteristics along a transition from annual crops to perennial rubber plantations. More specifically, we use a synchronic approach to compare rice (traditionnaly produced for self-consumption), maize (more recently introduced as a cash crop), young rubber plantations (grown with maize intercrop) and mature rubber plantation (tapped for selling latex) in Northern Thailand to answer the following question: **what are the interactions between management practices, weed communities and soil characteristics in a context of land-use change in mountainous, erosion-prone areas?**

More specifically, this study aims at :

1. Describing plant communities in terms of richness, abundance, and composition (part 3.1). While descriptions of Thai flora exist, little is available regarding weed species in maize and rubber plantations in Thailand (Nam-Matra 2017; Gnanavelrajah et al. 2007; Thothong et al. 2011), and to my knowledge nothing in this particular area.

2. Investigating the effect of land-use type and weeding methods on weed communities (part 3.2, 3.3).

3. Studying the interactions between plant communities and soil and landscape characteristics (part 3.4).

We hypothesize that: 1) land-use types and related management practices have a strong effect on weed communities' abundance and composition. In particular, low-intensity land uses result in richer weeds communities while intensive mature rubber plantations are subject to management and environmental (shade) pressures constraining weeds' abundance and richness. And 2) weed communities impact soil characteristics; weeds' abundance and richness in particular have positive effects on soil bulk density and humidity.

2   Material and Methods

2.1   Data collection

2.1.1   Study sites

Study sites were located in Huai Lang, Wiang Kaen district, in Northern Thailand (100°27'E, 20°55'N, c.f. map 2a). Cultivated lands cover most of the area, are usually located on very steep slopes (often more than 50%) and are subject to strong degradations from erosion. Two small catchment areas (one under annual crops mostly (ACC), the other under rubber tree (*Hevea brasiliensis*, Euphorbiaceae) plantations (RTC)) have been equiped with hydrological stations where discharge and suspended sediment loads are monitored since March and June 2015 (RTC and ACC, respectively). The monitoring of the streams is complemented with erosion plots where runoff and soil detachment are recorded after each rainy event. Meteorological data was recorded close to the two catchments from March, 2015. Reference evapotranspiration (ET_O) was only measured from March, 2016; but relative air humidity provides indications about evaporation demand (fig. 1b). In the year before the experiment, daily average temperature varied from 6.20 °C to 30.88 °C, with an average of 24.38 °C (fig. 1a). Total rainfall was 1346mm, with a strong seasonality (c.f. fig. 1c) characterized by a rainy season from April to September. The rainy season usually starts later, in May.

(a) Temperature	(b) Relative Humidity	(c) Total rainfall
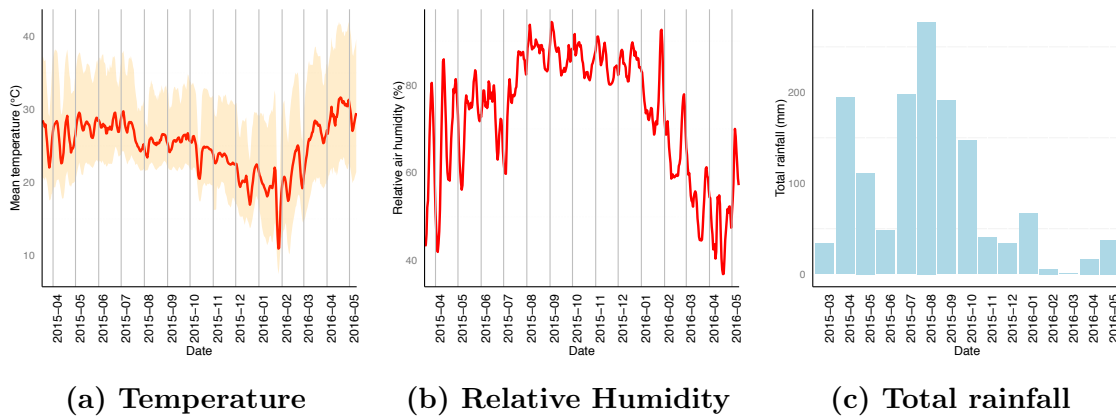
*Figure 1: **Meteorological data from March, 2015 to May, 2016***
Meteorological data was recorded in a meteo station very close to the catchments. Daily data for fig.1a and 1b have been averaged on a 5 days window for enhanced clarity. Orange ribbon in fig. 1a indicates daily minimal and maximal temperatures, averaged in a similar way.

All the plots were sampled between March, 6th and March, 30th, 2016. During this period, mean temperature was 26.9°C (daily minimum 17.0°C, maximum 39.7°C). Only two rainfall events were recorded, both with durations shorter than 1 minute and a cumul of less than 1 mm. Hence, the Antecedent Precipitation Index (API, a theoretical proxi of soil water content remaining from previous rains (Descroix et al. 2002)) was very small (under 0.1), which indicates that soil moisture was not dependant anymore on previous rains and was decreasing from evapotranspiration and drainage. Sampling was carried out during a period shortly preceding the beginning of planting season and hence before the beginning of

weeding and planting operations. Farmers had not started yet the tapping of rubber trees, which usually begins in May after the onset of the rainy season.

2.1.2   Sampling protocol

We sampled 5 sites for 4 main land-use types relevant for the transition from annual to perenial cultivation (upland rice (code ULR), maize (M), young rubber with maize intercrop (YR), and mature plantations (OR)) in or very close to the catchments. The distribution of the plots in the area is indicated in map 2b. According to a recent report from the Land Development Department (LDD), soils were loamy clays and belonged to 3 main soil series (Moklek, Woongsapoong and Thali series); they were mostly differenciated on depth and slope criteria (Jumpa 2012). Table S1 summarizes geomorphological and pedological data available for all plots.

(a) Position of Huai Lang in Thailand

(b) Repartition of plots in the area.

Figure 2: ***Location of Huai Lang and sampled plots***
The location of Huai Lang is represented on map 2a by the pink label.

In each site, one 10m x 10m plot was set in a representative area. Five $1m^2$ microplots were randomly chosen for further analysis, and covered with a PVC frame with a 20cm x 20cm grid (c.f. picture 3).

2.1.3   Description of plant cover

Plant cover was described at different levels.

The $100m^2$ plot was divided in a 2m x 2m grid, in which all lignous plants and C4 grasses were counted and identified.

Each of the five microplots was first photographed to measure total soil cover. The pictures were taken at 150cm above ground level, as parallel to the ground as possible. Residues (rice, maize and rubber; "residues biomass") and dry weeds ("dry biomass") where then sampled separately. A second picture was then taken to determine the proportion of soil covered by living plants (fig. 3). Finally, all living plants in each 20cm x 20cm square

(a) ULR3-2 (total cover)

(b) ULR3-2 (living cover)

(c) OR2-3 (total cover)

(d) OR2-3 (living cover)
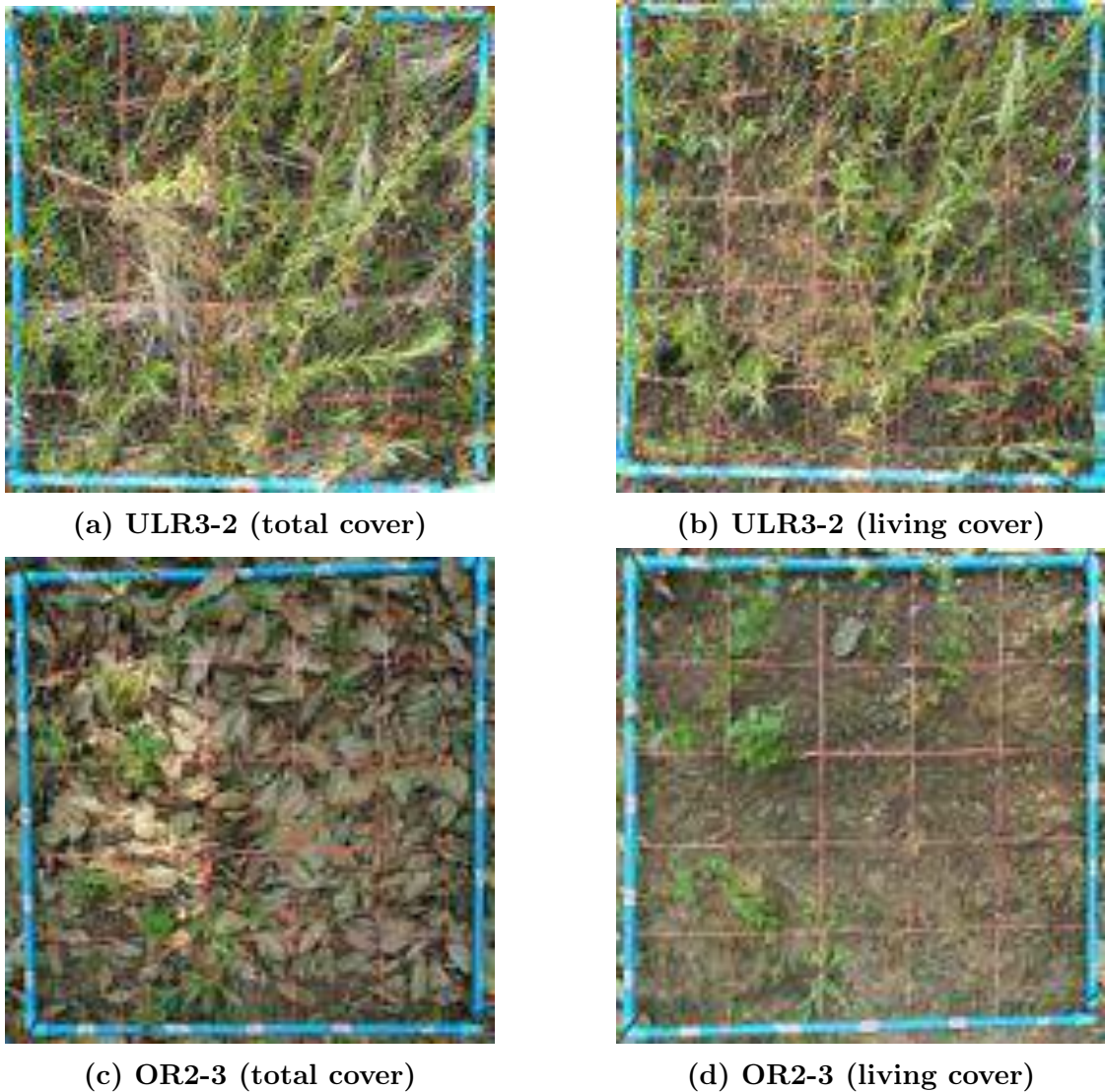
Figure 3: **Exemples of microplots before and after residues and dry biomass removal**

were counted, sampled and identified when possible. Residues, dry, and living biomass were stored in paper bags, then oven-dried and weighted at the end of April. Herbarium specimens of all the species encountered were sampled for record and further identification. Identification was realized by Bounsamai Soulileuth, botanist, who participated to part of the fieldwork.

In order to measure total soil cover by both dead and living plants and partial soil cover by living plants only, I first straightened the pictures to correct for perspective deformation using the GIMP software (GIMP core team 2015). The area of soil covered with vegetation was then calculated with ImageJ (Schindelin 2012), using visually adjusted color thresholding for each image. This method was only appropriate to measure partial soil cover by living plants, because it allowed to detect green areas corresponding to living plants. The measurement of total soil cover, that cannot rely on color detection only, will require the development of more precise methods and will not be used in this report.

The abundance of living weeds (individuals density, living soil cover and fresh biomass) decreased with time (p <0.05). Fig. S2 shows a strong decrease of these characteristics from day 15 (around April, 22nd). However to limit the effect of the time lapse required to complete the survey, we took care to entertwine the various land-use types in our sampling design. Thus, these variations are unlikely to affect general results described in this report.

2.1.4 Description of soil characteristics

After total plant removal, 8 pictures were taken from each microplot to further measure soil surface characteristics by photogrametry (Remondino et al. 2006). This data will not be analysed here.

Humidity was measured with a TDR probe (ML3 - ThetaProbe Soil Moisture Sensor; Delta-T devices, UK). 13 measurements (i.e. half of the positions defined by a 20cm x 20cm grid) were taken for each microplot, resulting in a total of 65 measurements per plot. $100cm^3$ of dry soil were sampled using a cylinder, and in the flattest of the neighbouring squares of the grid we realized a Beerkan infiltration test (Lassabatere et al. 2006): after sinking a 7.6cm cylinder vertically in the soil, we measured time needed to infiltrate a unit volume of 60ml of water. We continued pouring water and timing infiltration time for 30 minutes or until at least 20 volumes were poured. Due to time constraints, infiltration curves could not be processed yet. Finally, a $100cm^3$ cylinder of wet soil was sampled at the place of infiltration.

Both dry and wet soil samples were stored in impervious plastic bags. They were weighted, oven-dried and weighted again at the end of April to determine bulk density, porosity and saturation before and after infiltration test, respectively.

We thus had two different measures of humidity: TDR measures at the square level and soil sample humidity at the microplot level. Only humidity measured in samples will be used, except in part 3.4.2 where humidity measured by TDR will also be described for finer-scale investigation.

2.1.5 Topographical data

The position of the plot corners, of each microplot and of rubber trees in rubber plantations were recorded using a theodolite (Total station DTM320, Nikon). GPS coordinates were recorded using a GPSMAP Garmin 62S. Local slopes of each plot and microplots were calculated using the software Surfer (Surfer v12.8, Golden sofware Inc.). Global slope, exposition, and position of each plot on the hillside were estimated from existing topographical maps (c.f. table S1, fig. S1).

2.1.6 Description of farming practices

In order to investigate weeding practices and fields' history, we set up a questionnaire and interviewed at their home the owner of each field. The 20 investigated sites belonged to

a total of 15 farmers, among which one refused to be interviewed. The questionnaire (see english version in figure S3) was translated and conducted in thai language by one of the team's native thai speaker. It addressed primarily weeding practices, i.e. the types and dose of herbicides and fertilizers, the time spent on and method for manual weeding, and the field-cleaning techniques.

In addition to this questionnaire, 2 semi-structured interviews were also conducted in their fields with two farmers in order to investigate more deeply farmers' knowledge about weeds and their management. Due to time constraints and farmers' availability, it was not possible to do more field interviews.

2.2   Data analyses

All statistical analyses were conducted using the R software (R Core Team 2013).

2.2.1   Plant communities

Ordination methods are commonly used to investigate community structure in Ecology; correspondance analyses are particularly suitable for species abundance or species presence/absence matrices (Borcard et al. 2011). Detrended correspondance analysis is widely used as a way to correct for edge and arch effects in environmental gradients (see Hill et al. (1980) and function *decorana*, package VEGAN). While this method has various drawbacks (data distortion, no significance test) other methods (e.g. Hellinger transformation and canonical correspondance analysis) gave results difficult to interpret, and I thus chose to present only *decorana* results.

The results of the ordination were subsequently used to investigate data clustering (k-means: function *pam*, package CLUSTER) and hierarchical classification (function *hclust*). I also fitted these results to management and soil variables using the *envfit* function (package VEGAN).

2.2.2   Diversity indices

Our nested sampling protocol provides various levels to study diversity. Diversity α_μ (resp. α_p) refers to the richness of one microplot (resp. plot), while diversity β_μ (resp. β_p) refers to the variation of the microplots within one plot (resp. of the plots within one land-use type).

While species diversity provides information about all the species present in a site, Shannon index also accounts for species' relative abundance. Shannon measures can be easily decomposed into independant alpha and beta diversity components, which is not the case for other indices such as Jaccard, Sorensen, or Morisita-Horn (Jost 2007). Besides, Jost (2007) suggests to transform diversity indices into their effective numbers of species, i.e. the number of species equally distributed that gives the same index, for easier interpretation.

I thus used:

$$\alpha_\mu = exp(H_\mu) = exp(-\sum_{k=1}^{n} \pi_k ln\pi_k) \qquad \beta_p = \alpha_p - \frac{1}{n}\sum_{i=1}^{m} \alpha_{\mu,i}$$

$$\alpha_p = exp(H_p) = exp(\sum_{l=1}^{N} \pi_l ln\pi_l) \qquad \beta_c = \alpha_c - \frac{1}{n}\sum_{j=1}^{M} \alpha_{p,j} \tag{1}$$

With n (resp. N) the number of species in the microplot, π_k (resp. π_l) the abundance of species k in the microplot (resp. the plot), and m (resp M) the number of microplots in the plot (resp of plots per land-use type).

2.2.3 Linear models

Linear models were used to study relations between plant cover, management practices and soil variables. When the analyses were realized at the square or microplot level, random effects were used to account for nested sampling protocol (function *lme*, package NLME). Besides, globalized linear models were used for discontinuous or non-gaussian variables such as richness, abundance (poisson) (function *glm* or *glmer*, package LMER) or proportions (beta regression, function *betareg*). Homoscedasticity and normality of the residuals, when applicable, were checked visually. Although R^2 is not a perfect measure of model fitting for mixed model, I will use the marginal R_m^2 (resp. conditional R_c^2) provided by the function *r.squaredGLMM* (package MuMIn) as a proxy for proportion of variance explained by fixed effects (resp. fixed and random effects).

3   Results

3.1   Plant communities

3.1.1   Plant richness and abundance

Species encountered.   We found a total of 50 herbaceous species among which 35 were identified at least to genus level (see table S3), and belonged to 20 families. Among the identified species, Poaceae were dominant (8 species) followed by Asteraceae (7 species) and Euphorbiaceae (3 species). Only 18 species were found in more than 5 microplots and only 4 species were present in more than half the plots. We were not able to identify all tree samples yet, and uncertainties remain. We identified with certainty 31 species, 10 other species are clearly different from these ones, remaining individuals belong to 28 categories whose identification is still ongoing.

Figures 4a and 4b show species accumulation curves for herbaceous and lignous species, respectively. While herbaceous species were sampled at the microplot level, we identified trees at the plot level only, due to their size and sparsity. The curves show that we were able to sample most of the herbaceous diversity present in maize and rubber plantations; but not in rice fields which clearly appear to be more diverse than other fields; and nor for lignous species. Due to important uncertainties about lignous species, only data from herbaceous species will be further investigated here.

| (a) Herbaceous species | (b) Lignous species |
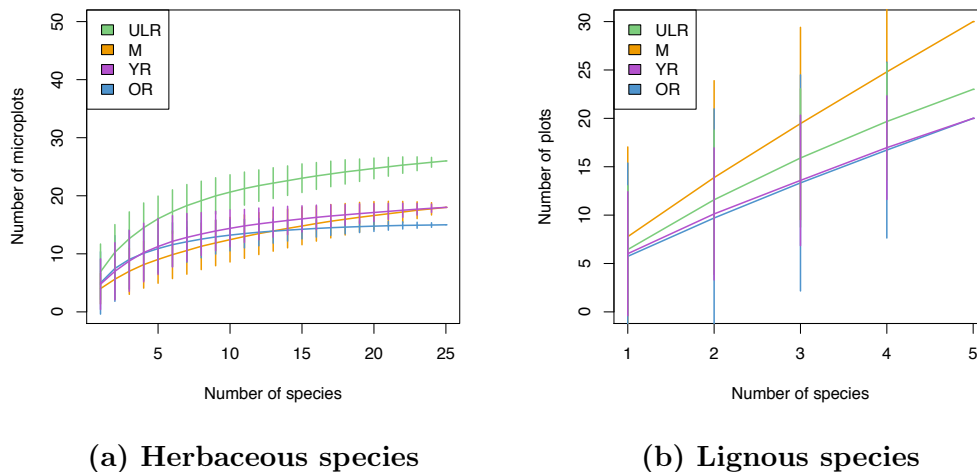
*Figure 4: **Species accumulation curves***
Species accumulation curves, built using the *speccacum* function. Vertical bars indicate standart error of the estimate.

Among the herbaceous plants, two species from the Asteraceae, *Ageratum conyzoides* and *Conyza sumatrensis* were dominant, present in 91 (resp. 90) microplots and representing 30% (resp. 51%) of all the herbaceous individuals. Neither total richness nor density of other species varied significantly with their abundances taken separately when correcting for plot

levels. Richness increased slightly with the sum of their abundances, although difference between plots explained most of the variation (fig. 5).

Figure 5: ***Variation of total species richness with* A. conyzoides *and* C. sumatrensis**

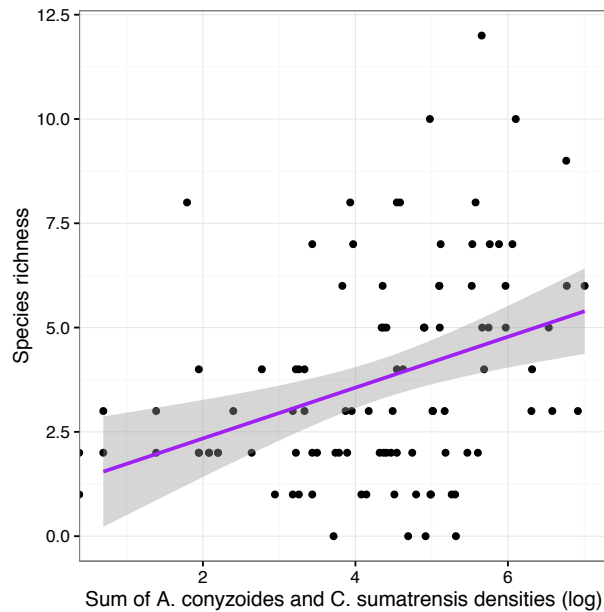p = 0.034. Fixed effects explain only 4% of the variance, and 68% when associated with random effects.

Information about weed status of the other species identified in the field can be found in table S3.

Species richness and abundance. Species richness at the microplot level varied from 1 (OR5-4) to 14 (ULR3-5) with a median of 5. At the plot level, it varied from 4 (M3) to 19 (ULR1) with a median of 10.

Total plant abundance at the micoplot level was estimated in various ways. Plant density gives an estimation of seedlings recruitment. There were from 4 (OR5-4, OR5-5) to 1177 (ULR2-1) individuals per m^2, with a median of 114 individuals per m^2.

Living soil cover, the proportion of soil covered with living plants, was a necessary complement to density in order to study soil protection. It varied from 0.4% (M4-5) to 71% (ULR2-1) (median 14%). Finally, plant biomass for living plants, dry weeds and crop residues provide information about soil protection as well as primary production. Fresh biomass varied from 0 to 258 $g.m^{-2}$, with an median of 36 $g.m^{-2}$. Dry biomass was higher than living biomass (p <0.01) with a median of 85 $g.m^{-2}$ (0 to 503 $g.m^{-2}$). Residues biomass was even higher than dry biomass and reached a median of 148 $g.m^{-2}$ (0 to 879 $g.m^{-2}$).

Both plant density and fresh biomass increased significantly with plant cover (fig. 6a, 6b).
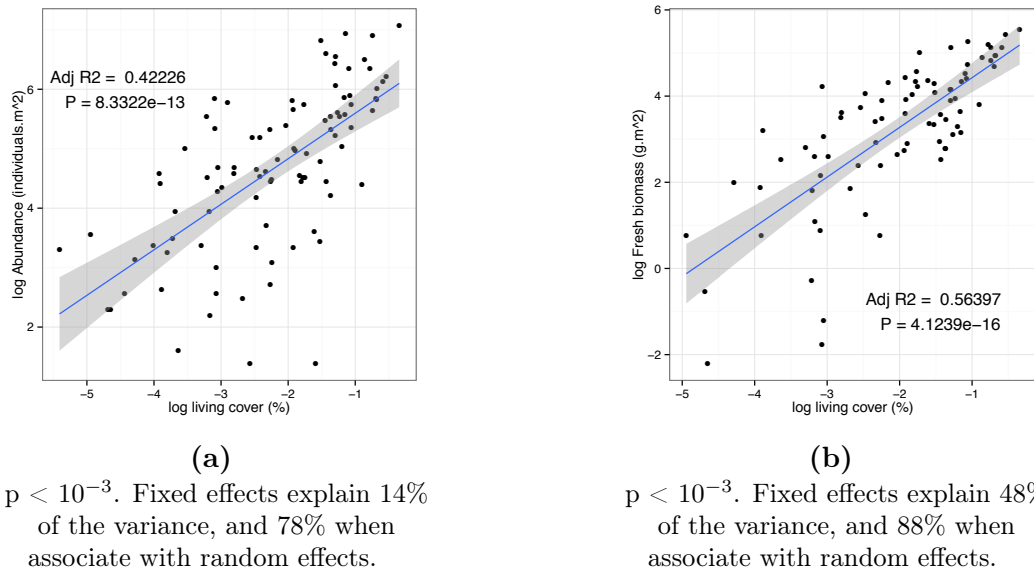
(a)

p $< 10^{-3}$. Fixed effects explain 14% of the variance, and 78% when associate with random effects.

(b)

p $< 10^{-3}$. Fixed effects explain 48% of the variance, and 88% when associate with random effects.

Figure 6: ***Variation of plant density (6a) and fresh biomass (6b) with living soil cover.***

3.1.2   Plant communities structure

We hypothetized that plant communities might differ in their structure, based on the absence or presence of some species and on their relative abundances.

A *decorana* analysis on the absence/presence of all herbaceous species in all the microplots is shown in fig. 7. We chose to use in a first time only presence data to avoid artifacts due to the over-abundance of the two dominant species. Fig. 7a shows that microplots from the same plot, while often close to each other, might sometimes differ significantly (e.g. plot M5, orange diamonds on the left). The repartition of species (gray crosses) does not show well-defined clusters, and it thus appears that at this period (end of dry season) there is no distinct species groups that are always associated.

To further investigate composition patterns, I first realized a cluster analysis on microplots coordinates in the *decorana*. The Bayesian Information Criteria (BIC) was maximum for 3 clusters, and the classes obtained by k-means clustering are represented in fig 7b. GLMs for each species' abundance against the clusters indicated that 10 of the 49 species differed significantly in their abundance between the clusters. More specifically, cluster *A* was characterized by high abundances of *Mimosa diplotricha* and *Spilanthes paniculata*, cluster *B* by high abundances of *Mitracarpus villosus*, *Conyza sumatrensis* and *Oxalis corniculata* and cluster C by *Biden pilosa*, *Chromoleana odorata*, *Pennisetum polystachion* and *Paspalum conjugatum*. These species were rather common (from 15 to 10497 individuals sampled, median of 226 individuals), and it is likely that other species' abundances did not vary significantly because of low abundances (1 to 731 individuals, median of 5 individuals).
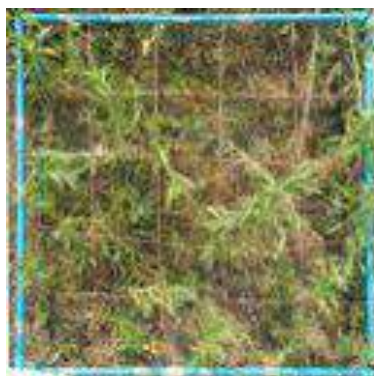
Three examples of microplots representative of each cluster (near the barycentre of each cluster) are shown in fig. 8, where different species can be seen that represent each cluster.
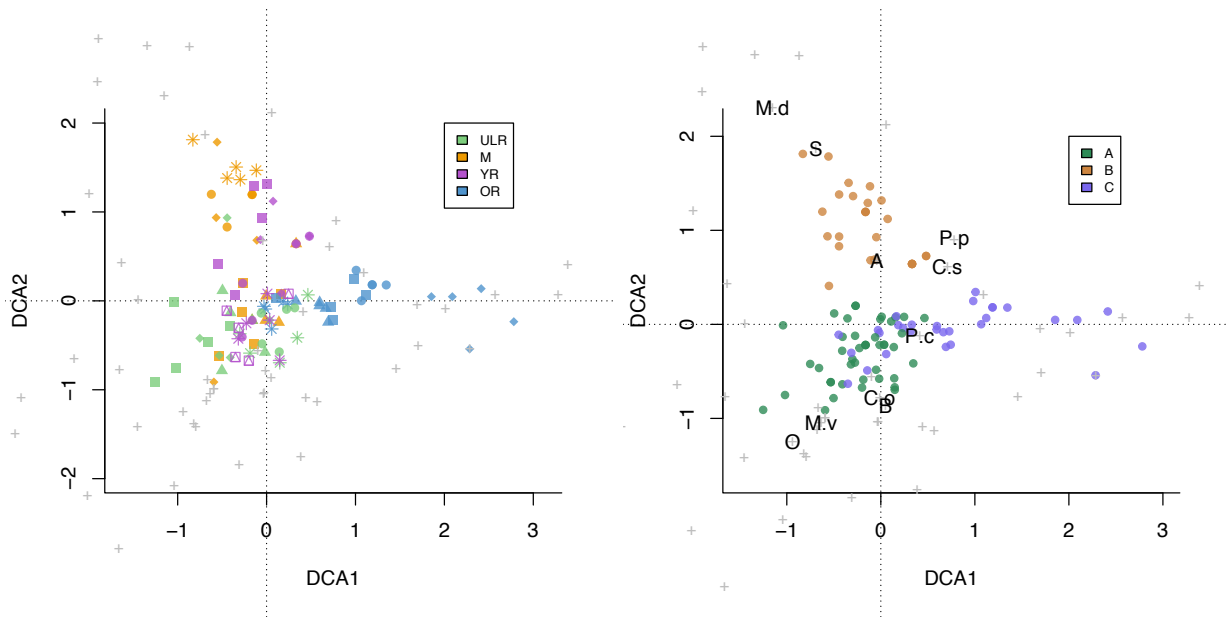
(a) Distribution of the microplots from each plot

(b) Clustering on the results of decorana

Figure 7: **Results of a** decorana *analysis on the presence/absence data of all herbaceous species.*
Different symbols indicate different plots. Labels indicate the 10 species whose abundances differ between clusters. M.d: *M. diplotricha*; S: *S. paniculata*; M.v: *M. villosus*; C.s: *Conyza sumatrensis*; O: *Oxalis corniculata*; B: *B. pilosa*; C.o: *C. odorata*; P.p: *P. polystachion* and P.c: *P. conjugatum.*

(a) Cluster 1 (microplot ULR3-3)
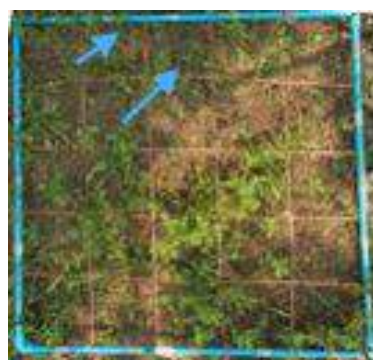
(b) Cluster B (microplot YR5-2)
Blue arrows indicate *M. diplotricha*
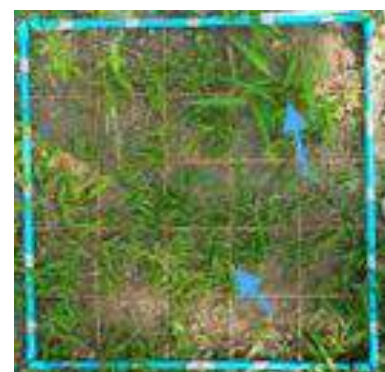
(c) Cluster C (microplot OR1-5)
Blue arrows indicate *P. conjugatum*

Figure 8: **Exemples of microplots representative of each cluster**
Microplots for this example were chosen close to the barycentre of each cluster.

3.2   Effect of cultivated crop on plant communities

3.2.1   Patterns of diversity

Species richness was significantly higher in rice crops (fig. 9a). No difference was found in microplot-level Shannon index (reported in effective numbers of species, see α_μ, part 2.2.2), unless the two dominant species were removed. In this case, rice microplots had on average higher, and maize microplots lower, Shannon indices than young and mature rubber plantations (fig. 9b). While Shannon index allows to detect variations in species' equity in a community, the two main species were so abundant and ubiquitous that small variations in their abundances would mask any change in other species' abundance. All Shannon indices reported in this report are thus calculated without the two main species.

I calculated beta diversity of each plot by removing from its Shannon index the mean Shannon index of its microplots (cf β_p, part 2.2.2). Plot beta diversity appears to be higher in mature plantations, although no significant difference was found (fig. 9c). This shows that within one plot, microplots differ more one from each other in mature plantations than in other land-use types. Besides, beta diversity at the crop level (Shannon index for one land-use minus mean Shannon index of its plots, β_c) appeared to be much higher in rice (12.6) than other land-use types (Maize : 6.4, young rubber : 7.6, old rubber : 7.2). This indicates that rice fields differ more one from each other than do other fields.

3.2.2   Effect on plant abundance

Individuals density was highly variable, especially in rice and maize fields. We were unable to find significant variation of density with land-use type, although rice fields appeared to have higher densities (fig. 9h). Interestingly, one maize field only had very high densities; this field is the only one that does not have crop rotation and has been cultivated with maize for 30 years.

Patterns were much clearer for living plant cover, that was very high in rice crops, very low in young rubber plantations and intermediate in maize fields and mature plantations (fig. 9g). As expected, fresh biomass followed similar patterns, although it was less variable than density in mature plantations (fig. 9d). On the contrary, residues biomass was quite low in rice, maize and young rubber plantations and peaked in mature plantations due to abundant litter (fig. 9f). Finally, dry biomass was maximal in young rubber plantations and minimal in mature rubber plantations (fig. 9e). Globally, total weed biomass (fresh + dry) was higher in rice, maize and young rubber plantations (182 ± 119 $g.m^{-1}$) than in old rubber plantations (31 ± 38 $g.m^{-1}$) (data not shown).

3.2.3   Association of land use types with specific plant communities

The classification obtained in fig. 7b, when crossed with each microplot's land-use, shows that cluster and land-use type are not independant (table 1a). Clusters A and C are defined
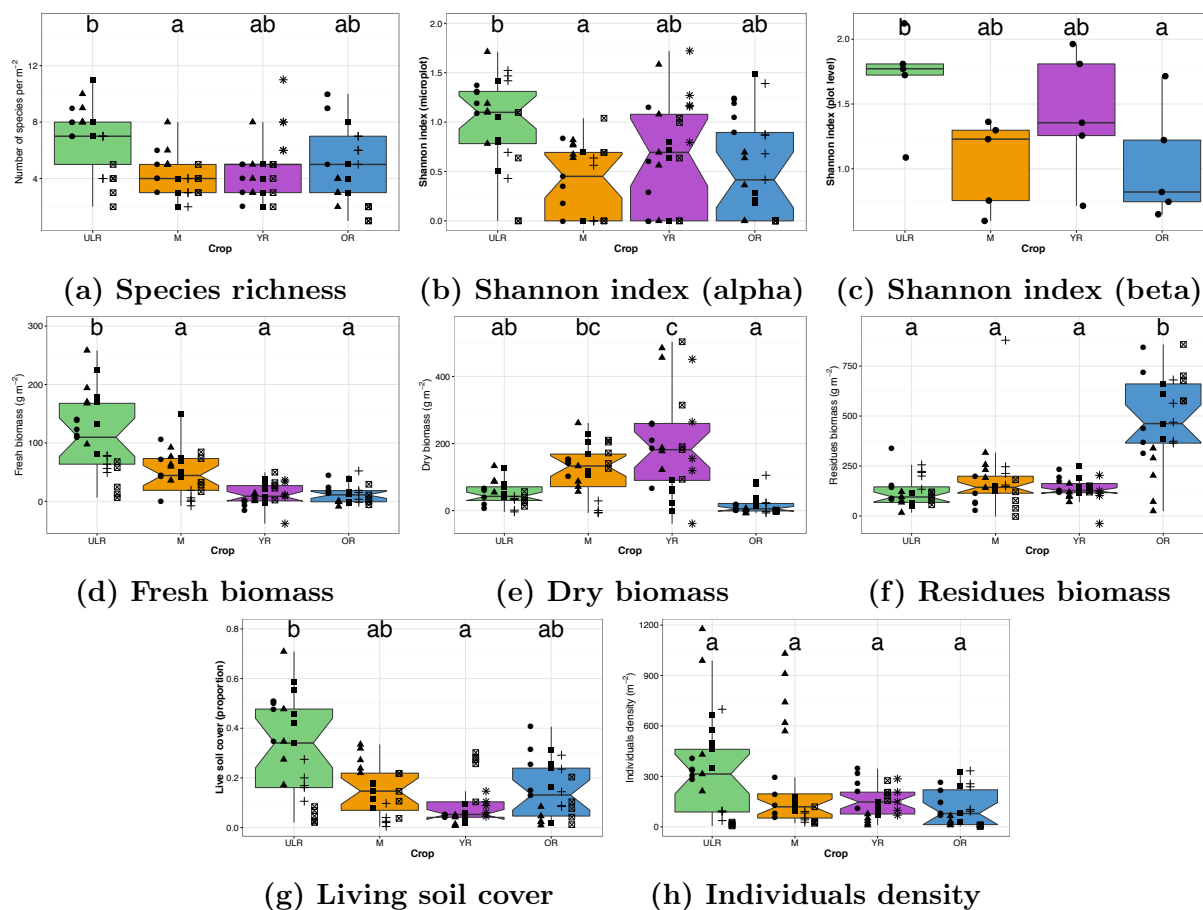
Figure 9: Interaction of plant community indices with land-use type.
Different letters indicate significative differences (p = 5%)

by a dominance of respectively rice and old plantations. Maize microplots are dominant, but less strongly so, in cluster B; and young plantations are more diffusely classified.

This strongly suggests that different land-use types, at this time of the year, were associated with particular plant communities. Microplots of each plot were sometimes separated in two different clusters (table 1b), especially for 2 young rubber plantations. For other land-use types, at least 4 of all microplots belonged to the same cluster. This indicates that the microplots are usually representative of the weed community at the plot level, except in young rubber plantations. In the following section, we will use each cluster as representing a distinct plant community and investigate their relations with management practices and soil characteristics. In analyses at the plot level, we will associate each crop to the cluster dominant within its microplots.

3.3   Impact of management practices on plant communities

3.3.1   Farmers' management practices

The farmers used mostly herbicides to weed their fields, along with knife-cutting for small trees. They used a total of 6 herbicides (Glyphosate, Gramoxone, Atrazine, Camry, Allmix, Metsulfuron-methyl). For the analyses metsulfuron-methyl, which is one main active ingre-

Cluster	ULR	M	YR	OR
A	23	9	11	1
B	1	15	10	0
C	1	1	4	24

(a) Number of microplot of each land-use type in each cluster

Cluster	M1	M2	M3	M4	M5	OR1	OR2	OR3	OR4	OR5
A	0	4	0	4	1	0	1	0	0	0
B	5	0	5	1	4	0	0	0	0	0
C	0	1	0	0	0	5	4	5	5	5

Cluster	ULR1	ULR2	ULR3	ULR4	ULR5	YR1	YR2	YR3	YR5	YR6
A	5	5	4	5	4	5	1	3	0	2
B	0	0	0	0	1	0	4	2	4	0
C	0	0	1	0	0	0	0	0	1	3

(b) Number of microplots from each land-use type in the different clusters

Table 1: *Description of clusters' composition*

Clusters have been obtained by maximizing BIC on the coordinates of the decorana. A χ^2 independance test confirms that proportions of each land-use for each cluster differ strongly (p $<2.10^{-12}$). Yellow (resp. orange) cases indicate dominant cluster in a crop, with 4 (resp. 5) microplots

dient of Allmix, has been grouped with the latter. Most farmers used at least one, and often more than two types of herbicides in their fields. Glyphosate was used in 15 fields and was, by far, the most common. They also used 3 types of fertilizers (46-00, 15-15-15 and 21-00) but the 46-00 formula (urea) was the most used. Fire was used prior to the current crop in 9 of the fields, although only 7 were burnt the year before the survey; the two other are rubber plantations that were burnt before tree planting. Tillage was not used among the interviewed farmers.

Fig. 10 shows the variability of herbicides and fertilizers amounts applied to each field, normalized per hectare. Neither land-use nor plant communities differ greatly in terms of management practices. The width and elongated form of the confidence ellipse around the clusters show that while some chemicals are mostly used in some crops and not others, amounts vary greatly from field to field and it is unlikely that farmers follow precise doses. Cluster A appears to be mostly diferenciated along the first axis, defined by the use of Camry (an herbicide) and 21-21-21 (fertilizer) mainly (correlation $>90\%$). Both are only used in rice fields; and indeed rice fields appear to be separated from the other crops along this axis (data not shown). The second axis is correlated to the use of Atrazine, another herbicide that is used mostly in maize fields but also in one young rubber plantation, where maize is grown as intercrop: cluster B, which is composed mostly of maize and young rubber fields, is indeed relatively well separated along this axis.

Interestingly, the surface of the field appears to be in the opposite quadrant of most of the herbicides and of the number of herbicides used. This indicates that farmers with small

fields are likely to use more herbicide per hectare. This might also be linked to the fact that the biggest fields investigated were rubber plantations, 2 of which are herbicides-free. The use of fire before the previous crop dominated in rice fields.
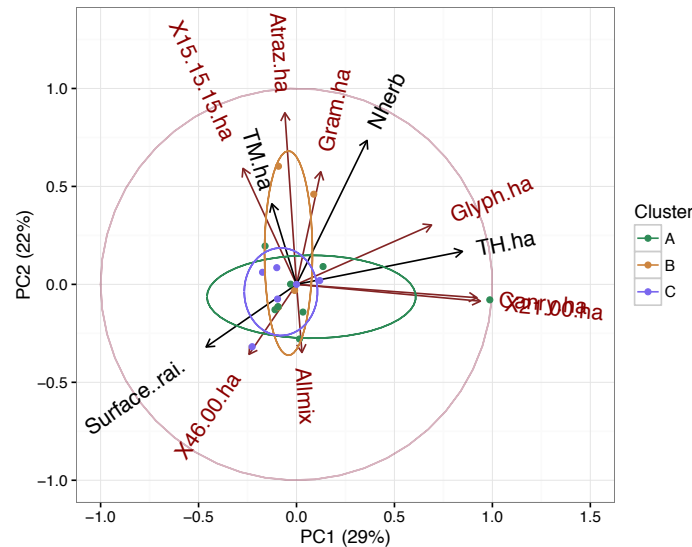

Figure 10: **PCA of weeding practices.**
PCA was realized on herbicides and fertilizers quantities per hectare and per year, as reported by farmers, for 19 fields. All variables were normalized before analysis; red arrows indicate active variables and black arrows supplementary variables. Atraz.ha: Atrazine, X15.15.15: fertilizer 15.15.15, Gram: Gramoxone, Glyph: Glyphosate, X21.00: fertilizer 21.00, X46.00 fertilizer 46.00, Nherb: number of herbicides used, TH: number of days-persons to apply herbicides, TM: number of days-persons to weed manually, Surface..rai: surface of the field.

The clustering shown in table 1b shows that while rice and mature ribber plots are consistently classified in clusters A or C, maize and young rubber plantations are mostly in cluster C but sometimes fall in another cluster. This variation in plant communities could be related to a variation of management practices. Among maize and young rubber plots, the one classified in cluster C appeared to received higher doses of glyphosate, which could explain the difference observed. Besides, all fields that were burnt last year fell in cluster A; this might also affect strongly plant communities. Due to the small size of the dataset, it was difficult to test the statistical significance of these effects.

3.3.2   Effect on weeds' richness and abundance

I then tested the variation of weeds' abundance and richness with the amount of all hebicides and fertilizers. Individuals' density increased with the number of herbicides used ($p = 0.058$), while living soil cover increased with the amounts of Canry, Allmix, Gramoxone, and fertilizer 15-15-15 ($p < 0.04$). Fresh biomass increased with amounts of Allmix, Canry and the number of herbicides used ($p < 0.03$) but decreased with the amount of Glyphosate. Dry biomass did not vary with any chemical. Species richness and Shannon index decreased with the use of Atrazine, and Shannon index also increased with the dose of Gramoxone.

3.4   Interaction with soil and landscape characteristics

3.4.1   Soil characteristics

We chose to study variations of soil humidity and bulk density as important parameters of soil physical quality for cultivation and of soil susceptibility to erosion. Figure 11a shows that soil humidity is significantly higher in cluster C than in other clusters, while bulk density does not vary with the cluster. Besides, soil humidity did not vary with bulk density globally nor in any of the clusters (p >0.1, data not shown).
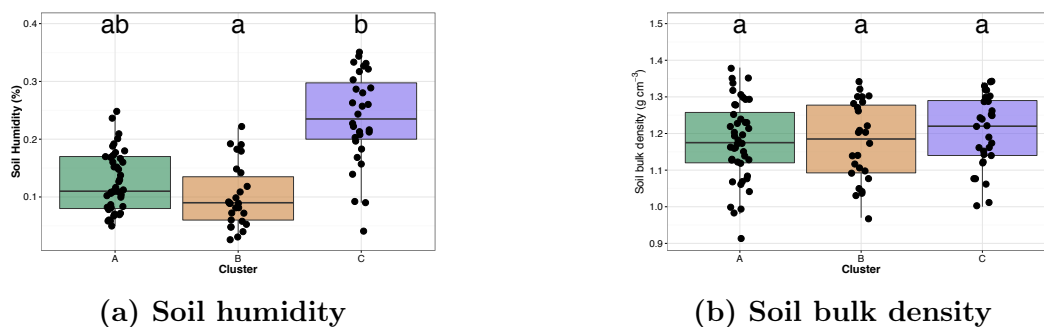

(a) Soil humidity	(b) Soil bulk density

Figure 11: **Variation of soil characteristics with plant community.**

3.4.2   Interaction of plant communities with soil characteristics.

Soil characteristics can be influenced by many parameters. I hypothesized that the following parameters could interact with soil characteristics :

Plant abundance, represented by plant biomass, soil cover and individuals density, can increase soil protection and modify its humidity;

Specific and functional richness influence root functional diversity, and thus their interactions with soil.

I investigated variations of soil humidity and bulk density at dry state with all these parameters, each interacting with the cluster as an indicator of the weed community composition, in linear mixed models. Plot was taken as a random effect to account for dependance between microplots in the same plot. The full models were recursively simplified to minimize AIC (c.f. table S2).

Soil bulk density was lower in cluster C than in the other clusters. It increased slightly with plant density, decreased with plant richness, except in cluster C where it increased with richness. It decreased strongly with living soil cover in cluster B and increased with residues biomass in cluster C. Finally, it increased with Shannon index in all clusters.

Soil humidity was higher in cluster C than other clusters, as found previously. It increased with residues biomass and abundance. Besides, it increased with living soil cover in cluster B and decreased with plant richness in cluster C. I also investigated relations between plant density, richness and soil humidity (measured with a TDR probe) at finer scale, within

20cm x 20cm squares. No significant effect was found when including random effects for microplots nested in plots. When taking into account only plot effect, humidity increased with plant density in cluster A but decreased with plant abundance in cluster C; however random effects explained most of the variation (fig. 12). Humidity appeared to increase with plant richness in cluster A and to decrease strongly with plant richness in cluster C, but these effects were not significant when random effects were included.
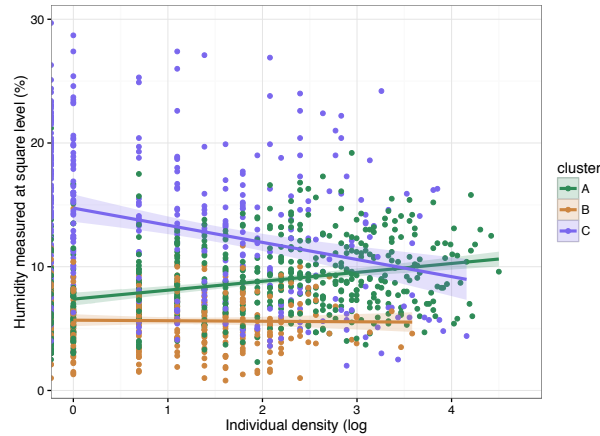

Figure 12: **Variation of humidity at the square level with individuals density.** Humidity measured by TDR probe increases with plant density in cluster A ($p = 0.003$) but decreases with plant density in cluster C ($p = 0.045$). Fixed effects explain only 0.6% of the variation, or 70% when associated with random effects.

3.5 Interaction of landscape, soil, and management practices with plant communities

The results of the decorana analysis were fitted to available environmental variables: local (microplot) and global (hill) slopes, soil humidity and bulk density, exposition, and position in the hillslope (in percentage, 100% is at the top and 0% at the river). Management practices (amounts of herbicides, the use of fire, number of herbicides) were also included in the analysis (data not shown). The R^2 of each explanatory variable, calculated as its correlation with the main axes, was maximal for soil humidity and cluster (resp. 56% and 43%) followed by the exposition (21%); the use of fire (15%), the position along the hillslope (14%) and the use of atrazine (14%). The local slope, the number of herbicides used and the date also affected significantly communities composition. Humidity appears to be the main factor determining the first axis, which is consistent with the findings that this axis separates mostly old rubber plantations from other crops (fig. 7a) and that mature plantations have higher humidity than other land-use types (fig. 11). This analysis also indicates that while old rubber plantations are mostly oriented towards North, other land-uses are generally exposed to South; this again might reinforce variations in humidity.

The position along hillslope did not differ significantly among crops nor with humidity, but appeared to be negatively correlated with the second axis. This indicates that some species (e.g. *Oxalis corniculata, Mitracarpus villosa*) are mostly found on hilltops.

4   Discussion

4.1   Sampling protocol

Our study aimed at investigating changes in weed communities and soil characteristics along the transition from annual to perennial crops. We adopted a synchronic approach to address the question of transition, choosing 4 states along the transition. This approach presents drawbacks: we were not able to control for fields' history, and our study is representative for only a very precise time. However, this method allowed to investigate various fields, which would not have been possible for long periods; it will be complemented in the future by new measurements made during the rainy season in particular. We investigated fields at the end of the dry season, before farmers start working in their fields. It is the time when plant cover is not critical because there is no erosion, and thus not ideal to investigate links between erosion and weeds. However, at that time human-induced disturbances are likely to be the lowest, because no intervention occured in the fields since early autumn; it is thus appropriate for a first approach of weed communities - although one should keep in mind that mostly drought-resistant weeds are left.

We focused our study on farmers' fields. While experimentation allows to control for many parameters that could influence weed communities and soil characteristics, only by studying farmers' fields and their diversity regarding management practices, soil type and history can we expect to understand better the relations between farming practices, weeds, and soils and thus to enhance erosion control (Mutsaers 1997). Experimental plots will be set up later in the study to investigate the impact of precise practices such as diminishing the dose of herbicides.

4.2   Composition of plant communities

Inventory of weed species.   We found a total of 50 herbaceous species, although only part of them were identified. The communities were clearly dominated by *Ageratum conyzoides* and *Conyza sumatrensis*. *A. conyzoides* is reported in the IUCN Global Invasive Species Database (GISD (Invasive Species Specialist Group ISSG 2015)) as a major weed. Originated in South America, it has ben reported mostly in disturbed areas and cultivated lands (Kohli et al. 2006). It is characterized by a very efficient reproduction by stolon and anemophilous seed dispersion. Besides, it exibits strong allelopathy and rapid growth that have been related to reduced crop yields (e.g. rice in Asia, (Invasive Species Specialist Group ISSG 2015)). It has been reported as a major weed in rice fields of Northern Thailand (Vongsaroj (1997) in Nam-Matra (2017)). Similarly, *C. sumatrensis* has been described as one of the most widespread species in the world (Hao et al. 2009). Originated in America, it has a very high seed production and fertility (Hao et al. 2009). To my knowledge no study has reported allelopathy in this species, but its resistance to various herbicides includ-

ing glyphosate and paraquat (Santos et al. 2014; Itoh et al. 1992) makes it a major weed in most cultivated areas. IUCN does not give information about this species. While the literature suggests that these species, and in particular *A. conyzoides* (Invasive Species Specialist Group ISSG 2015) decreases other species' richness or abundance, richness increased slightly with the sum of their abundances. Since the sampling period was at the end of the dry season, environmental filtering through drought (except maybe in mature plantations which were more humid) might have been more important than interspecific competition that would have resulted in a relative decrease in species richness. This hypothesis will have to be tested with similar sampling later in the rainy season.

Plant richness and abundance.   Our results regarding plant richness and abundance are consistent with what has been previously described in other areas of Thailand. For instance, a comparison of 11 land-use types in Eastern Thailand showed that herbaceous specific diversity varied from 9 species in paddy rice to 22 for rubber plantations (Shrestha et al. 2010; Gnanavelrajah et al. 2007). Most of the existing studies about weed communities in Thailand focus on rice, and especially paddy rice. However, many of the most abundant species have already been described as very serious weeds in upland rice as well (e.g. *A. conyzoides, S. paniculata, B. pilosa, M. invisa, M. villosus, E. indica*, Vongsaroj (1997) in Nam-Matra (2017)). The high richness we found in upland rice fields (33 species in total) is likely due to much lower intensivity in upland compared to paddy rice.

Average total herbaceous biomass (from 284 to $501 g.m^{-2}$) for each crop was higher than recorded in Shrestha et al. (2010) (0.47 to 2.63 $tons.ha^{-1}$). On the contrary, I found much lower Shannon indices. These differences could be due to different sampling protocols (e.g. inclusion of residues biomass), to major differences in environmental conditions (flat v. mountainous area, contrasted rainfall patterns, seasonality) or to different scales of study (alhtough it seems that herbaceous plants were sampled at the m^{-2} in this study too). Finally, plant densities were similar to those found in other studies in Europe (de Mol et al. 2015), although they are likely to increase during the rainy season.

Structuration of plant communities.   A *decorana* analysis was used to investigate variation in plant communities' composition. We obtained 3 cluster defining 3 types of weed communities. The microplots for each plot were often grouped (for at least 4 of them) in one cluster, which indicates that the scale of the microplot is quite representative of the plot. Only two young rubber plots were divided almost equally between two clusters, which might be due to the transitive character of this crop - combining maize and young rubber trees.

4.3   Effect of crop and management practices on plant communities.

Previous studies of plant communities have shown an important influence of land-use type and management practices on weeds communities (de Mol et al. 2015; Navas 2012; Fried

et al. 2008b). We found that indeed, land-use type had a strong impact on communities' abundance and composition. Species richness and Shannon indices at both microplot and plot levels were higher in rice fields than other land-use types; rice fields also had the highest beta diversity. This indicates that rice fields are more diverse, and more different one from each other, than other crops. Rice fields also had significantly higher living soil cover and living biomass that other crops.

Besides, the distinct plant communities, represented by three clusters, were representative of land-use types. Cluster C was particularly distinct from other plant communities, and composed almost exclusively of mature rubber microplots. This might be explained by the very specific environmental conditions in rubber plantations: while rice, maize and young rubber plantations have open canopy, mature plantations differ strongly in terms of light availability and air moisture due to a "buffer" effect of the canopy. The other land-use types, while less strongly distinct, could be further separated between rice fields on the one hand and maize and young rubber plantations on the other. This is probably due to the cultivation of maize intercrop between young rubbers, and shows that the presence of maize (or related management practice) has an important impact on weed communities' composition.

Results regarding the effects of management practices were less explicit. We recorded management practices from 15 farmers. While we explained the project and our questions as clearly as possible, it is possible that farmers sometimes gave erroneous data because of misunderstandings, fear (e.g. to have their field seize in case of bad management) or from simple oversight. Management practices will be investigated more precisely in the future, probably more easily because the first contact has already been established. We found that farmers' practices were extremely diverse and were not well correlated with land-use type or plant communities, except for some particular inputs such as Camry, used only in rice. Our results show that high weeds abundance is often related to high amounts of herbicides, although this is not true for all herbicides. It is not possible to determine if high doses favor some weeds in the long-term or whether farmers just use more herbicides when the abundance of weeds is more important.

Previous studies that investigated the role of management practices on weed communities often focused on one single land-use type (e.g. colza (Fried et al. 2007), maize (Odhiambo et al. 2015; de Mol et al. 2015), soya (Puricelli et al. 2012)). The variation due to the cultivated species, and the small size of our dataset might have masked the effect of management practices. Besides, we were not able to combine the doses and types of herbicides into a single meaningful variable, and the variety of practices made it difficult to isolate specific effects. The difficulty of dealing with herbicide practices has been reported elswhere (Fried et al. 2008a).

More generally, the ongoing replacement of diverse rice fields by cash crops or perennial plantations is likely to be related with a simplification of crop rotations, although we were

not able to investigate precisely this point yet. These changes will lead to habitat homogeneization, which has been related in Europe to a reduction of global weed cover and of weeds diversity (de Mol et al. 2015; Stevenson et al. 1997; Andreasen et al. 2008). Disturbed habitats such as intensively cultivated fields have been shown to be dominated by generalists species, leading to the disappearance of rarer, specialist species (Baessler et al. 2006; Storkey et al. 2012); and indeed we found lower diversity in maize or rubber plantations than in rice fields. The evolution of community composition related to land-use changes, based on the selection of some species over others, as well as the selection of given trait within species, might lead to profound changes in the funtionning of the agroecosystem (Díaz et al. 2001). For instance, previous results found modifications of resource use (e.g. more nitrogen-fixating Fabaceae in organic fields; increase in C4 Poaceae in conventionnal fields (Jose-Maria et al. 2011)), growth forms, and reproduction strategies, all of which are key parameters in the dynamics of the weeds community and its interaction with crops (Navas 2012).

Our results thus partly support our first hypothesis, showing that in the investigated fields land-use type affects weeds communities, but the effect of management practices is less clear.

4.4   Interactions with soil characteristics

Plants have been shown to be key elements in soil resistance and resilience to disturbances (Seybold et al. 1999). Leaves of herbaceous, ground-level species in particular play a major role in erosion control by reducing splash erosion (the destruction of soil aggregates by falling raindrops)(Nearing et al. 2005); and stems create physical barriers and irregularities that slow and reduce runoff (Durán Zuazo et al. 2008). Plant roots also enhance soil stability by direct enmeshment of soil aggregates or by secretion of exudates (Gyssels et al. 2005; Durán Zuazo et al. 2008). Thus, plant cover interacts with soil structural and hydrological properties.

We chose two characteristics to represent these interactions: soil bulk density and humidity. Soil humidity depends on various parameters. It is related to soil porosity, which determines both the potential size of water reservoir in the soil and the speed of infiltration. It is also influenced by plant cover, with a balance between soil evaporation and plant transpiration. We found that soil humidity was higher cluster C, represented by rubber plantations. This might be due to the orientation of the fields (mostly North for rubber plantations) and to the closed canopy, which creates an area with higher air humidity and lower temperature, altogether decreasing evaporation demand. Soil humidity increased with residues biomass, probably due to the buffer effect of a mulch cover on evaporation. We investigated the interaction of soil humidity with plant abundance and richness at both the 20 cm x 20 cm square or $1m^2$ microplot level, and found slightly different results. Globally, soil humidity appears to increase with individuals density and species richness in cluster A, had no variation with abundance or richness in cluster B and decreased with both pa-

rameters in cluster C. It thus seems that in these conditions and at this period of the year the protective effect of plant cover on soil humidity is more important than water losses through evapotranspiration in open-canopy fields represented in cluster A. Plant species associated to this cluster might also be adapted to drought and act as a "lift" for deep water ressources, resulting in higher surface humidities. Another hypothesis is that higher soil humidities favor germination and lead to higher individuals densities; this is supported by the fact that in cluster A humidity varies only with plant densities (i.e. including even plantules, with little effect on soil protection) and not with living plant cover or fresh biomass (which represent actual soil protection). Cluster B was associated with the highest dry biomass: this abundant mulch might act as a protection against evaporation and explain the lack of interaction between humidity and plant density. Finally, in cluster C (mostly represented by rubber plantations), direct evaporation is reduced by the canopy and abundant residues cover. Water is unlikely to be limitant because of high humidities, and species present in this cluster might not need drought adaptation; there, water losses are thus due to plant uptake mostly and increase with plant densities.

Previous results in Huai Lang suggest that runoff is higher in rubber plantations than other land-use types, which could be related to reduced soil porosity and infiltration rates. In particular, important kinetic energy from falling raindrops has been shown to result in more compact soil. In our study bulk density did not vary with plant communities alone, but when other parameters were taken into account it was lower in cluster C, which goes against previous results in rubber plantations of Malaysia and China (Li et al. 2012; Noguchi et al. 2003). This is probably due to abundant rubber roots at the surface that locally increase soil porosity. Bulk density increased with individuals' density, Shannon index and species richness (except in cluster C). A diverse plant cover is also likely to result in diverse rooting systems, with effects on porosity at different scales, which also contradicts our results; however, we sampled only the top 5cm of soil and weeds might have effects on porosity at more important depths. At this very dry period of the year, it is possible that weeds invest little in surface rooting systems, due to limited water availability in this layer. Further investigation of infiltration rates, roots abundance and precise rooting systems will be necessary to test these hypotheses.

Altogether, these results support our second hypothesis that plant communities interact with soil characteristisctics. Nevertheless the links are not simple, in particular here it appeared that weed abundance and richness do not systematically enhance soil porosity of the top soil and hence might have contrasted effects on water infiltration.

4.5 Interaction between soil, landscape, management and plant communities

We found that humidity and cluster (strongly associated with land-use type) were the factors best associated with weed communities composition, which was expected because clusters were built from community composition and one cluster was strongly associated with high humidities. However, we found that other parameters related to landscape characteristics were also associated to changes in community composition. Previous studies at larger scale reported similar results, with climatic factors and crop sequence being the most important factors in explaining variations in plant communities (de Mol et al. 2015; Fried et al. 2008b; Hanzlik et al. 2011; Cramb et al. 2009). For instance, position along hillslope can be related to different hydrological patterns likely to influence plant communities, while exposition is related to climatic variations at local scale. We also found that some specific herbicides, such as Atrazine, and the use of fire, were strongly related to particular communities and as important as landscape characteristics in the definition of weed communities.

Finally it appears that weed community speciation depends on land-use type and associated management. Eventhough a rather important variety exists between the farmers some key herbicides and fertilizers appeared to be associated with the different clusters of weed communities. This study also shows that environmental characteristics such as position along the slope, shadow from the canopy or exposition to sun, which play an important role in respect to water balance within the soil at the end of dry season, are also influencing the initial growth of weed communities.

Conclusion

This study investigates the relations between weed communities, weeding practices and soil characteristics in the transition from annual to perennial crops in Northern Thailand. Our results suggest that upland rice is the most favourable crop in terms of biodiversity conservation. Land-use types were represented by weed communities of distinct compositions, which in turn affected soil characteristics. While soil humidity was clearly higher in rubber plantations, the patterns for bulk density were less obvious; and bulk density appeared to increase with plant abundance. Overall, these findings indicate that weed communities have significant but complicated impacts on soil characteristics. They also suggest that there exist adaptations of weed species, in particular to drought at this time of the year, that differ from community to community. Further study is needed to determine precise interactions between plant communities' abundance and composition, field history and erosion-related soil properties (soil shear strenght, sorbtivity, surface state). The dynamic response of weeds to seasons and management practices will also have to be investigated to better understand these relations on the long-term. Overall, it appears that integrating results related to soil, weeds, and management could provide useful information to design more sustainable practices in the light of biodiversity conservation and erosion control.

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Table S1: *Geomorphological data of the different sampled plots*

Position indicates the position along hillslope: %0 at the river, 100% at the top. Material is the underlying rock: Trj = conglomerate, Ptrv = limestone. Series represent Moklek serie (Ml), Thali serie (Tl), Wongsapoung serie (Ws). Soil depth is shallow (s), medium (m) or deep (d).

Plot	Position (%)	Hillslope	Hillside length	Hints of land-slide	Exposition	Material	Serie	Soil depth
M1	74.1	22.3	110	n	S	Trj	Ml-gc	s
M2	84.4	32.1	252	y	E	Trj	WS-vd	d
M3	23.7	29.9	377	y	SE	Trj	Tl-cl	m
M4	58.8	39.9	229	y	NE	Ptrv	Ml-gc	s
M5	21.0	27.4	156	y	SE	Trj	Tl-cl	m
ULR1	71.2	24.4	223	?	N	Trj	WS-vd	d
ULR2	74.9	27.2	124	y	NE	Trj	Tl-cl	m
ULR3	29.6	34.5	209	y	N	Trj		
ULR4	75.3	42.7	269	n	NE	Ptrv	Ml-gc	s
ULR5	38.5	28.1	164	y	S	Trj	Tl-cl	m
YR1	87.1	43.9	184	y	NE	Trj	WS-vd	d
YR2	87.1	32.1	292	y	SW	Trj	WS-vd	d
YR3	11.7	29.8	291	y	SE	Trj	Tl-cl	m
YR5	21.3	23.0	149	y	SE	Trj	Tl-cl	m
YR6	83.4	41.2	240	n	NE	Ptrv	Ml-gc	s
OR1	78.2	36.3	161	y	NW	Trj	WS-vd	d
OR2	52.8	28.6	140	n	N	Trj	WS-vd	d
OR3	65.4	31.2	144	y	NW	Trj		
OR4	41.3	34.8	209	y	NW	Trj	Ml-sg	s
OR5	32.8	30.6	165	y	NW	Trj	Tl-cl	m

Table S2: **Results of linear mixed models of bulk density and humidity with vegetation parameters.**

Only significant effects (p <0.05) are shown. Different letters show significantly different effects.

Cluster	Bulk density			Humidity		
	A	B	C	A	B	C
Effect	1.3_a	1.32_a	0.98_b	0.096_a	0.059_a	0.162_b
Fresh biomass	⋯⋯	$n.s.$	⋯⋯	⋯⋯	$n.s.$	⋯⋯
Dry biomass	⋯⋯	$n.s.$	⋯⋯	⋯⋯	$n.s.$	⋯⋯
Residues biomass	$n.s.$	$n.s.$	3.10^{-3}	⋯⋯	$1\ 10^{-4}$	⋯⋯
Living soil cover	$n.s.$	-0.51	$n.s.$	$n.s.$	0.20	$n.s.$
Individuals density	⋯⋯	$1.5\ 10^{-3}$	⋯⋯	⋯⋯	$5.6\ 10^{-5}$	⋯⋯
Species richness	-0.043_a	-0.014_a	0.026_b	$n.s.$	$n.s.$	-0.011
Shannon index	⋯⋯	0.065	⋯⋯	⋯⋯	$n.s.$	⋯⋯
Proportion of variance explained by fixed effects	⋯⋯	46%	⋯⋯	⋯⋯	26%	⋯⋯
Proportion of variance explained by random + fixed effects	⋯⋯	52%	⋯⋯	⋯⋯	90%	⋯⋯

Table S3: **Description on abundance and weed status of all identified species. Information was obtained from the GISD database. Sq : number of 20cm x 20cm squares where the species was present. Ab : total number of individuals. Mic : number of microplots where the species was present.**

	Species	Family	Weed status	Sq	Ab	Mic
	Ageratum conyzoides	Compositae	Very invasive, present worldwide, interefere with plant growth (allelopathy).	1408	8433	19
/	Musa sp.	Musaceae	/	1	1	1
	Phragmites vallatoria (Phragmites australis)	Graminae	Invasive only in some cases.	4	11	1
	Bidens pilosa	Compositae	Troublesome in many crops, reduces yields (allelopathy)	89	261	9
	Blumea lacera	Compositae	/	55	65	10
/	Centella asiatica	Umbelliferae	/	4	4	1

Table S3: ***Description on abundance and weed status of all identified species. Information was obtained from the GISD database. Sq : number of 20cm x 20cm squares where the species was present. Ab : total number of individuals. Mic : number of microplots where the species was present.***

	Species	Family	Weed status	Sq	Ab	Mic
/	Chromolaena odorata	Compositae	Major weed in rubber plantations; promotes fires when dry. Allelopathy	15	15	6
	Conyza sumatrensis	Compositae	/	1337	10532	20
	Crassocephalum crepidioides	Compositae	/	132	243	11
	Cyclosorus subelatus	Thelypteridaceae	/	180	742	11
	Cynodon dactylon	Graminae	Potential weed, host to pests	19	64	1
	Desmodium gangeticum	Fabaceae	/	2	2	2
	Digitaria radicosa	Graminae	/	98	611	2
	Eleusine indica	Fabaceae	/	46	70	4
	Euphorbia hirta	Euphorbiaceae	/	114	182	8
	Hedyotis auricularia	Rubiaceae	/	4	7	1

Table S3: **Description on abundance and weed status of all identified species. Information was obtained from the GISD database. Sq : number of 20cm x 20cm squares where the species was present. Ab : total number of individuals. Mic : number of microplots where the species was present.**

	Species	Family	Weed status	Sq	Ab	Mic
	Manihot ultissima	Euphorbiaceae	/	3	3	1
	Mimosa diplotricha	Mimosaceae	Major weed dut to its ability to climb.	63	77	9
	Mitracarpus villosus	Rubiaceae	/	170	266	14
	Mollugo sp.	Molluginaceae	/	7	8	2
	Oxalis corniculata	Oxalidaceae	Invasive, no strong impact on crops reported	83	227	7
	Paederia pilifera	Rubiaceae	/	10	10	4
	Paspalum conjugatum	Graminae	/	161	610	9
	Pennisetum polysta-chion (Cenchrus polysta-chios)	Graminae	Very invasive. Host to maize pests and increase the risk of fire.	156	225	9
	Phyllanthus amarus	Euphorbiaceae	/	2	2	2
	Scoparia dulcis	Schrophulariaceae	/	4	4	1

Table S3: **Description on abundance and weed status of all identified species. Information was obtained from the GISD database. Sq : number of 20cm x 20cm squares where the species was present. Ab : total number of individuals. Mic : number of microplots where the species was present.**

	Species	Family	Weed status	Sq	Ab	Mic
	Selaginella helferi	Selaginellaceae	/	8	12	2
	Solanum nigrum	Solanaceae	/	30	42	5
	Spilanthes paniculata	Compositae	/	89	149	10
	Thunbergia grandiflora	Acanthaceae	Major weed that can outcompete all plants by covering the ground.	6	6	2
	Thysanolaena latifolia	Graminae	/	6	11	1

Figure S1: **Hillslope profiles for each plot**

Each profile has been realized along the steepest slope. Red triangles indicate the position of the plot. Colors indicate the position of the plot along the hillslope ('LOW' : lowest third, 'HIGH' : highest third, 'MID' : middle.)
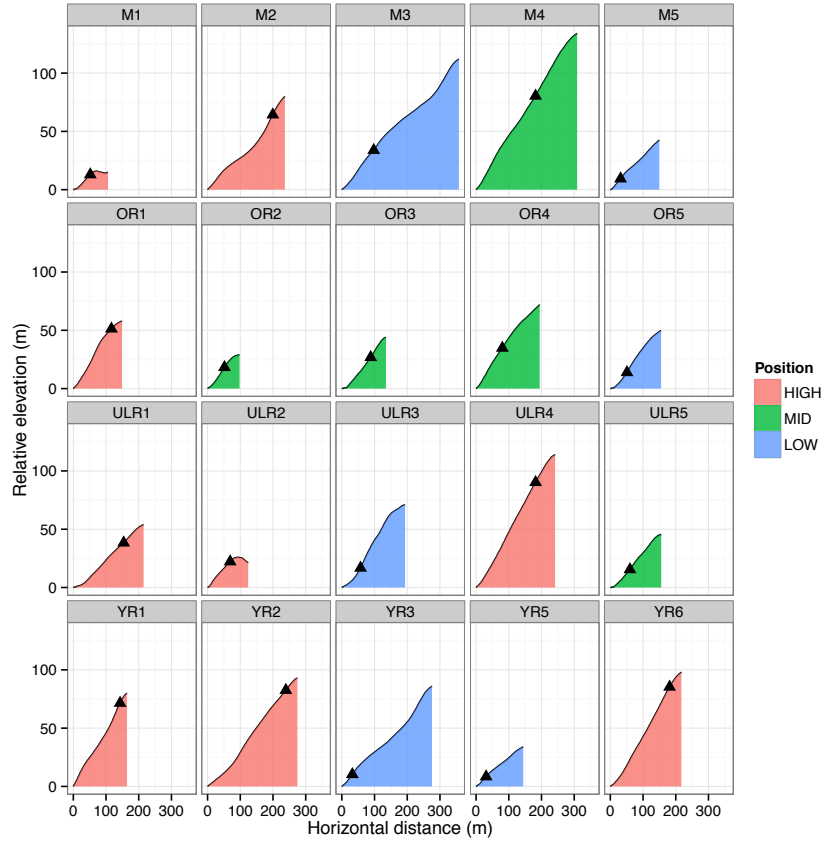

Figure S2: **Variation of plant richness and abundance with time.**

Each variable was normalized by its maximum to represent relative variations in time. Point data has been smoothed using the stat_smooth function (package ggplot2) to aid the visualisation. Ribbons indicate 95% confidence intervals around the prediction.
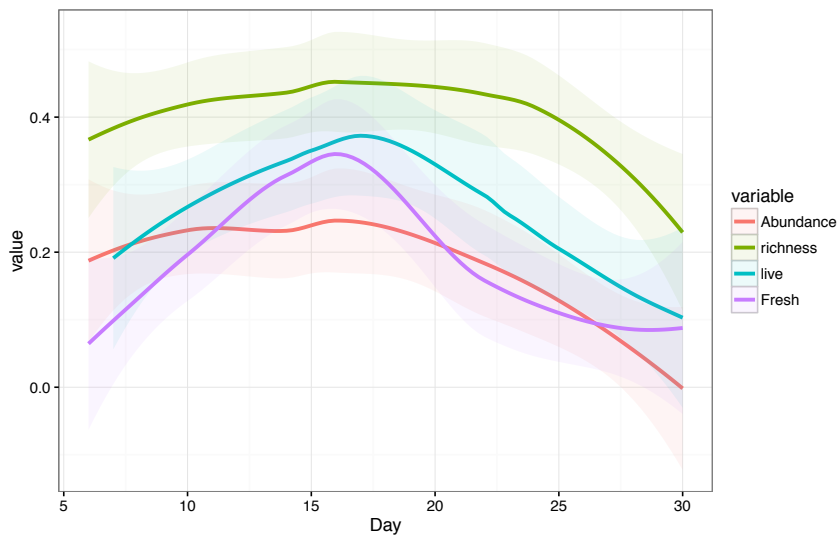
Figure S3: **Questionnaire used in farmers' interviews**

Date:
Plot number:

Farmer details:

Name   Age
Address   Province
District   Sub-district
Village
Phone number

Interviewee:
Owner .... Member of family.............
Worker ....

Total area cultivated:
Area for each crop:

Who takes decision regarding field management?
Who do you receive advice from (family, friends, institutions...)?

Who usually work in the field?
Owner .... Member of family...............
Friends.............. Worker ....

About the field

Previous crop: 2015
                2014
                2013

How did you prepare the land before sowing?

Date of sowing:
Date of harvest:

Do you use fertilizer? Yes / no
                Name:
                When:
                Dose:

Do you use hebicides: Yes / no
                Name:
                When:
                Dose:

Do you weed manually? Yes / no
                How (cutting machine, knife, hoe...):
                When:

Weed tolerance: *no weed.....few weeds ....any*

Small trees tolerance: *no tree.....few tree ....any*
Why?
Competition....... Difficult to work...... Esthetic ....other
                Details:

Total time spent on weeding (time x persons):
                herbicides:
                manual weeding:

General questions:

Do you think soil erosion is a problem in your field?
                Not at all .....   could be ......
                a little problem......   very serious problem

Are weeds a problem in your field?
                Not at all .....   could be ......
                a little problem......   very serious problem

What do you think about the abundance of weeds in the field this year?
Did you notice new species in the past few years?

According to you, how do weeds appear in the field?

Do you have any comment?

Abstract

Changements écologiques liés à la transition des cultures annuelles aux plantations d'hévéa (*Hevea brasiliensis*) dans les régions montagneuses du Nord de la Thaïlande.

Dans les dernières décennies, les zones montagneuses d'Asie du Sud-Est ont été soumises à des dégradations environnementales importantes liées à la croissances démographique et à des changements d'usage du sol. En particulier, la transition depuis les cultures annuelles vers les cultures pérennes, telle que celle de l'hévéa (*Hevea brasiliensis*), pourrait avoir des conséquences majeures en terme de biodiversité et de contrôle de l'érosion. Ceci pourrait être atténué par une meilleure gestion de la biodiversité non-cultivée. Dans ce rapport, nous étudions les relations entre les propriétés physiques du sol (densité, humidité), les communautés d'adventices (composition, abondance) et les pratiques de gestion (herbicides, feu) dans deux bassins versants de Huai Lang, Thailande. Nous avons échantillonné 20 plots appartennant à 4 types d'usage des sols le long de la transition (riz pluvial, maïs, jeunes plantations et plantations matures d'hévéa). Nous avons trouvé des communautés végétales distinctes ("clusters") pour A. les champs de riz, B. les champs de maïs et les jeunes plantations et C. les plantations matures; les champs de riz avaient les abondances et richesses spécifiques les plus élevées. L'humidité du sol était maximale dans le cluster C, où elle diminuait avec la densité d'adventices. Elle augmentait avec la densité de plantes dans le cluster A. De manière suprenante, la densité du sol était basse dans le cluster C et augmentait avec la densité de plantes. Au global, nous avons montré que les communautés de mauvaises herbes, les pratiques de gestion, les caractéristiques du sol et du paysage interagissent fortement. Des recherches plus poussées seront nécessaires pour étudier les mécanismes sous-jacents, en particulier concernant les adaptations des systèmes racinaires des adventices.

Ecological changes related to the transition from annual crops to rubber plantations (*Hevea brasiliensis* in mountainous areas of Northern Thailand.)

In the past decades, mountainous areas of North-East Asia have been subject to severe environmental degradations due to population growth and land-use changes. In particular, the transition from annual to perrenial crops such as rubber (*Hevea brasiliensis*) plantations could have important consequences on biodiversity and erosion control, which might be alleviated by enhanced management of non-cultivated biodiversity. In this study, we investigate the relations between soil physical properties (bulk density, humidity), weed communities (composition, abundance) and management practices (use of herbicides, fire) in two small catchments of Huai Lang, Thailand. A nested sampling protocol was set and we sampled 20 plots from 4 main land-use types along the transition (upland rice, maize, young rubber plantations, mature rubber plantations). We found distinct plant communities ("clusters") for A. rice fields, B. maize and young rubber plantations and C. rubber plantations, with rice fields having the richest and most abundant communities. Herbicide practices appeared to have unconsistent effects on communities' composition and abundance. Regarding soil characteristics, soil humidity was higher in cluster C, where it decreased with plant densities; it increased with plant densities in cluster A. Surprisingly, soil bulk density was low in cluster C and globally decreased with plant abundance. Altogether, we found that weed communities, management practices, soil characteristics and landscape are closely intertwined. Further research is needed to investigate precise mechanisms underlying these interactions, in particular regarding adaptation of weeds' rooting systems.