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1 **Long-term dynamics of cocoa agroforestry systems established on lands previously occupied by**
2 **savannah or forests**

3 Annemarijn Nijmeijer^{1,2,3}, Pierre-Eric Lauri², Jean-Michel Harmand^{4,5,6}, Gregoire T. Freschet⁷, Jean-
4 Daniel Essobo Nieboukaho^{1,2,3}, Patrick Kenfack Fogang³, Seguy Enock^{1,2,3}, Stéphane Saj^{1,2*}

5

6 ¹ CIRAD, UMR System, Montpellier, France.

7 ² SYSTEM, Univ Montpellier, CIRAD, CIHEAM-IAMM, INRA, Montpellier SupAgro, Montpellier, France.

8 ³ IRAD, Département des plantes stimulantes, Yaoundé, Cameroon.

9 ⁴ CIRAD, UMR Eco&Sols, F-34398 Montpellier, France.

10 ⁵ Eco&Sols, Univ Montpellier, CIRAD, INRA, IRD, Montpellier SupAgro, Montpellier, France.

11 ⁶ World Agroforestry Centre (ICRAF), Yaoundé, Cameroon.

12 ⁷ Centre d'Écologie Fonctionnelle et Évolutive, UMR 5175 (CNRS – Université de Montpellier –
13 Université Paul-Valéry Montpellier – EPHE – IRD), Montpellier, France.

14

15 * Corresponding author: stephane.saj@cirad.fr

16 Present address: Stéphane Saj, CIRAD Guyane, Campus Agronomique de Kourou - BP 701, 97387

17 KOUROU Cedex - France

18 **Abstract**

19 Cocoa agroforestry systems (cAFS) in Central Cameroon are established on lands which were either
20 forest or savannah. The functioning and ecosystem services (ES) delivery of an agroecosystem can be
21 influenced by past land-use. We hypothesised that savannah-derived cocoa agroforestry systems (S-
22 cAFS) and forest-derived cocoa agroforestry systems (F-cAFS) would (i) progressively drift away from
23 past land-use, and (ii) eventually converge and support comparable levels of ecosystem services. We
24 selected 25 ecosystem **attributes** directly related to at least one of the following six ecosystem
25 (dis)services (ES): species conservation, carbon storage, crop production, nutrient cycling, soil quality
26 and soil pollution. We followed their temporal evolution in S- and F-cAFS along >70-year
27 chronosequences. Our results showed that the **attributes** and services studied followed typical
28 temporal trajectories in S- and F-cAFS while generally tending to reach comparable levels on the long
29 run. However, the time needed to do so varied strongly and ranged from 20-30 years for perennial
30 species diversity to more than 70 years for C storage or some components of soil quality. The results
31 also demonstrated that S-cAFS could sustainably improve many of the studied **attributes** and ES.
32 Regarding the **attributes** related to the cocoa stand, both S- and F-cAFS seemed influenced by their
33 previous land-use up until 15 and 30 years, respectively, after their establishment. With respect to
34 soil quality, nutrient cycling and carbon storage, only S-cAFS could be significantly distinguished from
35 their past land-use, after 15 to 30 years.

36

37 **Keywords:** afforestation; **ecosystem service;** land-use legacies; litterfall; plant diversity; soil quality;
38 **Theobroma cacao.**

39

40 1. Introduction

41 Ecosystem services and underlying functions depend on both current ecosystem ecological attributes
42 and historical legacies. Disturbances, natural or anthropogenic, can lead to long-term fluctuations in
43 ecosystem structure and functioning. The frequency, type, size, timing and intensity of a disturbance
44 determines its impact which could eventually lead to land-use change (Chapin *et al.*, 2011). In
45 general, the impact of human interference, for example in the form of agricultural activities, is larger
46 than that of natural events (Foster *et al.*, 2003). All organic components, above- and below- ground,
47 seem to be highly influenced by past land-use (Bellemare *et al.*, 2002; Jangid *et al.*, 2011; Perring *et*
48 *al.*, 2016). Such legacies are demonstrated for an array of ecosystem attributes such as nutrient
49 cycling (Dupouey *et al.*, 2002), carbon storage (Freschet *et al.*, 2014), soil microbial community and
50 heterotrophic respiration (Kallenbach and Stuart Grandy, 2015). Yet, land-use legacies might be
51 overruled if current disturbances are strong and long enough, ultimately leading to novel ecosystems
52 (Hobbs *et al.*, 2006).

53 Agricultural systems can be established from contrasting ecosystems. The conversion of a tropical
54 forest into an agricultural suitable environment is mainly achieved by slash-and-burn technics, which
55 are very similar all over the world (Nepstad *et al.*, 1999; Achard *et al.*, 2002; Palm *et al.*, 2005).
56 Tropical grasslands are also used for agricultural purposes after vegetation burning (Kugbe *et al.*,
57 2012). Over the last century, half of the tropical grasslands and savannahs had been converted to
58 agricultural land (UNDP, 2005). Often, the same crops are grown on differing past land-uses. This is
59 the case of cocoa agroforestry systems (cAFS) from the forest–savannah transition zone of Central
60 Cameroon which are either created on forest or on savannah land (Jagoret *et al.*, 2012). In the forest-
61 derived cAFS (F-cAFS), farmers operate a selective clearing of forest trees for the provision of shade
62 along with food and/or additional income (Jagoret *et al.*, 2014; Saj *et al.*, 2017a). In the savannah-
63 derived cAFS (S-cAFS), farmers use specific techniques to build up a tree canopy (Jagoret *et al.*, 2012).
64 Central Cameroon farmers' practices are known to drive cAFS' structure, tree species composition
65 and biomass on the long run (Jagoret *et al.*, 2012; Saj *et al.*, 2017a; Jagoret *et al.*, 2018a).

66 Interestingly, full-grown S-cAFS and F-cAFS seem to exhibit comparable multi-strata structure, cocoa
67 yields and C storage abilities despite differing previous land-use and *a fortiori* differing legacies
68 (Jagoret *et al.*, 2012; Saj *et al.*, 2013; Nijmeijer *et al.*, 2018).

69 Land-use change from savannah or forest into cAFS probably affects both above- and below- ground
70 ecosystem functioning and related services. For instance, conversion of forest into cAFS was shown
71 to alter litter inputs and soil properties, putatively altering nutrient cycling (Beer *et al.*, 1998; Schroth
72 *et al.*, 2001; Hartemink, 2005; Adeniyi *et al.*, 2017). Similarly, transitioning from savannah to another
73 (agro or eco)system or vice-versa was shown to alter both litter inputs and soil properties (Don *et al.*,
74 2011; Nouvellon *et al.*, 2012; Sugihara *et al.*, 2014). In this paper we explored the long-term legacies
75 of past land-use in F- and S-cAFS from Central Cameroon.

76 First, we hypothesised that S- and F- cAFS ecosystem **attributes** were likely to progressively drift
77 away from those of their initial ecosystem. We expected that the timespan needed to observe
78 significant changes would depend both on the previous land-use (PLU) and the considered ecosystem
79 attribute. Secondly, we hypothesised that the magnitude and the direction of the temporal
80 evolution, hereafter called trajectories, of some ecosystem **attributes** were to differ between S- and
81 F-cAFS. We expected these differential trajectories to attain comparable levels for some of the
82 studied **attributes**. We tested both hypotheses using a selected number of **attributes** in cAFS, whose
83 levels were studied through decade-long chronosequences. **On the one hand, we focused on S-cAFS**
84 **trajectories and their PLU, savannah, and on the other hand, we studied F-cAFS trajectories and their**
85 **PLU, forest.** Each of the 25 ecosystem **attributes** studied (plant biomass, production, litter production
86 and storage, soil organic matter and nutrient contents and associated perennials diversity...) relates
87 directly to at least one of the following six (dis)services: species conservation, carbon storage, crop
88 production, nutrient cycling, soil quality and soil pollution.

89

90 **2. Material and methods**

91 2.1. Site characteristics and sampled plots

92 The study was carried out in the district of Bokito, in the villages Bakoa and Guéfigué (4°30 latitude N
93 and 11°10 longitude E), located in a forest–savannah transition zone in Central Cameroon. The
94 landscape consists of hills with gentle slopes at an altitude between 400 and 550 m a.s.l. and is
95 characterised by a patchwork of forests, agroforests and herbaceous savannahs (Jagoret *et al.*, 2012).
96 Annual rainfall ranges from 1300 to 1400 mm with a main dry season lasting from mid-November to
97 the beginning of March (Jagoret *et al.*, 2012). The region is dominated by desaturated ferralitic soils
98 (Elangwe, 1979). Here the cocoa plantations consist mainly of decade-old diversified agroforestry
99 systems (cAFS) containing many associated trees (Sonwa *et al.*, 2007; Jagoret *et al.*, 2011; Saj *et al.*,
100 2013). We selected 16 plots of cAFS created on savannah (S-cAFS) and 16 plots created on secondary
101 forest (F-cAFS) whose age was distributed along a gradient from 1 (farmers just started the planting
102 process of cocoa) to over 70 years old. Besides, five control plots of each past land-use (savannah
103 and forest) were selected for comparison with the S- and F-cAFS. Savannahs in the area are annually
104 burned and periodically cultivated, therefore we chose plots where no agricultural activity could be
105 noticed for the last seven years, as savannah controls. The forest patches are degraded compared to
106 other secondary forests that can be found in the region (Saj *et al.*, 2017a). Plot size was of 40 m x 60
107 m (2400 m²), each containing a subplot of 20 m x 40 m (800 m²; see below and Nijmeijer *et al.*, 2018).

108 2.2. Ecosystem attributes

109 2.2.1. Conservation

110 A floristic survey enabled us to compute two attributes which relate to species conservation, i.e.
111 perennial species richness and diversity. We also computed species rarefaction curves. We surveyed
112 all the perennial plants found in the studied systems including both typical trees and “tree-like”
113 perennials, i.e.: cocoa, associated trees, palms and bananas. All the perennials with a diameter at
114 breast height (DBH) over 30 cm were surveyed in 2400 m² plots. Those with a DBH between 5 and 30
115 cm were surveyed in 800 m² subplots within the 2400 m² area already selected. Height, DBH and
116 species were recorded as described in Nijmeijer *et al.* (2018). When the DBH couldn't be measured,
117 we followed the recommendations from Weyerhaeuser and Tennigkeit (2000) to indirectly estimate

118 it. In total, we counted 3036 cocoa trees and 670 associated perennials in the cAFS studied. In the
119 forest and savannah control plots, we identified 304 and 92 perennials, respectively. Associated
120 perennials were classified according to their species: (i) native species from the African continent and
121 (ii) exotic species introduced from other continents. Among all the individuals counted in cAFS, forest
122 and savannah plots, 88.4 % could be identified at the species level. The number of individuals per
123 species in the plots were extrapolated to number of individuals per species per hectare. Abundance
124 and diversity data of associated perennials were used to calculate species richness using Shannon-
125 Wiener and Sørensen indices (Peet, 1974; Magurran, 2004).

126 2.2.2. Carbon storage

127 Using the above-cited survey we calculated the total biomass of large associated trees (DBH > 30 cm)
128 and the biomass of cocoa trees, two attributes directly relating to carbon storage (Saj *et al.*, 2013).
129 Aboveground biomass (AGB) of associated trees was estimated after Chave *et al.* (2014). Their
130 belowground biomass (BGB) was estimated after (Cairns *et al.*, 1997). The biomass of each tree was
131 then calculated as the sum of AGB and BGB.

132 2.2.3. Crop production

133 Five **attributes** related to crop production were computed using the above-cited floristic survey and
134 cocoa pod production counts, namely: cocoa tree stand density and basal area, cocoa tree basal area
135 share (CTBAS), accessible cocoa yield and banana stem density. CTBAS was calculated as: [basal area
136 of cocoa trees (at 1.30m height) : basal area of whole stand] (Saj *et al.* (2017b). Cocoa pod
137 production and subsequent yield in cocoa beans were estimated for three consecutive production
138 cycles in 2014, 2015 and 2016. Pods with a length > 10 cm were counted four to five times during the
139 year (April, June, August, October and December) to get most of the annual production cycle. Such a
140 count indicates the maximum number of pods per plot that can be produced and physiologically
141 reach maturity within a production cycle. This has been defined as the “accessible” production of
142 pods from which we can then derive the “accessible” yield in cocoa beans used in this study with
143 calculations described in Saj *et al.* (2017b).

144 2.2.4. Nutrient cycling

145 Six **attributes** related to nutrient cycling were computed, namely: annual leaf and total litterfalls, leaf
146 and total standing litters, leaf litter and total litter cycling indicators. Litterfall was monitored from
147 November 2015 to October 2016. Three 0.5 m² collectors were randomly placed within the 2400 m²
148 area of each plot, and once a month their positions were changed to account for spatial variability
149 (12 different positions for each collector during the study; Schroth, 2003). They were emptied every
150 two weeks (111 collections in total). Once collected, the litter was air-dried and sorted to distinguish
151 leaf litter from total (ie. leaf + branches + reproductive organs) litter. Subsamples were then dried at
152 60 °C for 72 hours and weighed for dry matter content calculation. Standing litter was measured at
153 the end of the rainy season (October 2016), when decomposition started to slow down due to
154 seasonal climate transition. In each plot, litter was collected in four randomly distributed 1 m²
155 quadrants for fresh weight measurement. Litters from a 0.0625 m² (25 x 25 cm) sub-quadrant were
156 then dried at 60 °C for 72 hours and weighed for dry matter content calculation. These subsamples
157 were also sorted to distinguish leaf litterfall from total (ie. leaf + branches + reproductive organs)
158 litterfall. Standing litter and litterfall were not measured in the savannah control plots due to the
159 very low density of perennials in these plots. Two indicators of litter decomposition were calculated
160 after Tripathi and Singh (1994) : (i) one including all the organs constituting the litter (leaves,
161 branches and reproductive organs), which we called “total litter cycling”: [total litterfall : (total
162 litterfall + total standing litter)] ; (ii) one including only leaves, hereafter called “leaf litter cycling”:
163 [leaf litterfall : (leaf litterfall + leaf standing litter)].

164 2.2.5. Soil quality and contamination

165 Ten **attributes** related to soil quality and possible contamination by pesticide-driven Cu were
166 computed, namely: pH, organic carbon (C), total N, C:N, Inorganic P, exchangeable K, cation exchange
167 capacity, as well as exchangeable Ca, Mg and Cu. A composite soil sample of 0-15 cm depth was built
168 from eight subsamples (each of 135 cm³) systematically distributed in each 800 m² subplot after
169 brushing off the litter layer. Particle size distribution and soil chemical composition and particle size

170 distribution were determined by the IITA soil laboratory in Yaoundé (November 2016; www.iita.org).
171 Soils were air-dried and sieved at 2 mm. Particle size distribution (three fractions) of sieved soil
172 samples (0-2mm) was estimated after Bouyoucos (1951); pH in water was determined in a 1:2.5
173 (10w:v) soil:water suspension. To determine soil organic C (SOC), soils were further ground to reach a
174 particle size ≤ 0.5 mm before proceeding to chromic acid digestion and spectrophotometric analysis
175 (Heanes, 1984). Total nitrogen (N) was determined from a wet acid digest (Buondonno *et al.*, 1995)
176 and analyzed by colorimetry (Anderson and Ingram, 1993). Inorganic phosphorus (P) was extracted
177 using Bray 1 extractant and analyzed using the molybdate blue procedure (Murphy and Riley, 1962).
178 Exchangeable cations (calcium (Ca), magnesium (Mg), potassium (K)) were extracted by ammonium
179 acetate at pH 7 and analyzed by flame atomic absorption spectrophotometry (David, 1960).
180 Exchangeable copper (Cu) was extracted using the Mehlich-3 procedure and determined by atomic
181 absorption spectrophotometry (Mehlich, 1984).

182 2.3. Chronosequence validation

183 We defined four cAFS age categories [0-14], [15-30], [31-50] and [>50] years to represent the
184 different temporal stages of cAFS while trying to balance the number of plots per category. Yet we
185 noticed a significant soil clay content heterogeneity among the plots sampled (Nijmeijer *et al.*, 2018)
186 which challenged the validity of the chronosequence (Pickett, 1989). To take into account a putative
187 soil texture effect, a preliminary ANCOVA, including age categories, past land-use and soil clay
188 content as a covariate, was run on the whole set of cAFS. It showed that the soil clay content still
189 significantly impacted - and interacted with – cAFS age and/or previous land-use on numerous
190 ecosystem **attributes** (data not shown). This was probably due to the fact that most of the S-cAFS in
191 the sampled region were located at the foot of gentle slopes while F-cAFS were located slightly
192 higher (Nijmeijer, 2017). Consequently, we split the studied plots into two according to their clay
193 content: a group with low clay content soils (LCCS; containing between 9.8 to 16.2 % of clay), a group
194 with high clay content soils (HCCS; containing more than 19.6 % of clay). The number of F-cAFS plots
195 in the LCCS group and the number of S-cAFS plots in the HCCS group were too low to establish

196 chronosequences. Hence, we ended up studying a S-cAFS chronosequence on LCCS, and a F-cAFS
197 chronosequence on HCCS. The LCCS group was comprised of 20 plots (n S-AFS = 11, n savannah
198 controls = 3, n F-cAFS = 3, n forest controls = 3). The HCCS group contained 18 plots (n S-AFS = 4, n
199 savannah controls = 2, n F-cAFS = 10, n forest controls = 2). We further used ANOVAs to check,
200 separately for each soil clay content group, that cAFS age categories did not differ in soil clay content.

201 Appendix 1 shows the mean values resulting from ANOVA and post-hoc (SNK) of the 25 studied
202 attributes for the 4 land-use types regardless of plot age and soil texture (42 plots in total).

203 2.4. Data analyses

204 We performed all statistical analyses for the LCCS and HCCS groups separately. Two principal
205 component analyses (PCA) followed by a Varimax rotation were performed on the whole set of
206 ecosystem attributes studied to estimate cAFS plot positions in multivariate space of ecosystem
207 attributes and identify major axes of variations. The scores of each S- or F-cAFS plot on the two axes
208 of the PCA were then extracted and, for each axis, one-way ANOVAs with post-hoc SNK tests were
209 run to determine which age categories significantly differed from their respective control (ie. past
210 land-use). Each of the 25 ecosystem attributes (Tab 1) studied were then tested separately to check
211 for differences between age categories and control plots with one-way ANOVAs followed by SNK as
212 post-hoc (or with non-parametric Kruskal–Wallis tests followed by the Steel-Dwass-Critchlow-Fligner
213 test when variables did not exhibit homogeneity of variance). These analyses were followed by the
214 study of the temporal evolution of each attribute using linear, polynomial or logarithmic regressions
215 – choosing for each the best fitted model (RMSE). The significance of each regression was then tested
216 comparing the model's residuals against their predicted values (F-test). All statistical analyses were
217 performed using XLStat (Addinsoft, 2015) and statistical significance was set at $P < 0.05$. Finally,
218 (associated) perennial species rarefaction curves were computed to check for differences between
219 the four land-use types. These curves were computed using EstimateS (version 9.1.0) from Colwell
220 (2013) and their visual comparison was used to evaluate the differences between land-uses (Barlow
221 *et al.*, 2007).

222

223 **3. Results**

224 3.1. Principal component analyses

225 The first two axes of the PCA explained 63% and 54.7% of the total variance of the two systems
226 studied i.e. S-cAFS in the low clay content soil group (LCCS) and F-cAFS in the high clay content soil
227 group (HCCS), respectively (Fig 1a,b). For both groups, the **attributes** related to soil quality, nutrient
228 cycling and carbon storage were the main contributors to the first axis (D1), accounting respectively
229 for 40.27% of the total variance in LCCS group and 36.58% in HCCS group. For both groups, the
230 **attributes** related to cocoa stands were the main contributors to the second axis (D2), accounting
231 respectively for 22.73% of the total variance in the LCCS group and 18.12% in the HCCS group (Fig
232 1a,b; Tab 1). Standing leaf litter significantly participated to the D2 of the LCCS group (Fig 1a,b; Tab
233 1). The projection of the plots from both groups clearly discriminated between forest and savannah
234 control plots while showing significant evolutions of the agroforestry systems created on savannah
235 (Fig 2a,b). Agroforestry systems established on savannah (S-cAFS), could be distinguished from
236 savannah on D1 and D2 as soon as their age reached 15-30 years ($p=0.002$ and $p=0.01$, respectively;
237 Fig 2a). Agroforestry systems established on forest lands (F-cAFS) could not be distinguished from
238 forest lands on D1 ($p=0.103$) but could be distinguished on D2 as soon as their age was over 30-50
239 years ($p=0.016$; Fig 2b).

240 3.2. Ecosystem services levels and trajectories

241 3.2.1. Conservation

242 S-cAFS exhibited equivalent associated perennials diversity and species richness to F-cAFS and
243 savannah but lower than those of forest (Tab 2a). While no significant differences in Shannon index
244 and species richness were observed between local forest and young F-cAFS (<30 years), mature and
245 old F-cAFS (more than 30 years old) exhibited lower associated perennials diversity values (Tab 2b).
246 Regressions showed that, around 30 years old, S-cAFS and F-cAFS reached comparable diversity
247 levels (Fig 3a). S-cAFS associated perennial species richness appeared constant (ca. 7.8 sp ha^{-1}) while

248 it decreased with time in F-cAFS reaching that of S-cAFS ca. 90-100 years after establishment (Fig 3b).
249 Rarefaction curves were computed for African and total (associated) perennial species identified in
250 each system type (Fig 4a,b). Forested systems (forest control, F- and S-cAFS) revealed comparable
251 curve shapes while their levels underlined clear differences. These systems were found to exhibit
252 very different species accumulation abilities than those exhibited by savannah (Fig 4 a,b).
253 Furthermore, the sampling effort needed in cAFS to reach forest control species richness levels
254 appeared at least three times higher. S-cAFS exhibited slightly lower abilities to accumulate species
255 than F-cAFS - notably due to their lower associated tree abundance (Nijmeijer et al., 2018). The share
256 of African individuals in S-cAFS and F-cAFS appeared close, being respectively of 44.1 and 47.6% (Fig
257 3 a,b). Forest control plots exhibited a fair number of exotic individuals (> 10%, Fig 4 a,b). Finally, F-
258 and S-cAFS shared 29 and 19 African species with forest plots, respectively (Sørensen index: 0.68 and
259 0.48). S and F-cAFS shared 22 African species (Sørensen index = 0.61).

260 3.2.2. Carbon storage

261 In S-cAFS, large (DBH >30cm) associated tree and cocoa tree biomass increased with age, especially
262 between [15-30] and [31-50] years old categories (Tab 2a). Large associated tree biomass did not
263 differ significantly between F-cAFS age categories, S-cAFS and forest plots (Tab 2b). Regressions
264 showed that large associated tree biomass in S-cAFS reached about the same values (140 t ha⁻¹) as F-
265 cAFS ca. 70 years after establishment (Fig 3c). Regressions showed that cocoa tree biomass followed
266 similar trends and reached ca. 20-25 t ha⁻¹ 50 years after establishment (Fig 3d).

267 3.2.3. Crop production

268 For the **attributes** related to cocoa production, no significant differences were found between F-cAFS
269 age categories and S-cAFS (Tab 2b). For S-cAFS, basal area of cocoa trees, cocoa tree basal area share
270 (CTBAS) and accessible yield were found to increase with time, especially between [0-14] and [15-30]
271 years old categories (Tab 2a). Regressions underlined that S-cAFS exhibited more cocoa trees during
272 the first 20 years (> 1500 ha⁻¹) (Fig 5a). Cocoa tree density reached a maximum when S-cAFS were
273 around 20 years old and when F-cAFS were approx. 40 to 50 years old. They then slowly decreased

274 and stabilised around 1000 trees ha⁻¹ for both systems (Fig 5a). Cocoa tree basal area regressions
275 followed the same trend for S-cAFS and F-cAFS up until 60-70 years of age. Afterwards, basal areas
276 decreased in F-cAFS (Fig 5b). Cocoa tree basal area share (CTBAS) followed the same trend in S- and
277 F-cAFS while it appeared consistently higher in S-cAFS. After 60 years, regressions showed that CTBAS
278 reached a value of ca. 40% in S-cAFS versus ca. 30-32% in F-cAFS (Fig 5c). F-cAFS accessible yields did
279 not evolve significantly with time and showed a mean of 693 kg ha⁻¹. S-cAFS accessible yield
280 increased with time and tended to reach values of 800 kg ha⁻¹ or higher 40 years after establishment
281 (Fig 5d). Banana stems appeared more numerous in F-cAFS that were [15-30] years of age (Tab 2b).
282 Banana density did not however show any significant trend on the long-term (mean of 97.5 ind ha⁻¹)
283 in F-cAFS. Contrastingly, it quickly decreased after S-cAFS establishment as banana stems were then
284 barely found in plots older than 5 years of age (Fig 5e).

285 3.2.4. Nutrient cycling

286 In S-cAFS, leaf litterfall increased the first 20 years after establishment and could not be distinguished
287 from F-cAFS and forest levels from 20-30 years onwards (Tab 2a; Fig 6a). S-cAFS total litterfall
288 increased with time but remained lower than that of local forest (Tab 2a, Fig 6d). In F-cAFS, leaf
289 litterfall did not significantly evolve with time and showed a mean of 4.88 t year⁻¹ ha⁻¹. Total litterfall
290 was found lower than that of forest in old F-cAFS (> 50 years) (Tab 2b). Total litterfall increased
291 significantly until ca. 40 years in S-cAFS, time at which it reached the F-cAFS total litterfall mean (7.93
292 t year⁻¹ ha⁻¹; Fig 6d). No significant differences could be detected for standing litters for both S and F-
293 cAFS (Tab 2a, b). Yet, in F-cAFS, regressions showed that leaf standing litter increased with time and
294 could reach values close to 2 t ha⁻¹ for plots older than 80 years – a value corresponding to the mean
295 obtained in S-cAFS at the same age (Fig 6b). In S-cAFS, total standing litter increased marginally with
296 time ($p < 0.1$) to reach equivalent amounts to those in F-cAFS already 15-20 years after establishment
297 (mean F-cAFS = 4.19 t ha⁻¹; Fig 6e). In S-cAFS, total litter cycling significantly increased and could not
298 be distinguished from F-cAFS or forest total litter cycling when over 30 years of age (Tab 2a). For F-
299 cAFS, both litter cycling indicators decreased with time and ended up lower than forest indicators,

300 after 30 years for leaf cycling and 50 years for total cycling (Tab 2b). Regressions showed that both
301 leaf litter and total litter cycling indicators displayed significant opposite trends between S-cAFS
302 (increasing) and F-cAFS (decreasing) to eventually reach comparable values at ca. 60 years of age (Fig
303 6c,e).

304 3.2.5. Soil quality and contamination

305 In S-cAFS, soil pH, cation exchange capacity (CEC) as well as soil organic C, total N, exchangeable Ca
306 and Cu concentrations increased significantly with time - reaching levels comparable to F-cAFS
307 and/or local forest after 30 or 50 years. Oppositely, the C:N ratio significantly decreased with time
308 (Tab 2a). In F-cAFS, soil **attributes** didn't reveal much significant differences with time, inorganic P
309 was found lower after 50 years old, C:N ratio tended to increase with time while pH exhibited an
310 opposite trend (Tab 2b). Regressions showed that S-cAFS soil pH increased over time to reach that of
311 F-cAFS (ca. 6.1-6.2) 50 years after establishment (Fig 7a). No significant evolution was found for soil
312 organic C in F-cAFS, these values had large variability (mean = 2%). Soil organic C increased
313 significantly in S-cAFS where the regression showed a ca. 50% increase 70 to 80 years after plot
314 establishment (Fig 7b). Regressions showed that 65-70 years after establishment, S-cAFS and F-cAFS
315 exhibited similar levels of soil total N i.e. approx. 0.13% (Fig 7c). Regressions for soil C:N ratio showed
316 an increase for F-cAFS and a steady decrease for S-cAFS - similar levels (ca. 14) being reached around
317 50-55 years after plot establishment (Fig 7d). No significant regression was found for soil
318 exchangeable P in S-cAFS, however a marginal decrease was detected in F-cAFS (mean P in S-cAFS=
319 4.8 ppm; Fig 7e). Regressions made on CEC were not significant in F-cAFS (mean= 7 cmol kg⁻¹) whilst a
320 significant increase was found in S-cAFS (Fig 7f). No significant regression was found for soil
321 exchangeable K content in S-cAFS (mean= 0.16 cmol kg⁻¹) while the decrease was significant in F-cAFS
322 (Fig 7g). Regressions made on exchangeable Ca showed a marginal decrease in F-cAFS and a
323 significant increase in S-cAFS – similar levels (ca. 5-5.5 cmol kg⁻¹) being met around 65 years after plot
324 establishment (Fig 7h). Regressions showed no significant evolution for exchangeable Mg, neither in
325 S-cAFS nor in F-cAFS (mean: S-cAFS= 1 cmol kg⁻¹; F-cAFS= 1.9 cmol kg⁻¹; Fig 7i). Finally, regressions

326 made on soil exchangeable Cu content showed a significant increase in S-cAFS while no trend could
327 be established for F-cAFS (mean = 7 ppm, Fig 7j).

328

329 **4. Discussion**

330 4.1. S-cAFS and F-cAFS general trajectories

331 Our results demonstrated that F- and S-cAFS underwent highly contrasting trajectories after their
332 establishment. Ecosystem **attributes** related to soil quality, plant diversity and nutrient cycling
333 appeared to generally converge among S-cAFS and F-cAFS along the chronosequences studied,
334 whereas **attributes** related to crop production varied in a more similar way. Overall our results
335 revealed that, for the pool of **attributes** and services studied, agroforestry systems always evolved
336 away from their past land-use state. Such differences became statistically apparent after 15 to 30
337 years for S-cAFS and after 30 to 50 years for F-cAFS. Hence, depending on **attributes**, past land-use
338 legacies differed in magnitude and lasted from a few years to several decades. S- and F-cAFS
339 displayed comparable levels of most **attributes** after a certain timespan, as previously suggested by
340 other studies in the same region (Jagoret *et al.*, 2012; Saj *et al.*, 2017a; Nijmeijer *et al.*, 2018).
341 However, for other **attributes** the temporal projections did not seem to display a stabilization phase
342 at later stages. It suggests that these **attributes**, after converging at intermediate time scales, may
343 keep evolving in contrasting directions for S- and F-cAFS. **This could be related to the different types**
344 **of soils studied (Adeniyi *et al.*, 2017) as well as farmers' differential management within a generation**
345 **and between generations (Jagoret *et al.*, 2018a) - both putatively altering ecosystem's functioning.**
346 **Answering this question would need further investigations on a broader array of soil types and longer**
347 **timespans.**

348 4.2. Ecosystem services temporal trajectories

349 4.2.1. Species conservation

350 Our results underlined the relatively fast (ca. 20 years) convergence in terms of perennial species
351 diversity between S- and F-cAFS. Interestingly, S-cAFS exhibited a large number of African species.

352 This high number of native species in S-cAFS could be explained by the important gene bank (native
353 trees, seeds and seedlings) present in their soils or in that of nearby forests or agroforests. Such a
354 result also points at the active introduction, preservation or transfer of these species into S-cAFS
355 (Jagoret *et al.*, 2018b). Interestingly, rarefaction curves highlighted the similarity of species
356 accumulation between S- and F-cAFS. Yet, despite a fair proportion of African species (over 50% of
357 associated individuals), S-cAFS demonstrated an overall lower potential of conservation since the
358 abundance of associated perennials was found lower than in F-cAFS (Nijmeijer *et al.*, 2018). Besides,
359 some species occurred in S- or F-cAFS even they were not present in forest controls. This was the
360 case of locally consumed *Cola* species but also of *Entandrophragma cylindricum*, a commercial timber
361 species, which is currently classified 'vulnerable' in the IUCN red list (IUCN, 2018). All in all, F-cAFS
362 still exhibited a forest legacy a century after establishment whilst both S- and F-cAFS showed an
363 ability to enrich the local pool of species. Our study emphasised the important role **that** both
364 agroforestry systems may currently play in the region in perennial species conservation, even though
365 they do not preserve as many species as forests (De Beenhouwer *et al.*, 2013; Mortimer *et al.*, 2017).
366 Furthermore, since associated diversity and abundance are largely driven by the practices and uses of
367 associated flora (Jagoret *et al.*, 2014; Saj *et al.*, 2017a), a particular attention shall be given to old
368 systems which rejuvenation depends on farmer strategies and may eventually lead to less
369 multifunctional and simplified systems (Saj and Jagoret, 2017; Jagoret and al, 2018b).

370 **4.2.2. Carbon storage**

371 In terms of C storage, the land-use legacy appeared very significant in young systems and tended to
372 disappear on the long term. While the biomass of large associated trees of S-cAFS increased steadily
373 over decades, it decreased in F-cAFS. These results underline the ability of S-cAFS to gain in C storage
374 with ageing, at least up to a certain point (Saj *et al.*, 2013). The results further emphasised the slow,
375 but steady, decrease in C storage abilities in F-cAFS. In a region where old cAFS are numerous
376 (Jagoret *et al.*, 2011), such results point to the need to include selection/management (at the species
377 and individual level) of potentially large trees in the renewal process of these systems (Jagoret *et al.*,

378 2018b). Such management schemes would lead to the renewal of mature and old systems whilst
379 keeping good C storage abilities. However, the timespans - and levels - of C storage of Cameroonian
380 cAFS remain highly significant in comparison to other agricultural systems or cocoa monocultures
381 (Schroth *et al.*, 2015; Schneidewind *et al.*, 2018).

382 4.2.3. Crop production

383 The **attributes** chosen to indicate cocoa production abilities correspond to cocoa stands' or system
384 **attributes** known for their contribution to yield in the studied systems (Saj *et al.*, 2017b). The higher
385 density of cocoa trees in S-cAFS compared to F-cAFS up to 20-30 years after establishment may
386 reflect the insurance practices of local farmers which often "overseed" their S-cAFS to control
387 grasses such as *Imperata cylindrica* (Jagoret *et al.*, 2012). These practices probably support successful
388 establishments since accessible yields in S-cAFS appeared overall similar or slightly higher than that
389 of F-cAFS plots. Except for very young S-cAFS, where banana stems provide beneficial shade to young
390 cocoa seedlings and temporary income/food/feed (Jagoret *et al.*, 2012), banana stems appeared
391 more numerous in F-cAFS than in older S-cAFS. **This discrepancy could underline farmer practices**
392 **favouring cocoa in soils where competition for water can be harsh as the S-cAFS studied were**
393 **established on relatively sandy soils (van Vliet and Giller, 2017).** It could also underline the
394 differential role S- and F-cAFS may have in the provision of co-products (Jagoret *et al.*, 2012; Saj *et*
395 *al.*, 2013). Such differentiations may be interpreted as management legacies inherited from past
396 land-use or adaptation to soil type. Furthermore, cocoa yields reached comparable levels at the
397 latest 15 years after cAFS establishment. This confirms that, despite unfavourable conditions in
398 savannah (such as low soil fertility, weed competition and almost no shade trees), afforestation is
399 clearly achievable using shaded cocoa (Jagoret *et al.*, 2012). Finally, the constantly lower basal area
400 share of cocoa trees in F-cAFS compared to S-cAFS may be considered as a legacy from previous land
401 use (forest) as mature trees are already present at establishment. It can be hypothesised that the
402 maintenance of these trees with an already developed canopy may alter light capture on the long
403 term (Blaser *et al.*, 2017).

404 4.2.4. Nutrient cycling

405 Litterfall and its subsequent decomposition are considered to be effective in the improvement and
406 conservation of soil quality and, as such, play an important role in the regulation of nutrient cycling
407 (Vitousek and Sanford, 1986; de Carvalho *et al.*, 2014). Litterfall in S-cAFS increased steadily up to 40-
408 50 years after establishment, reaching the levels of F-cAFS litterfall. In F-cAFS the forest legacy
409 maintained a leaf litterfall amount close to that of the initial forest. The litter cycling indicators
410 clearly showed an increase in S-cAFS contrasting with a decrease in F-cAFS. These indicators show
411 comparable levels around 50 years, suggesting a convergence for both S-and F-cAFS. The
412 temperature and moisture levels in forests with a closed canopy generally favour decomposition of
413 litter and could explain the lower standing litter of the forest control plots compared to the more
414 open canopy of cAFS (Prescott, 2002; Steffan-Dewenter *et al.*, 2007). The probably drier and warmer
415 conditions in young S-cAFS, which are still lacking a closed canopy and producing mainly low quality
416 cocoa litter (Dawoe *et al.*, 2010), could also explain the higher litter stock in young S-cAFS, despite
417 their lower litter production. Overall, the similar cocoa productivity after savannah and forest
418 conversions may suggest that, while young cocoa plantations established after savannah benefited
419 less from the nutrients released by litter decomposition than these established on forest, the lower
420 competition for light they encountered offset the low soil fertility and actually authorised an
421 equivalent productivity level compared to young F-cAFS (Blaser *et al.*, 2017). Besides, as cAFS mature
422 and the cocoa stands develop, the poor quality of cocoa leaf litter and its subsequent lower
423 decomposition rate (Dawoe *et al.*, 2010) may account for the slight increasing leaf standing litter
424 noticed in F-cAFS chronosequence.

425 4.2.5. Soil quality and contamination

426 In S-cAFS established on low clay content soils many of the studied attributes exhibited a steady
427 evolution with time underlining an overall improvement of soil quality and nutrient availability. This
428 improvement can be explained by the increase of litter - and linked litter cycling - in S-cAFS over time
429 when compared to the very low soil organic content (SOC) content and litter cycling of the initial

430 savannahs. This was not the case in F-cAFS established in high clay content soils where a decrease in
431 pH, K and Ca and an increase of the C:N ratio may point to a low but steady decline of soil quality and
432 nutrient availability – results in line with the recent study of Adeniyi *et al.* (2017). Noticeably, soil Cu
433 concentrations seemed to increase with time at least in S-cAFS and could point to a putative soil
434 contamination by pesticides, as farmers use copper oxide or hydroxide to treat against black pod
435 disease (Sonwa *et al.*, 2008; Jagoret *et al.*, 2011). As a result of the differences in previous land-uses
436 (savannah vs. forest) - emphasised by the differences in soil texture (LCCS vs HCCS) – the
437 convergence of soil attributes between S- and F-cAFS took a long the timespan: 40-60 years after plot
438 establishment. This timespan may have been increased by the lower soil clay content of the initial
439 savannah. Indeed, Nijmeijer *et al.* (2018) found that the annual increase in SOC concentration of S-
440 cAFS was lower in soils with low clay content (10–15%) than in soils with higher clay content (20–
441 25%). In the same way, Feller *et al.* (2001) reported that the annual rate of soil carbon increase was
442 lower in a degraded than in a non-degraded soils. Soil organic C concentration is generally positively
443 related to fine silt and clay content (Plante *et al.*, 2006). As CEC is a positive function of soil clay and
444 organic carbon concentrations, forest soils also may have had intrinsically larger nutrient contents
445 than savannah soils.

446 The values found for macronutrients fell within the range already noticed in Cameroonian cAFS
447 (Duguma *et al.*, 2001). Yet, soil organic matter (represented here by the SOC) did not decrease in F-
448 cAFS after conversion contrasting with other studies (Yang *et al.*, 2004; Snoeck *et al.*, 2010). The
449 forest control plots in our study region were highly disturbed with low and rather similar litter
450 production as in F-cAFS, which may explain the rather similar SOC contents of both systems.
451 Furthermore, the production of cocoa was reported to be linked to the acidification of the soil
452 (Hartemink, 2005; Snoeck *et al.*, 2010; Adeniyi *et al.*, 2018). However, despite a clear decrease over
453 the long term, pH in F-cAFS did not show significant differences with the forest control. Other studies
454 revealed idiosyncratic results (Dawoe *et al.*, 2010; Isaac and Kimaro, 2011) and it may be
455 hypothesised that the composition and abundance of associated trees and their diverse litter

456 restitution to the soil could account for such results (Finzi *et al.*, 1998). This could also partly explain
457 the pH increase with time in S-cAFS. The overall lower pH and nutrient contents in savannah plots
458 might be explained by annual burning and periodical cultivation of savannah with staple crops,
459 practices which are known to lead to extensive carbon and nutrient losses resulting in soil
460 desaturation (Kugbe *et al.*, 2012; Dubiez *et al.*, 2018). The low levels of soil C and N in savannah plots
461 are in accordance with previous studies (Lal and Bruce, 1999; Jagoret *et al.*, 2012). However, the
462 increase of organic C in older S-cAFS showed that the systems were able to build-up SOC over time
463 and increase their soil fertility which may support cocoa yield (Adeniyi *et al.*, 2018). The decreasing
464 trajectory exhibited by K in the soils of F-cAFS after conversion may be linked to lower recycling of K
465 in cAFS than in forest and high absorption of K by cocoa trees and its exportation with cocoa-beans
466 harvest (van Vliet and Giller, 2017). Yet, in S-cAFS, the relative stability of K at a minimum level over
467 time and the trend towards these K levels in F-cAFS after around 80 years suggests that K input to the
468 top soil through recycling (litter and throughfall) (Hartemink, 2005) could, at least partly, compensate
469 K loss through cocoa bean exports.

470

471 **5. Conclusion**

472 As a whole, the 25 **attributes** related to the six ecosystem (dis)services (ES) studied underwent
473 distinct temporal trajectories and showed that S- and F-cAFS could be significantly distinguished from
474 their past land-use, savannah and forest, after 30 and 50 years, respectively. Past land-use legacies
475 were strong enough to last decades but, in the end, S- and F-cAFS agroforests revealed typical and
476 largely convergent profiles despite different initial systems and soil types. Such results indirectly
477 point to the role of farmers in the establishment and maintenance of decade-old agroforestry
478 systems as well as the significant contribution of associated plant diversity to ES provision in these
479 systems. The levels and timespans at which the studied complex cAFS provide multiple ES are worth
480 comparing with simpler (or full sun) systems. In the current context of climate change, where the
481 choice of species and densities of associated perennials in cocoa plantations are debated, such

482 multifunctionality comparisons could help determine long-term strategies which would use plant
483 biodiversity as an actionable lever to adapt and mitigate climate change.

484

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692

693 **Tables**694 Table 1

695 Regressions coefficients (R^2) of the principal component analyses (PCA) of the studied **attributes** after
 696 Varimax rotation for the first two dimensions, D1 and D2, run for S-cAFS in low clay content soils and
 697 for F-cAFS for high clay content soils (in bold: $R^2 > 0.5$).

Service	Attribute	Abbreviation	S-cAFS		F-cAFS	
			low clay content soils		high clay content soils	
			D1	D2	D1	D2
Conservation	Perennials shannon index	Shannon	0.36	0.03	0.36	0.19
	Perennials species richness (nb ha ⁻¹)	Species R	0.28	0.13	0.31	0.05
C Storage	Large associated trees biomass (t ha ⁻¹)	LT biomass	0.53	0.03	0.53	0.00
	Cocoa trees biomass (t ha ⁻¹)	Cac biomass	0.05	0.87	0.00	0.16
Crop production	Density of cocoa trees (nb ha ⁻¹)	Cac dens	0.00	0.70	0.02	0.72
	Basal area of cocoa trees (m ² ha ⁻¹)	BA Cac	0.06	0.89	0.01	0.75
	Cocoa trees basal area share (%)	CTBAS	0.01	0.76	0.01	0.25
	Mean accessible yield (kg ha ⁻¹)	Cac yield	0.06	0.88	0.00	0.00
	Density of banana stems (nb ha ⁻¹)	Ban dens	0.02	0.08	0.07	0.12
Nutrient cycling	Leaf litterfall (t ha ⁻¹)	LLF	0.56	0.11	0.04	0.08
	Total litterfall (t ha ⁻¹)	TLF	0.59	0.15	0.23	0.09
	Leaf standing litter (t ha ⁻¹)	LSL	0.05	0.28	0.00	0.11
	Total standing litter (t ha ⁻¹)	TSL	0.08	0.31	0.19	0.23
	Leaf litter cycling	L cycle	0.52	0.02	0.39	0.36
	Total litter cycling	T cycle	0.70	0.05	0.56	0.46
Soil quality	pH	pH	0.72	0.02	0.81	0.76
	Organic C (%)	Org C	0.86	0.03	0.79	0.00
	Total N (%)	N	0.80	0.01	0.92	0.02
	C:N	C/N	0.60	0.00	0.54	0.07
	Inorganic P (ppm)	P	0.64	0.00	0.63	0.01
	CEC (cmol kg ⁻¹)	CEC	0.83	0.03	0.62	0.00
	Exchangeable K (cmol kg ⁻¹)	K	0.34	0.14	0.45	0.00
	Exchangeable Ca (cmol kg ⁻¹)	Ca	0.76	0.06	0.80	0.05
	Exchangeable Mg (cmol kg ⁻¹)	Mg	0.54	0.02	0.62	0.00
Soil contamination	Exchangeable Cu (ppm)	Cu	0.10	0.07	0.24	0.03

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700 Tables 2a and 2b

701 Results from ANOVA (F) or Kruskal-Wallis (H) and mean values for the 25 attributes in S- and F-cAFS, savannah and forest controls, from plots with low clay
702 content soils (LCCS, 2a) and plots with high clay content soils (HCCS, 2b). In the case of LCCS plots, age categories were applied only on S-cAFS (2a). In the
703 case of HCCS plots, age categories were applied only on F-cAFS (2b) (see text). °: P < 0.1; *: P < 0.05; **: P < 0.01; ***: P < 0.001. Differences at P < 0.05
704 between the different age categories and land-uses are indicated by different letters after the mean.

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717 (2a)

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Service	Attribute	F or H	S-cAFS				<i>F-cAFS</i>	<i>forest</i>	
			savannah	[0-14] years	[15-30] years	[31-50] years			[50>] years
Conservation	Perennials shannon index	8.134 ***	1.094 b	1.423 b	1.820 b	1.700 b	1.731 b	1.958 b	2.832 a
	Perennials species richness (nb ha ⁻¹)	25.644 ***	5.0 b	8.0 b	8.0 b	7.3 b	8.0 b	10.7 b	26.0 a
Carbon storage	Large associated trees biomass (t ha ⁻¹)	4.330 *	0.8 b	31.0 b	22.5 b	134.1 ab	103.7 ab	220.0 a	177.2 ab
	Cocoa trees biomass (t ha ⁻¹)	6.531 **	-	2.0 b	11.9 ab	20.7 a	20.1 a	17.5 a	-
Crop production	Density of cocoa trees (nb ha ⁻¹)	0.456	-	1170.8	1593.8	1316.7	1087.5	1320.8	-
	Basal area of cocoa trees (m ² ha ⁻¹)	6.154 *	-	1.272 b	5.906 a	8.504 a	9.081 a	7.442 a	-
	Cocoa trees basal area share (%)	16.448 ***	-	8.4 c	49.0 a	33.6 ab	41.9 a	21.2 bc	-
	Mean accessible yield (kg ha ⁻¹)	4.422 *	-	129.4 b	699.0 ab	919.7 a	1000.8 a	947.6 a	-
	Density of banana stems (nb ha ⁻¹)	2.304 °	-	116.7	6.3	4.2	12.5	37.5	-
Nutrient cycling	Leaf litterfall (t ha ⁻¹)	4.448 *	-	2.3 b	5.4 a	6.1 a	6.2 a	6.3 a	7.4 a
	Total litterfall (t ha ⁻¹)	8.745 **	-	3.4 c	6.4 bc	8.6 bc	7.6 bc	9.0 b	14.7 a
	Leaf standing litter (t ha ⁻¹)	1.313	-	2.1	2.7	2.4	1.1	1.2	0.5
	Total standing litter (t ha ⁻¹)	1.063	-	4.1	5.9	6.4	3.0	5.4	3.2
	Leaf litter cycling	2.669	-	0.448	0.517	0.530	0.712	0.591	0.854
	Total litter cycling	3.934 *	-	0.666 b	0.681 b	0.752 ab	0.862 ab	0.869 ab	0.963 a
Soil quality	pH	4.460 *	5.8 ab	5.5 b	5.8 ab	5.9 ab	6.4 a	6.5 a	6.3 ab
	Organic C (%)	9.132 ***	1.10 bc	0.99 c	1.34 ab	1.52 a	1.54 a	1.58 a	1.61 a
	Total N (%)	6.298 **	0.05 bc	0.04 c	0.10 abc	0.10 ab	0.12 a	0.11 ab	0.14 a
	C:N	5.675 **	20.5 ab	22.3 a	16.1 abc	14.8 bc	13.5 bc	14.6 bc	11.6 c
	Inorganic P (ppm)	2.456 °	1.80	2.83	1.90	6.48	5.22	6.53	7.98
	CEC (cmol kg ⁻¹)	4.733 **	3.0 bc	2.6 c	4.2 abc	4.4 abc	5.6 a	5.0 abc	5.3 ab
	Exchangeable K (cmol kg ⁻¹)	1.902	0.16	0.17	0.17	0.13	0.17	0.20	0.31
	Exchangeable Ca (cmol kg ⁻¹)	5.092 **	1.59 b	1.72 b	3.39 ab	3.32 ab	5.82 a	4.58 ab	4.33 ab
	Exchangeable Mg (cmol kg ⁻¹)	1.712	0.87	0.74	1.34	0.82	1.17	1.27	1.18
Soil contamination	Exchangeable Cu (ppm)	5.165 **	6.20 ab	0.79 b	1.47 b	3.42 ab	8.54 a	3.51 ab	1.57 b

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722 (2b)

High clay content soils										
Service	Attribute	F or H	forest	F-cAFS [0-14] years	F-cAFS [15-30] years	F-cAFS [31-50] years	F-cAFS [50>] years	S-cAFS	savannah	
Conservation	Perennials shannon index	4.237 *	2.571 a	2.276 ab	1.681 ab	1.500 b	1.583 b	1.775 ab	1.452 b	
	Perennials species richness (nb ha ⁻¹)	6.492 **	20.5 a	14.0 ab	13.0 ab	9.7 bc	8.3 bc	8.0 bc	2.500 c	
Carbon storage	Large associated trees biomass (t ha ⁻¹)	2.113	284.4	248.6	267.5	182.2	124.9	191.2	14.3	
	Cocoa trees biomass (t ha ⁻¹)	4.463 *	-	5.3 b	5.1 b	25.9 a	18.2 a	19.2 a	-	
Crop production	Density of cocoa trees (nb ha ⁻¹)	3.693 *	-	870.8	937.5	1633.3	895.8	1040.6	-	
	Basal area of cocoa trees (m ² ha ⁻¹)	3.795 *	-	2.545	2.548	10.515	8.154	8.369	-	
	Cocoa trees basal area share (%)	1.140	-	18.5	6.6	36.5	30.5	30.2	-	
	Mean accessible yield (kg ha ⁻¹)	0.080	-	630.9	669.6	723.5	732.6	801.2	-	
	Density of banana stems (nb ha ⁻¹)	4.842 *	-	62.5 b	175.0 a	112.5 ab	58.3 b	18.8 b	-	
Nutrient cycling	Leaf litterfall (t ha ⁻¹)	3.094 °	7.7 a	5.4 a	7.6 a	5.5 a	5.0 a	5.4 a	-	
	Total litterfall (t ha ⁻¹)	4.220 *	15.1 a	8.9 ab	15.4 a	9.1 ab	6.8 b	10.3 ab	-	
	Leaf standing litter (t ha ⁻¹)	3.121 °	0.7 a	0.9 a	1.0 a	0.9 a	2.2 a	1.0 a	-	
	Total standing litter (t ha ⁻¹)	0.370	4.5	3.5	4.6	4.1	4.8	4.8	-	
	Leaf litter cycling	10.405 **	0.836 a	0.674 b	0.812 a	0.622 b	0.573 b	0.638 b	-	
	Total litter cycling	6.176 **	0.947 a	0.890 a	0.928 a	0.905 a	0.732 b	0.892 a	-	
Soil quality	pH	4.872 *	6.5 a	7.1 a	7.0 a	6.3 a	5.7 ab	6.6 a	4.9 b	
	Organic C (%)	1.598	2.18	2.10	2.96	1.76	1.78	2.49	1.43	
	Total N (%)	2.233	0.20	0.17	0.24	0.13	0.12	0.19	0.08	
	C:N	3.832 *	11.2 b	12.1 b	12.4 b	13.8 ab	15.1 ab	13.4 ab	18.8 a	
	Inorganic P (ppm)	4.800 *	7.215 ab	5.716 ab	-	3.977 ab	3.332 b	9.110 a	2.270 b	
	CEC (cmol kg ⁻¹)	1.500	8.0	7.3	11.3	5.5	6.9	9.5	5.5	
	Exchangeable K (cmol kg ⁻¹)	2.246	0.29	0.33	0.50	0.19	0.19	0.34	0.18	
	Exchangeable Ca (cmol kg ⁻¹)	2.356	8.56	10.23	15.86	5.09	4.69	10.16	1.61	
Exchangeable Mg (cmol kg ⁻¹)	1.076	2.14	2.15	2.86	1.38	1.92	2.17	1.11		
723	Soil contamination	Exchangeable Cu (ppm)	0.928	3.44	2.78	4.39	3.48	15.79	14.83	1.93

724

725 **Figure captions**

726 Figure 1

727 Vectors of the principal component analysis (PCA) after Varimax rotation for the low clay content
728 soils group (a) and the high clay content soils group (b). Abbreviations are explained in table 1. The
729 colour and the shape of the ending point of each vector display the ecosystem service to which each
730 attribute has been related to: big violet dot = carbon storage; red diamond = crop production; green
731 square = species conservation; blue triangle = nutrient cycling; small black dot = soil quality and
732 contamination.

733

734 Figure 2

735 Biplot of the PCA for the forest, savannah and cAFS plots on (a) low clay content soils or (b) high clay
736 content soils. Dots represent individual plots, squares represent systems' means. The name of each
737 agroforestry system age category, noted in (a) S-cAFS [age 1 – age2] and in (b) F-cAFS [age 1 – age2],
738 is followed by an exponent stating for which dimension (D1 and/or D2) its mean was found
739 significantly different from past land-use mean. In (a), forests and F-cAFS plots and means appear in
740 grey. These plots contributed to the PCA but were not included in the ANOVA made on plot scores to
741 distinguish between S-cAFS age categories and savannah. In (b), savannah and S-cAFS plots and
742 means appear in grey. These plots contributed to the PCA but were not included in the ANOVA made
743 on plot scores to distinguish between F-cAFS age categories and local forest. Arrows between
744 savannah and S-cAFS (a, orange) and between forest and F-cAFS (b, green) were added manually on
745 the biplot to highlight the “virtual” path followed by the agroforestry systems according to their past
746 land-use.

747

748 Figure 3

749 Temporal evolution of perennial plant Shannon index (a) and species richness (b), large associated
750 trees biomass (c) and cocoa trees biomass (d), in S- and F-cAFS. Plots from the LCCS group (low-clay

751 content soils) are represented with white symbols. Plots from the HCCS (high-clay content soils) are
752 represented with black symbols. Squares: F-cAFS; circles: S-cAFS; triangles: forest (F); diamonds:
753 savannah (S). Control plots (F and S) are shown on the right side of each sub-figure which background
754 appears in light grey. For each indicator, significant temporal evolution is represented by a solid
755 regression line or curve which is black for F-cAFS and grey for S-cAFS. Dashed lines (black for F-cAFS
756 and grey for S-cAFS) correspond to the variables' means when no significant temporal evolution
757 could be found. °: $P < 0.1$; *: $P < 0.05$; **: $P < 0.01$.

758

759 Figure 4

760 African (a) and total (b) perennial plant species rarefaction curves for forest (green line with green
761 squares), F-cAFS (green line with white squares), S-cAFS (orange line with white circles) and savannah
762 (orange line with orange circles) plots. The 95% intervals (shaded regions) were obtained by a
763 bootstrap method based on 100 replications. The numbers within the brackets next to the system
764 type correspond to: the number of plots needed (first number) to reach the sample size, the number
765 of individuals counted (second number) and the number of species (third number) obtained for the
766 studied sample size.

767 Figure 5

768 Temporal evolution of crop production indicators (a to e) in S- and F-cAFS. Plots from the LCCS group
769 (low-clay content soils) are represented with white symbols. Plots from the HCCS (high-clay content
770 soils) are represented with black symbols. Squares: F-cAFS; circles: S-cAFS; triangles: forest (F);
771 diamonds: savannah (S). Control plots (F and S) are shown on the right side of each sub-figure which
772 background appears in light grey. For each indicator, significant temporal evolution is represented by
773 a solid regression line or curve which is black for F-cAFS and grey for S-cAFS. Dashed lines (black for F-
774 cAFS and grey for S-cAFS) correspond to the variables' means when no significant temporal evolution
775 could be found. °: $P < 0.1$; *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$.

776

777 Figure 6

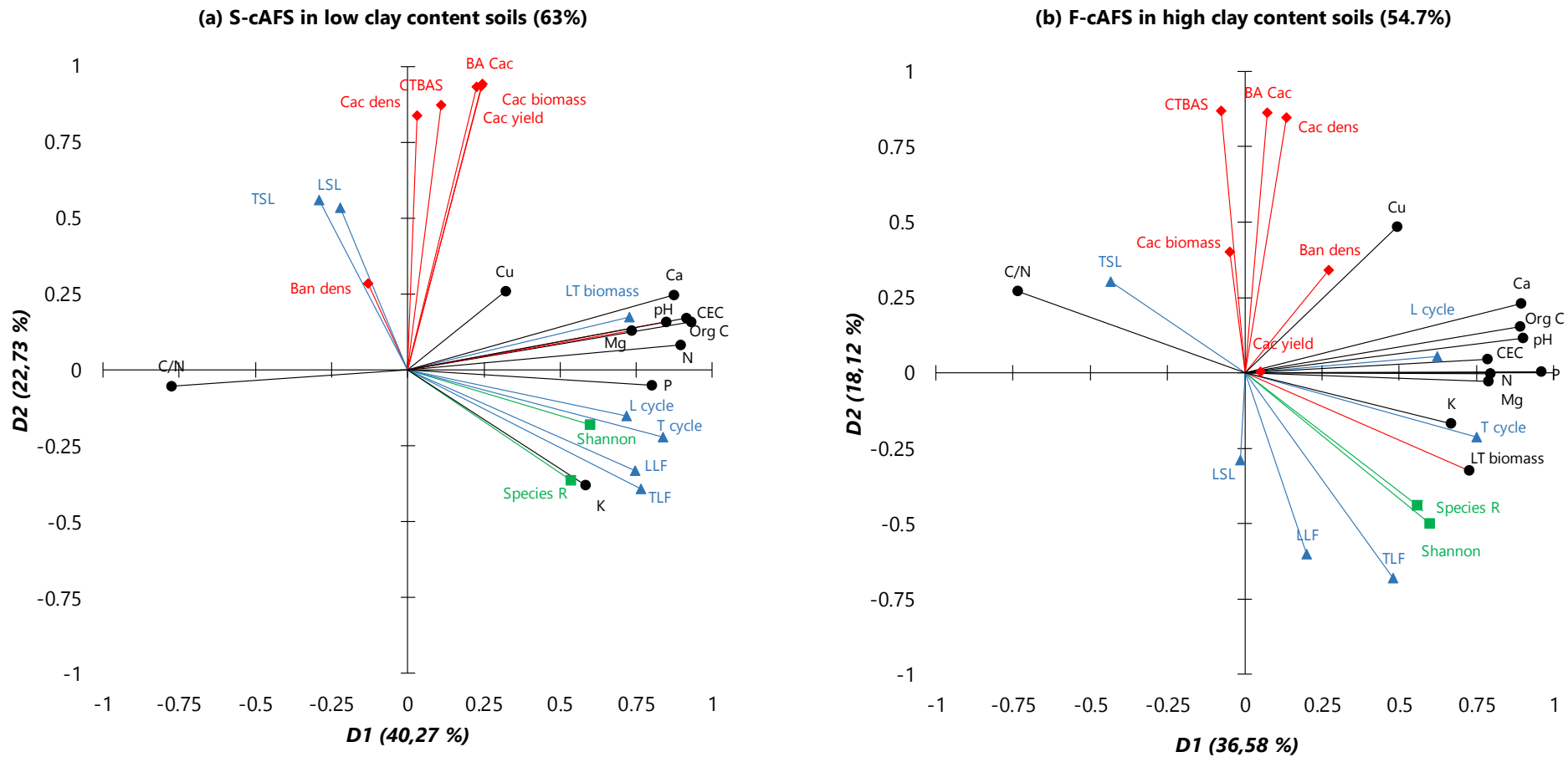
778 Temporal evolution of litter dynamic indicators (a to f) in S- and F-cAFS. Plots from the LCCS group
779 (low-clay content soils) are represented with white symbols. Plots from the HCCS (high-clay content
780 soils) are represented with black symbols. Squares: F-cAFS; circles: S-cAFS; triangles: forest (F);
781 diamonds: savannah (S). Control plots (F and S) are shown on the right side of each sub-figure which
782 background appears in light grey. For each indicator, significant temporal evolution is represented by
783 a solid regression line or curve which is black for F-cAFS and grey for S-cAFS. Dashed lines (black for F-
784 cAFS and grey for S-cAFS) correspond to the variables' means when no significant temporal evolution
785 could be found. °: $P < 0.1$; *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$.

786

787 Figure 7

788 Temporal evolution of soil quality (a to i) and pollution (j) indicators in S- and F-cAFS. Plots from the
789 LCCS group (low-clay content soils) are represented with white symbols. Plots from the HCCS (high-
790 clay content soils) are represented with black symbols. Squares: F-cAFS; circles: S-cAFS; triangles:
791 forest (F); diamonds: savannah (S). Control plots (F and S) are shown at the right side of each sub-
792 figure which background appears in light grey. For each indicator, significant temporal evolution is
793 represented by a solid regression line or curve which is black for F-cAFS and grey for S-cAFS. Dashed
794 lines (black for F-cAFS and grey for S-cAFS) correspond to the variables' means when no significant
795 temporal evolution could be found. °: $P < 0.1$; *: $P < 0.05$; **: $P < 0.01$; ***: $P < 0.001$.

796



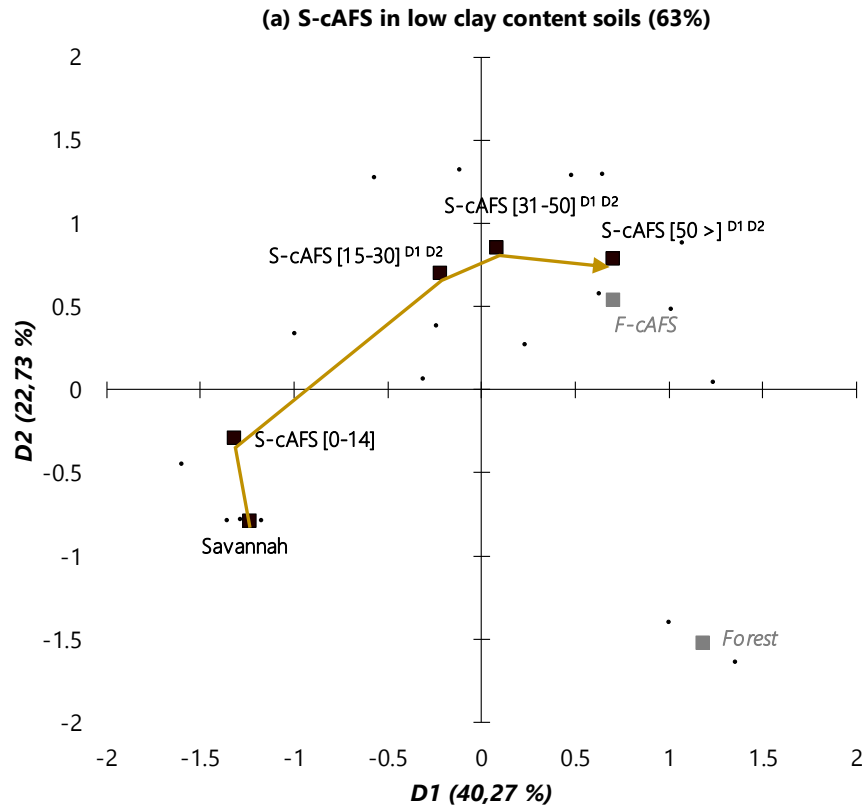
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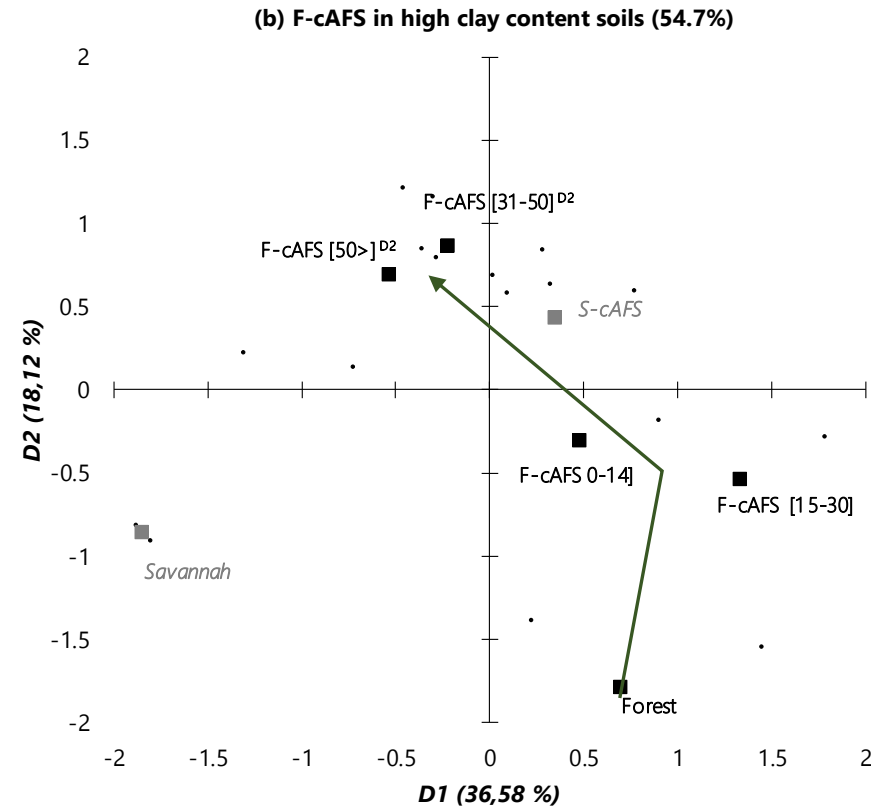
802 **Figure 2**

803



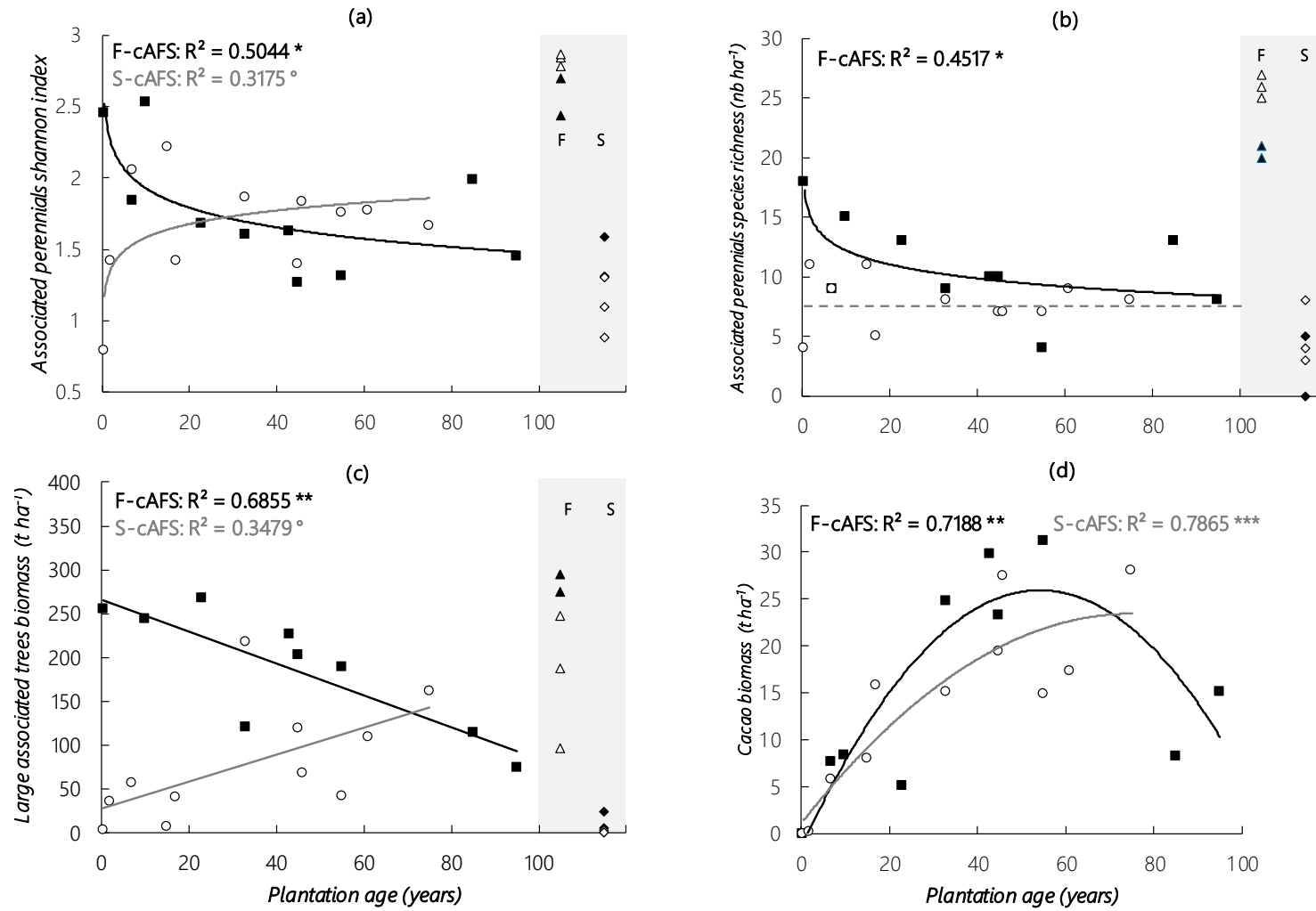
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806 **Figure 3**

807 **Conservation and carbon storage**

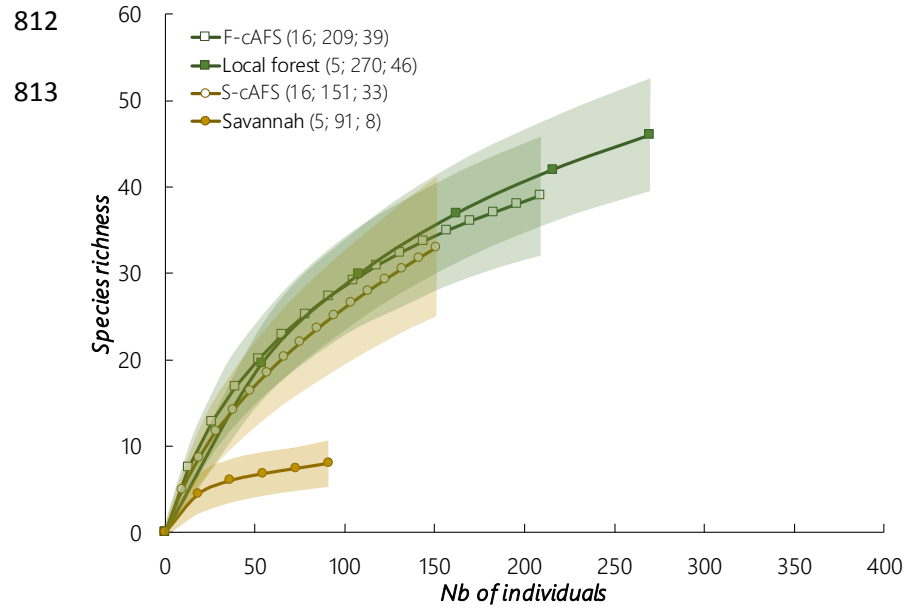


808

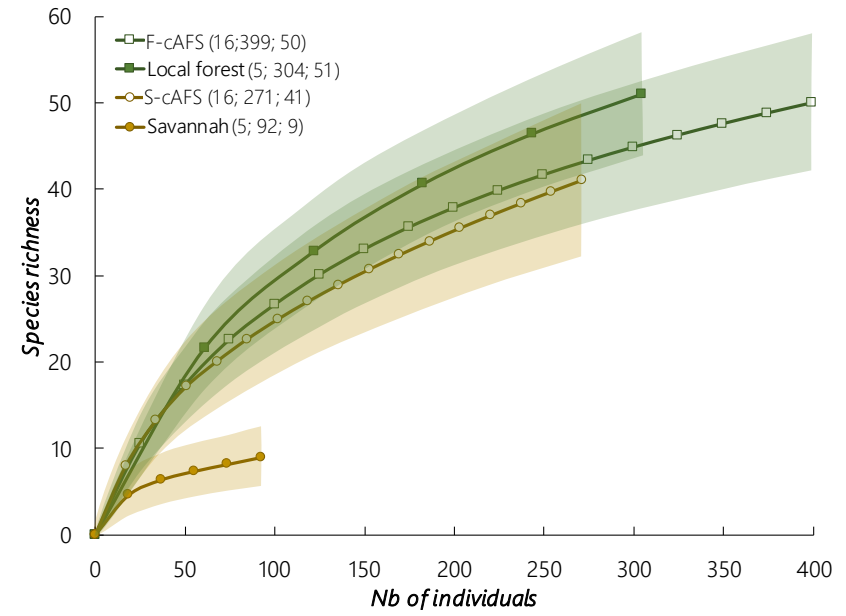
809 **Figure 4**

810

811 **(a) African perennial species**

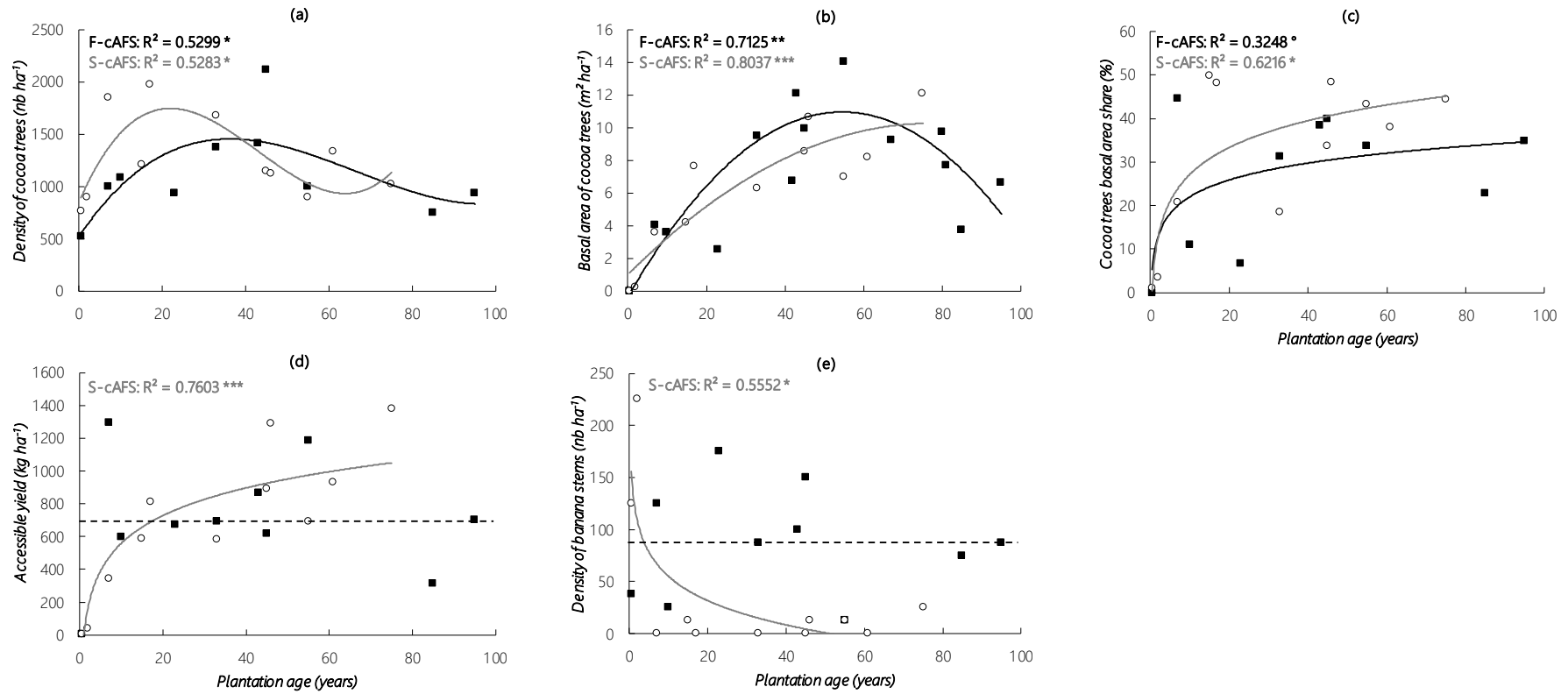


(b) All perennial species



814 **Figure 5**

815 **Crop production**

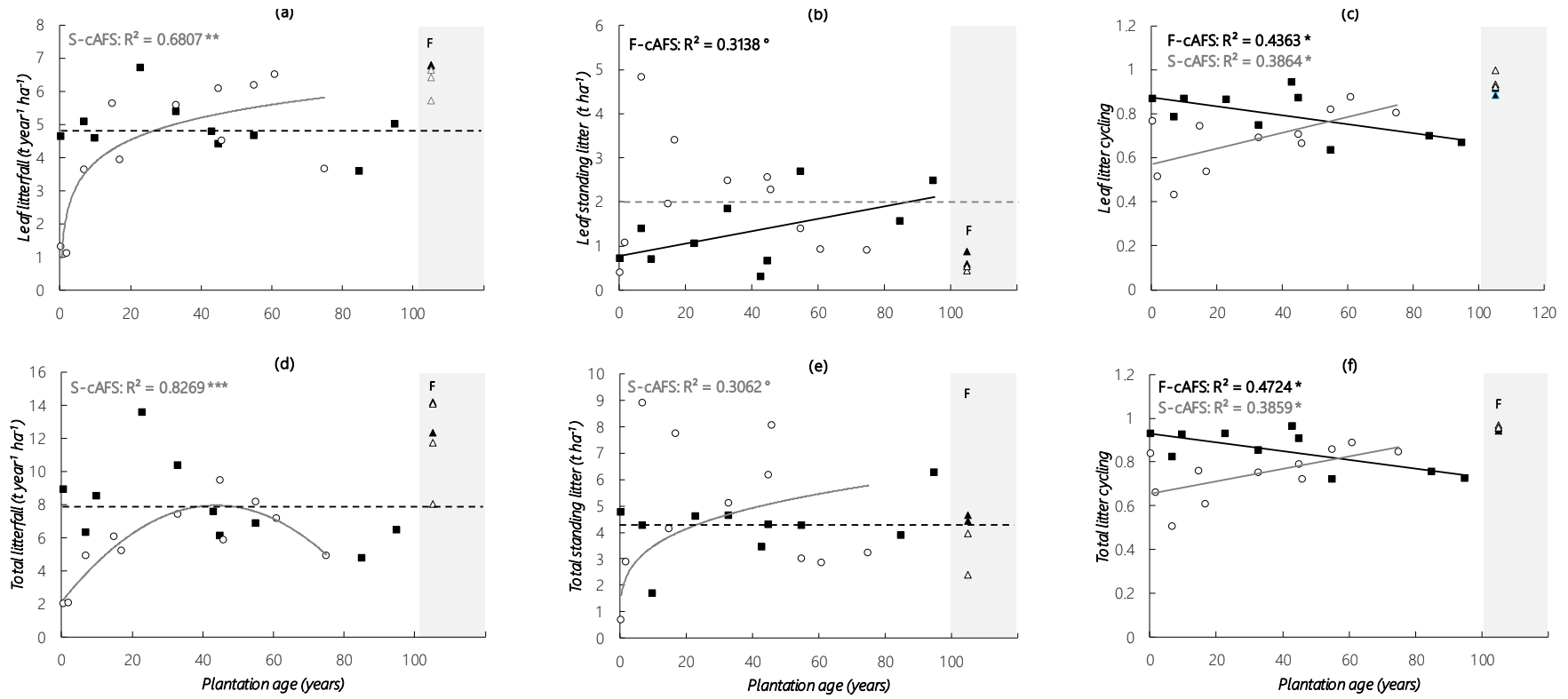


816

817

818 **Figure 6**

819 **Nutrient cycling**

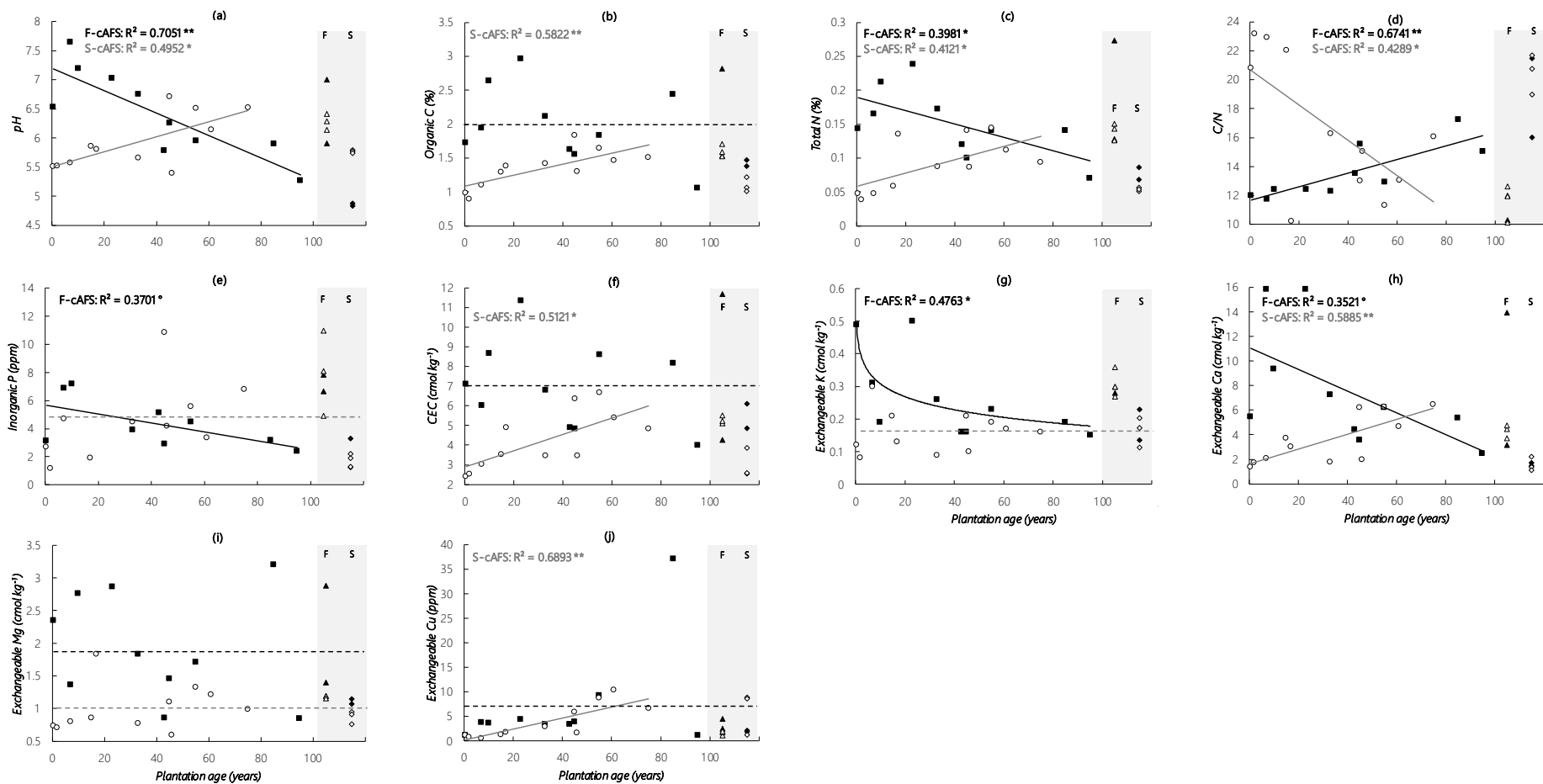


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821

822 **Figure 7**

823 **Soil quality and contamination**



824

825 **Appendix 1**

826 Results from ANOVA (F) and mean values of the 25 studied ecosystem attributes in S- and F-cAFS,

827 savannah and local forest controls, irrespective to their soil clay content and age. °: P < 0.1; *: P <

828 0.05; **: P < 0.01; ***: P < 0.001. Differences at P < 0.05, after SNK test, between land-uses are

829 indicated by different letters after the mean.

Service	Attribute	F	savannah	S-cAFS	F-cAFS	forest
Conservation	Perennials shannon index	15.141 ***	1.238 c	1.707 b	1.749 b	2.727 a
	Perennials species richness (nb ha ⁻¹)	48.072 ***	4.0 c	8.1 b	10.6 b	23.8 a
Carbon storage	Large associated trees biomass (t ha ⁻¹)	5.629 **	6.2 b	107.1 a	161.9 a	220.1 a
	Cocoa trees biomass (t ha ⁻¹)	0.13	-	15.4	14.19	-
Crop production	Density of cocoa trees (nb ha ⁻¹)	0.027	-	1174.2	1197.7	-
	Basal area of cocoa trees (m ² ha ⁻¹)	0.049	-	6.812	6.509	-
	Cocoa trees basal area share (%)	0.779	-	31.5	26.3	-
	Mean accessible yield (kg ha ⁻¹)	0.011	-	716.7	701.9	-
	Density of banana stems (nb ha ⁻¹)	4.225 *	-	33.6 b	97.7 a	-
Nutrient cycling	Leaf litterfall (t ha ⁻¹)	4.451 *	-	4.5 b	5.2 b	6.5 a
	Total litterfall (t ha ⁻¹)	8.951 **	-	6.7 b	8.0 b	12.1 a
	Leaf standing litter (t ha ⁻¹)	0.705	-	4.8	4.7	3.7
	Total standing litter (t ha ⁻¹)	3.031 °	-	1.8 a	1.4 ab	0.6 b
	Leaf litter cycling	3.522 *	-	0.497 b	0.533 b	0.640 a
	Total litter cycling	5.964 *	-	0.785 b	0.844 b	0.952 a
Soil quality	pH	4.249 *	5.4 b	6.1 a	6.4 a	6.4 a
	Organic C (%)	1.958	1.23	1.660	1.85	1.84
	Total N (%)	3.687 *	0.06 b	0.116 ab	0.14 a	0.16 a
	C:N	4.625 **	19.8 a	15.9 b	14.4 b	11.4 b
	Inorganic P (ppm)	4.379 *	1.99 b	5.44 a	4.74 a	7.67 a
	CEC (cmol kg ⁻¹)	1.189	4.0	5.6	6.2	6.4
	Exchangeable K (cmol kg ⁻¹)	1.680	0.17	0.21	0.24	0.30
	Exchangeable Ca (cmol kg ⁻¹)	2.016	1.60	5.20	6.34	6.02
	Exchangeable Mg (cmol kg ⁻¹)	1.921	0.97	1.30	1.70	1.56
Soil contamination	Exchangeable Cu (ppm)	0.469	4.49	6.79	5.44	2.32

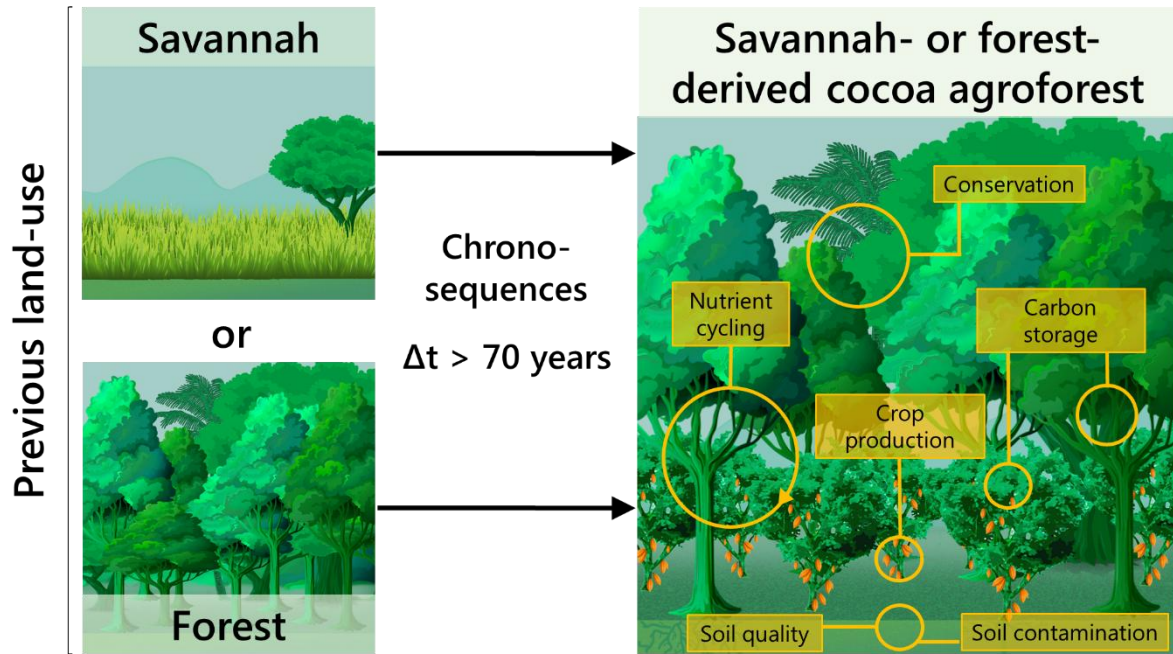
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831

832 Graphical abstract caption

833 Highlights of the study design and considered ecosystem services.

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835

Table 1
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Service	Attribute	Abbreviation	S-cAFS		F-cAFS	
			low clay content soils		high clay content soils	
			D1	D2	D1	D2
Conservation	Perennials shannon index	Shannon	0.36	0.03	0.36	0.19
	Perennials species richness (nb ha ⁻¹)	Species R	0.28	0.13	0.31	0.05
C Storage	Large associated trees biomass (t ha ⁻¹)	LT biomass	0.53	0.03	0.53	0.00
	Cocoa trees biomass (t ha ⁻¹)	Cac biomass	0.05	0.87	0.00	0.16
Crop production	Density of cocoa trees (nb ha ⁻¹)	Cac dens	0.00	0.70	0.02	0.72
	Basal area of cocoa trees (m ² ha ⁻¹)	BA Cac	0.06	0.89	0.01	0.75
	Cocoa trees basal area share (%)	CTBAS	0.01	0.76	0.01	0.25
	Mean accessible yield (kg ha ⁻¹)	Cac yield	0.06	0.88	0.00	0.00
	Density of banana stems (nb ha ⁻¹)	Ban dens	0.02	0.08	0.07	0.12
Nutrient cycling	Leaf litterfall (t ha ⁻¹)	LLF	0.56	0.11	0.04	0.08
	Total litterfall (t ha ⁻¹)	TLF	0.59	0.15	0.23	0.09
	Leaf standing litter (t ha ⁻¹)	LSL	0.05	0.28	0.00	0.11
	Total standing litter (t ha ⁻¹)	TSL	0.08	0.31	0.19	0.23
	Leaf litter cycling	L cycle	0.52	0.02	0.39	0.36
	Total litter cycling	T cycle	0.70	0.05	0.56	0.46
Soil quality	pH	pH	0.72	0.02	0.81	0.76
	Organic C (%)	Org C	0.86	0.03	0.79	0.00
	Total N (%)	N	0.80	0.01	0.92	0.02
	C:N	C/N	0.60	0.00	0.54	0.07
	Inorganic P (ppm)	P	0.64	0.00	0.63	0.01
	CEC (cmol kg ⁻¹)	CEC	0.83	0.03	0.62	0.00
	Exchangeable K (cmol kg ⁻¹)	K	0.34	0.14	0.45	0.00
	Exchangeable Ca (cmol kg ⁻¹)	Ca	0.76	0.06	0.80	0.05
	Exchangeable Mg (cmol kg ⁻¹)	Mg	0.54	0.02	0.62	0.00
Soil contamination	Exchangeable Cu (ppm)	Cu	0.10	0.07	0.24	0.03

Table 2
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(2a)

Service	Attribute	F or H	Low clay content soils						<i>F-cAFS</i>	<i>forest</i>
			savannah	S-cAFS [0-14] years	S-cAFS [15-30] years	S-cAFS [31-50] years	S-cAFS [50>] years			
Conservation	Perennials shannon index	8.134 ***	1.094 b	1.423 b	1.820 b	1.700 b	1.731 b	<i>1.958 b</i>	<i>2.832 a</i>	
	Perennials species richness (nb ha ⁻¹)	25.644 ***	5.0 b	8.0 b	8.0 b	7.3 b	8.0 b	<i>10.7 b</i>	<i>26.0 a</i>	
Carbon storage	Large associated trees biomass (t ha ⁻¹)	4.330 *	0.8 b	31.0 b	22.5 b	134.1 ab	103.7 ab	<i>220.0 a</i>	<i>177.2 ab</i>	
	Cocoa trees biomass (t ha ⁻¹)	6.531 **	-	2.0 b	11.9 ab	20.7 a	20.1 a	<i>17.5 a</i>	-	
Crop production	Density of cocoa trees (nb ha ⁻¹)	0.456	-	1170.8	1593.8	1316.7	1087.5	<i>1320.8</i>	-	
	Basal area of cocoa trees (m ² ha ⁻¹)	6.154 *	-	1.272 b	5.906 a	8.504 a	9.081 a	<i>7.442 a</i>	-	
	Cocoa trees basal area share (%)	16.448 ***	-	8.4 c	49.0 a	33.6 ab	41.9 a	<i>21.2 bc</i>	-	
	Mean accessible yield (kg ha ⁻¹)	4.422 *	-	129.4 b	699.0 ab	919.7 a	1000.8 a	<i>947.6 a</i>	-	
	Density of banana stems (nb ha ⁻¹)	2.304 °	-	116.7	6.3	4.2	12.5	<i>37.5</i>	-	
Nutrient cycling	Leaf litterfall (t ha ⁻¹)	4.448 *	-	2.3 b	5.4 a	6.1 a	6.2 a	<i>6.3 a</i>	<i>7.4 a</i>	
	Total litterfall (t ha ⁻¹)	8.745 **	-	3.4 c	6.4 bc	8.6 bc	7.6 bc	<i>9.0 b</i>	<i>14.7 a</i>	
	Leaf standing litter (t ha ⁻¹)	1.313	-	2.1	2.7	2.4	1.1	<i>1.2</i>	<i>0.5</i>	
	Total standing litter (t ha ⁻¹)	1.063	-	4.1	5.9	6.4	3.0	<i>5.4</i>	<i>3.2</i>	
	Leaf litter cycling	2.669	-	0.448	0.517	0.530	0.712	<i>0.591</i>	<i>0.854</i>	
	Total litter cycling	3.934 *	-	0.666 b	0.681 b	0.752 ab	0.862 ab	<i>0.869 ab</i>	<i>0.963 a</i>	
Soil quality	pH	4.460 *	5.8 ab	5.5 b	5.8 ab	5.9 ab	6.4 a	<i>6.5 a</i>	<i>6.3 ab</i>	
	Organic C (%)	9.132 ***	1.10 bc	0.99 c	1.34 ab	1.52 a	1.54 a	<i>1.58 a</i>	<i>1.61 a</i>	
	Total N (%)	6.298 **	0.05 bc	0.04 c	0.10 abc	0.10 ab	0.12 a	<i>0.11 ab</i>	<i>0.14 a</i>	
	C:N	5.675 **	20.5 ab	22.3 a	16.1 abc	14.8 bc	13.5 bc	<i>14.6 bc</i>	<i>11.6 c</i>	
	Inorganic P (ppm)	2.456 °	1.80	2.83	1.90	6.48	5.22	<i>6.53</i>	<i>7.98</i>	
	CEC (cmol kg ⁻¹)	4.733 **	3.0 bc	2.6 c	4.2 abc	4.4 abc	5.6 a	<i>5.0 abc</i>	<i>5.3 ab</i>	
	Exchangeable K (cmol kg ⁻¹)	1.902	0.16	0.17	0.17	0.13	0.17	<i>0.20</i>	<i>0.31</i>	
	Exchangeable Ca (cmol kg ⁻¹)	5.092 **	1.59 b	1.72 b	3.39 ab	3.32 ab	5.82 a	<i>4.58 ab</i>	<i>4.33 ab</i>	
Exchangeable Mg (cmol kg ⁻¹)	1.712	0.87	0.74	1.34	0.82	1.17	<i>1.27</i>	<i>1.18</i>		
Soil contamination	Exchangeable Cu (ppm)	5.165 **	6.20 ab	0.79 b	1.47 b	3.42 ab	8.54 a	<i>3.51 ab</i>	<i>1.57 b</i>	

(2b)

			High clay content soils						
Service	Attribute	F or H	forest	F-cAFS [0-14] years	F-cAFS [15-30] years	F-cAFS [31-50] years	F-cAFS [50>] years	S-cAFS	savannah
Conservation	Perennials shannon index	4.237 *	2.571 a	2.276 ab	1.681 ab	1.500 b	1.583 b	1.775 ab	1.452 b
	Perennials species richness (nb ha ⁻¹)	6.492 **	20.5 a	14.0 ab	13.0 ab	9.7 bc	8.3 bc	8.0 bc	2.500 c
Carbon storage	Large associated trees biomass (t ha ⁻¹)	2.113	284.4	248.6	267.5	182.2	124.9	191.2	14.3
	Cocoa trees biomass (t ha ⁻¹)	4.463 *	-	5.3 b	5.1 b	25.9 a	18.2 a	19.2 a	-
Crop production	Density of cocoa trees (nb ha ⁻¹)	3.693 *	-	870.8	937.5	1633.3	895.8	1040.6	-
	Basal area of cocoa trees (m ² ha ⁻¹)	3.795 *	-	2.545	2.548	10.515	8.154	8.369	-
	Cocoa trees basal area share (%)	1.140	-	18.5	6.6	36.5	30.5	30.2	-
	Mean accessible yield (kg ha ⁻¹)	0.080	-	630.9	669.6	723.5	732.6	801.2	-
	Density of banana stems (nb ha ⁻¹)	4.842 *	-	62.5 b	175.0 a	112.5 ab	58.3 b	18.8 b	-
Nutrient cycling	Leaf litterfall (t ha ⁻¹)	3.094 °	7.7 a	5.4 a	7.6 a	5.5 a	5.0 a	5.4 a	-
	Total litterfall (t ha ⁻¹)	4.220 *	15.1 a	8.9 ab	15.4 a	9.1 ab	6.8 b	10.3 ab	-
	Leaf standing litter (t ha ⁻¹)	3.121 °	0.7 a	0.9 a	1.0 a	0.9 a	2.2 a	1.0 a	-
	Total standing litter (t ha ⁻¹)	0.370	4.5	3.5	4.6	4.1	4.8	4.8	-
	Leaf litter cycling	10.405 **	0.836 a	0.674 b	0.812 a	0.622 b	0.573 b	0.638 b	-
	Total litter cycling	6.176 **	0.947 a	0.890 a	0.928 a	0.905 a	0.732 b	0.892 a	-
Soil quality	pH	4.872 *	6.5 a	7.1 a	7.0 a	6.3 a	5.7 ab	6.6 a	4.9 b
	Organic C (%)	1.598	2.18	2.10	2.96	1.76	1.78	2.49	1.43
	Total N (%)	2.233	0.20	0.17	0.24	0.13	0.12	0.19	0.08
	C:N	3.832 *	11.2 b	12.1 b	12.4 b	13.8 ab	15.1 ab	13.4 ab	18.8 a
	Inorganic P (ppm)	4.800 *	7.215 ab	5.716 ab	-	3.977 ab	3.332 b	9.110 a	2.270 b
	CEC (cmol kg ⁻¹)	1.500	8.0	7.3	11.3	5.5	6.9	9.5	5.5
	Exchangeable K (cmol kg ⁻¹)	2.246	0.29	0.33	0.50	0.19	0.19	0.34	0.18
	Exchangeable Ca (cmol kg ⁻¹)	2.356	8.56	10.23	15.86	5.09	4.69	10.16	1.61
Exchangeable Mg (cmol kg ⁻¹)	1.076	2.14	2.15	2.86	1.38	1.92	2.17	1.11	
Soil contamination	Exchangeable Cu (ppm)	0.928	3.44	2.78	4.39	3.48	15.79	14.83	1.93

Appendix 1

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Appendix 1

Service	Attribute	F	savannah	S-cAFS	F-cAFS	forest
Conservation	Perennials shannon index	15.141 ***	1.238 c	1.707 b	1.749 b	2.727 a
	Perennials species richness (nb ha ⁻¹)	48.072 ***	4.0 c	8.1 b	10.6 b	23.8 a
Carbon storage	Large associated trees biomass (t ha ⁻¹)	5.6295 **	6.2 b	107.1 a	161.9 a	220.1 a
	Cocoa trees biomass (t ha ⁻¹)	0.1296	-	15.4	14.19	-
Crop production	Density of cocoa trees (nb ha ⁻¹)	0.0268	-	1174.2	1197.7	-
	Basal area of cocoa trees (m ² ha ⁻¹)	0.0488	-	6.812	6.509	-
	Cocoa trees basal area share (%)	0.7786	-	31.5	26.3	-
	Mean accessible yield (kg ha ⁻¹)	0.0115	-	716.7	701.9	-
	Density of banana stems (nb ha ⁻¹)	4.2254 *	-	33.6 b	97.7 a	-
Nutrient cycling	Leaf litterfall (t ha ⁻¹)	4.4507 *	-	4.5 b	5.2 b	6.5 a
	Total litterfall (t ha ⁻¹)	8.951 **	-	6.7 b	8.0 b	12.1 a
	Leaf standing litter (t ha ⁻¹)	0.705	-	4.8	4.7	3.7
	Total standing litter (t ha ⁻¹)	3.031 °	-	1.8 a	1.4 ab	0.6 b
	Leaf litter cycling	3.522 *	-	0.497 b	0.533 b	0.640 a
	Total litter cycling	5.964 *	-	0.785 b	0.844 b	0.952 a
Soil quality	pH	4.249 *	5.4 b	6.1 a	6.4 a	6.4 a
	Organic C (%)	1.958	1.23	1.660	1.85	1.84
	Total N (%)	3.6868 *	0.06 b	0.116 ab	0.14 a	0.16 a
	C:N	4.625 **	19.8 a	15.9 b	14.4 b	11.4 b
	Inorganic P (ppm)	4.379 *	1.99 b	5.44 a	4.74 a	7.67 a
	CEC (cmol kg ⁻¹)	1.189	4.0	5.6	6.2	6.4
	Exchangeable K (cmol kg ⁻¹)	1.680	0.17	0.21	0.24	0.30
	Exchangeable Ca (cmol kg ⁻¹)	2.016	1.60	5.20	6.34	6.02
Exchangeable Mg (cmol kg ⁻¹)	1.9206	0.97	1.30	1.70	1.56	
Soil contamination	Exchangeable Cu (ppm)	0.469	4.49	6.79	5.44	2.32

Figure 1

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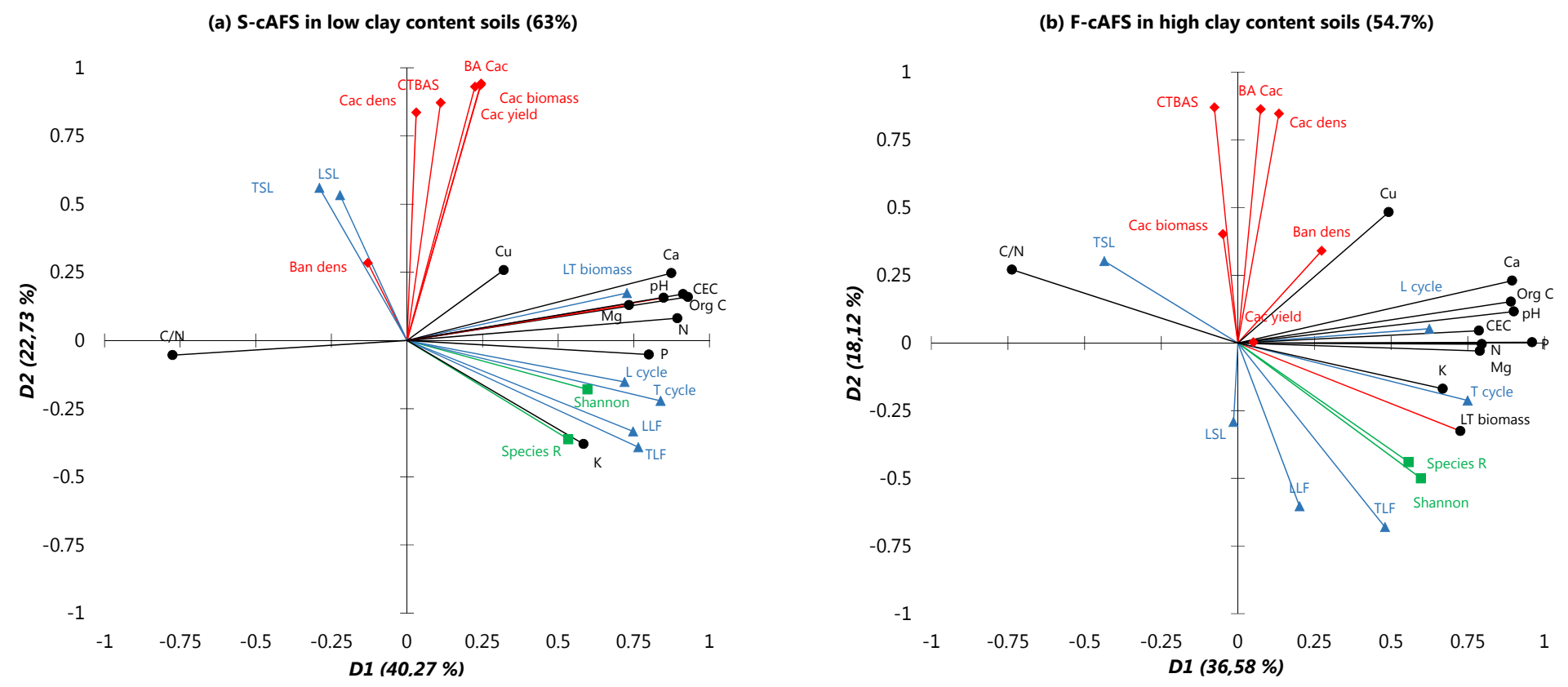


Figure 2

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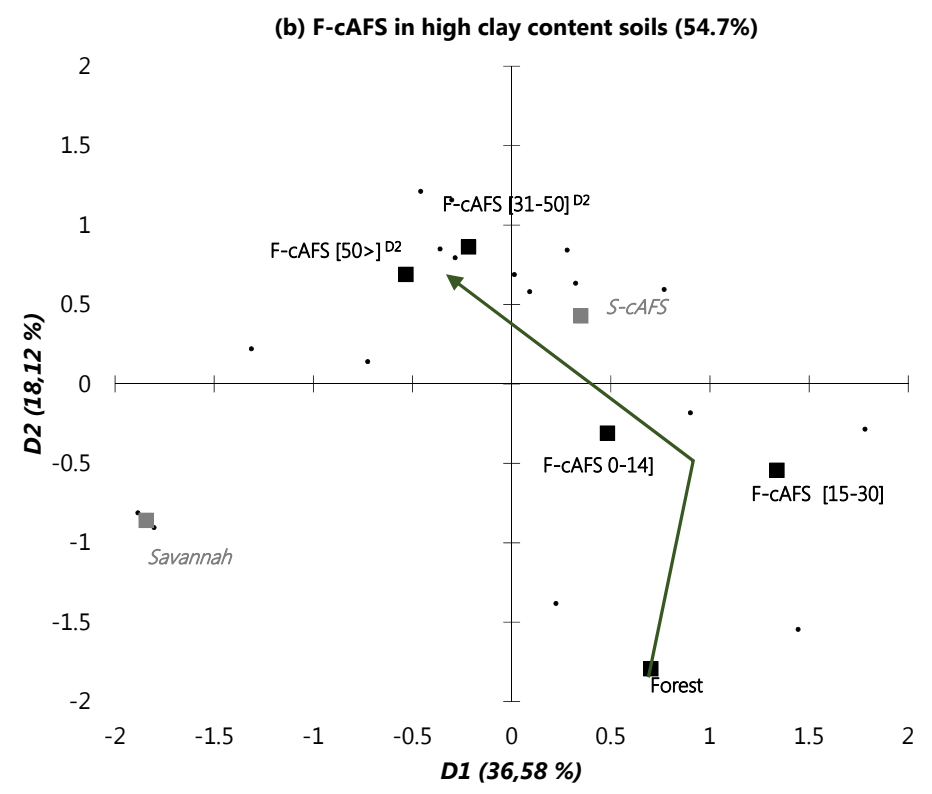
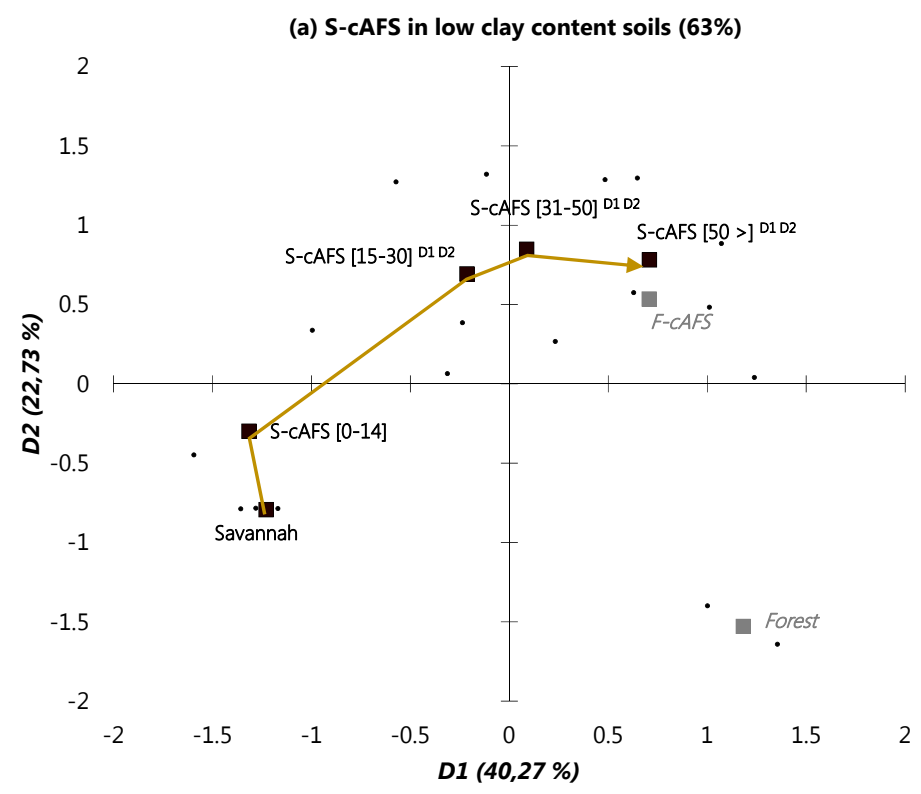


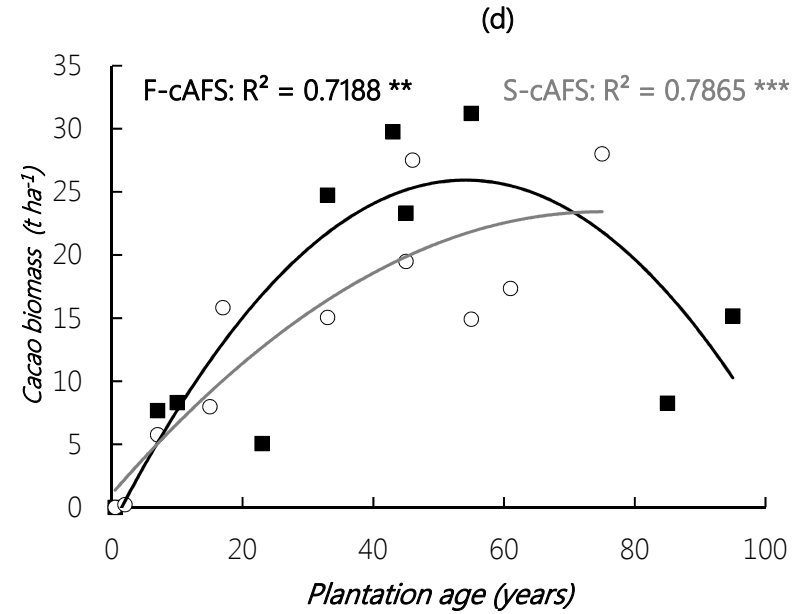
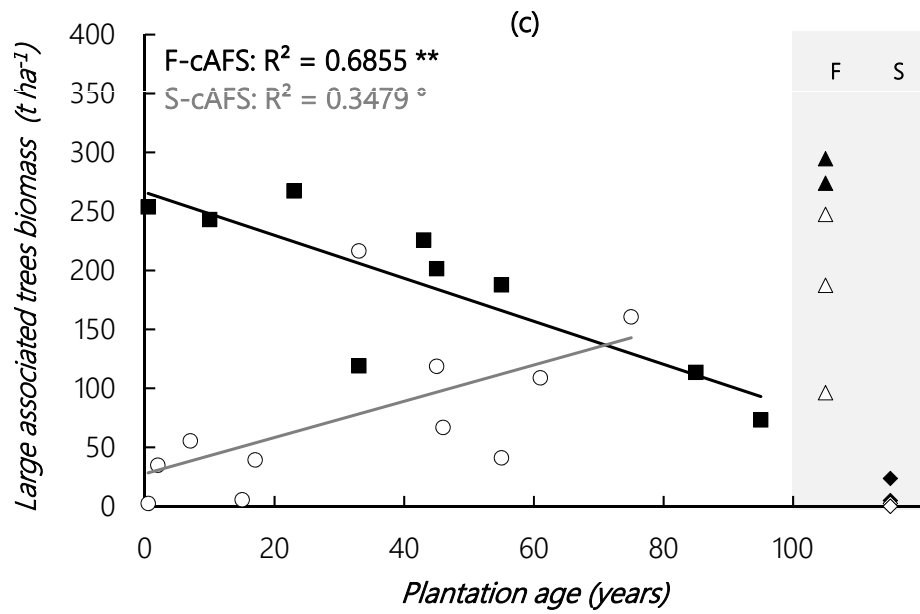
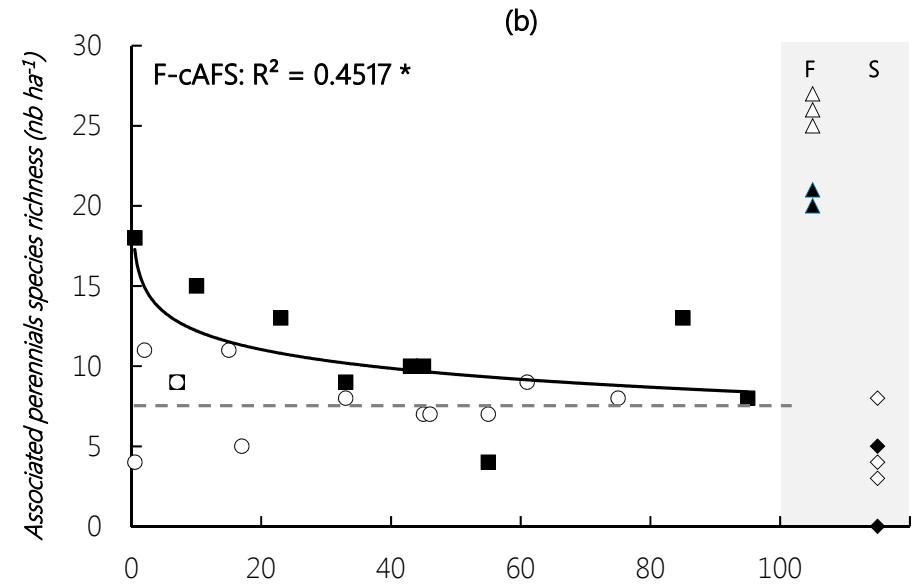
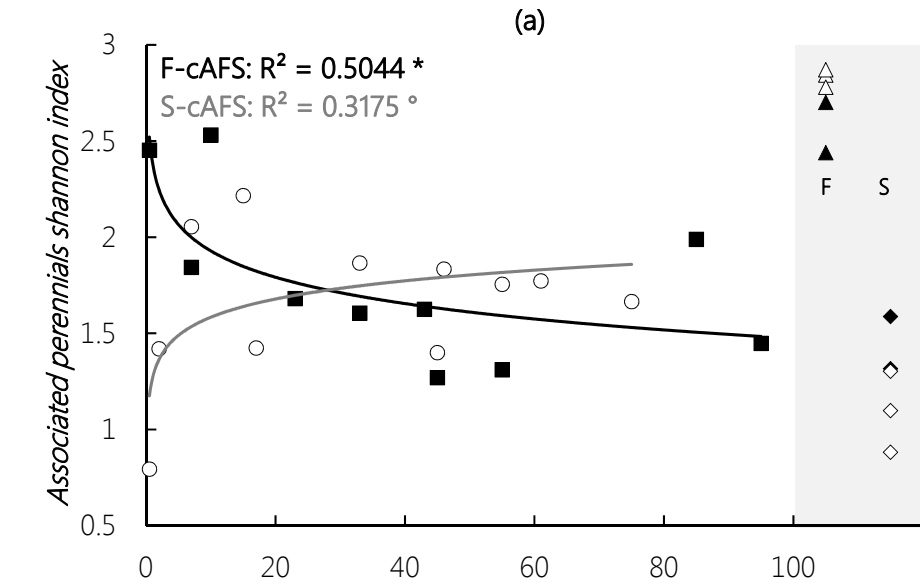
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Figure 4

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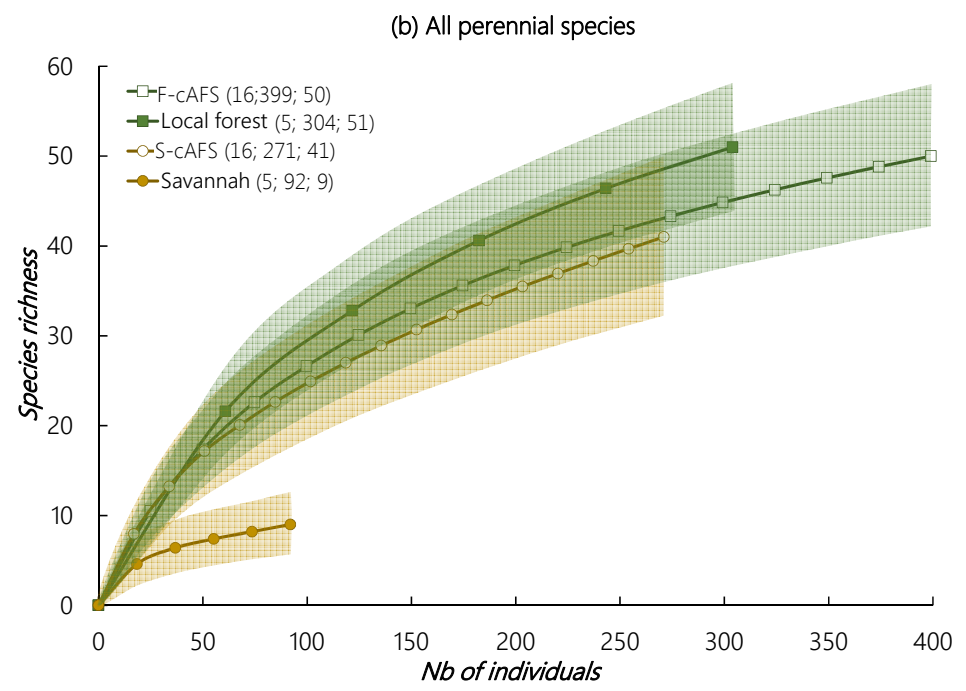
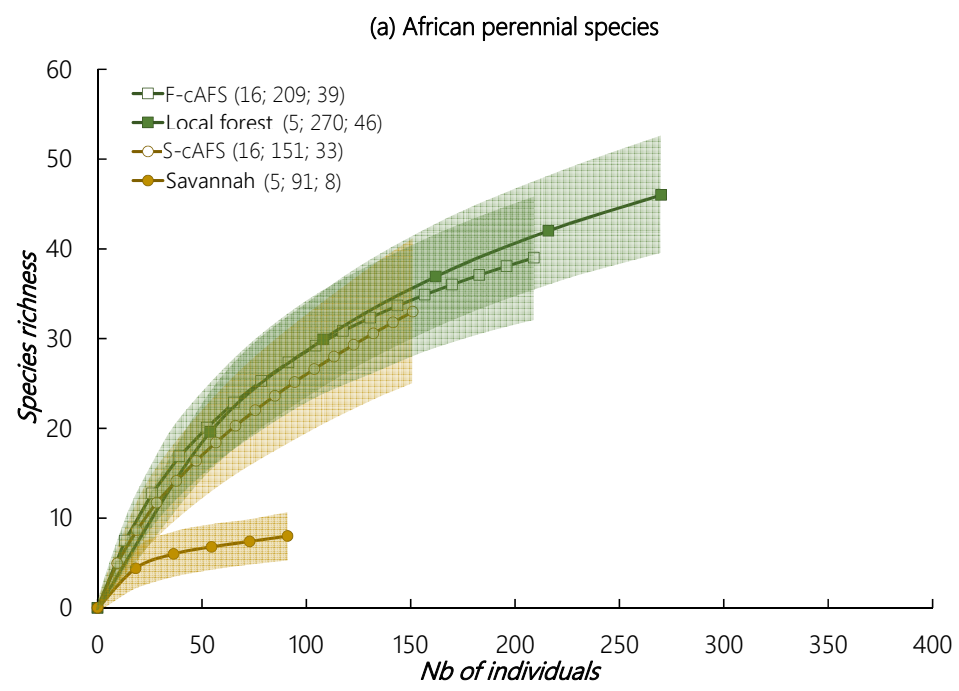


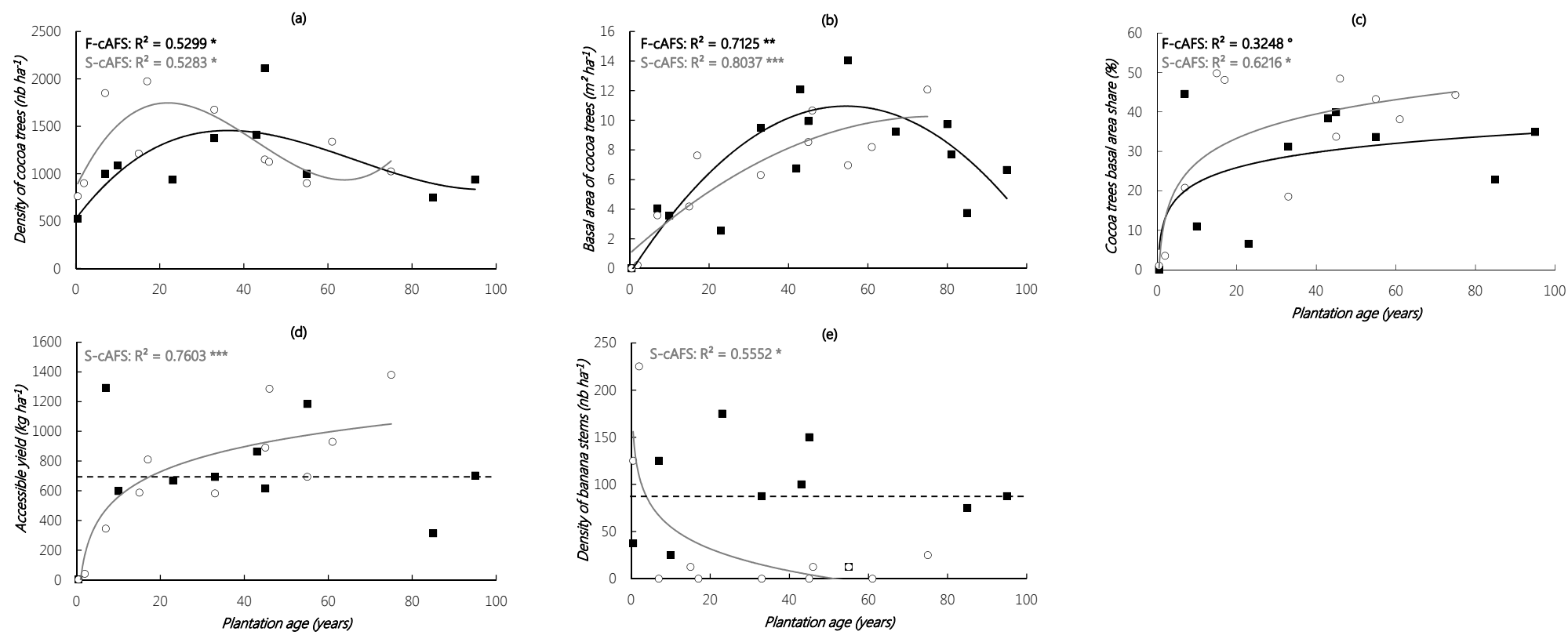
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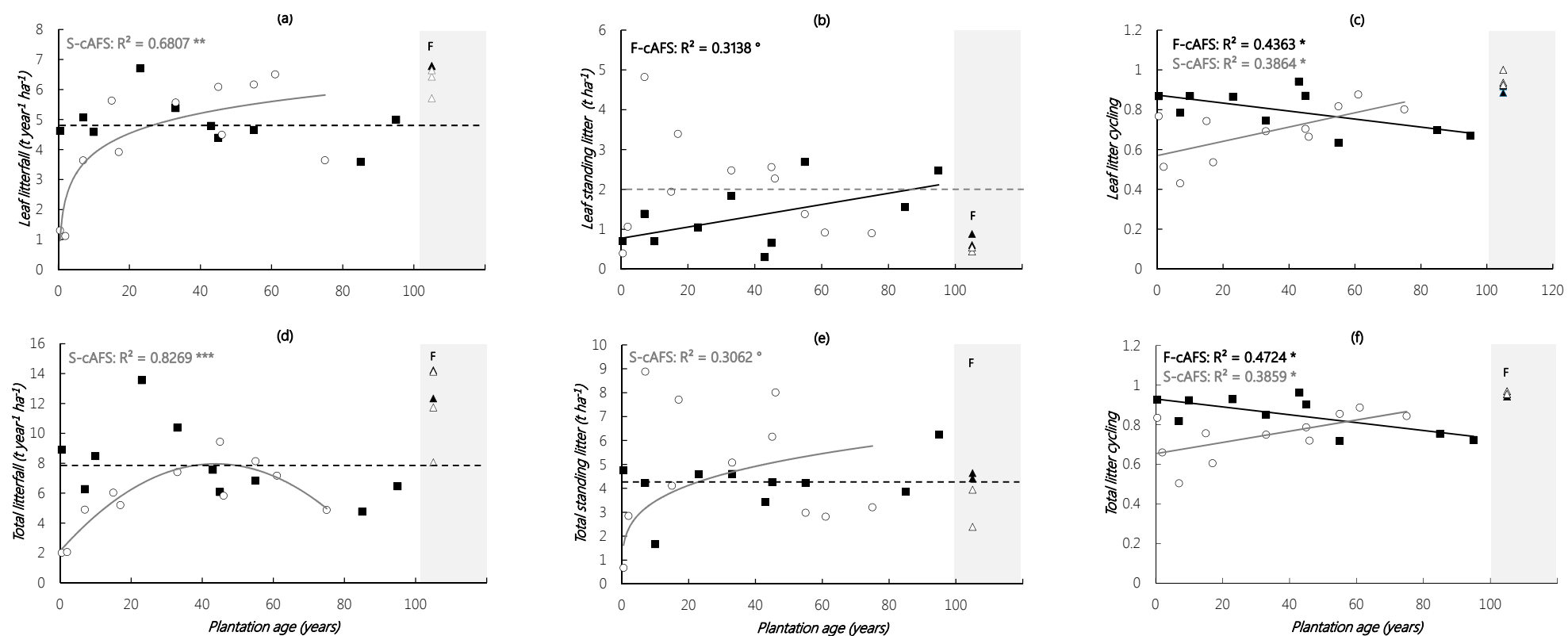
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