



HAL
open science

Root litter decomposition in a sub-Saharan agroforestry parkland dominated by *Faidherbia albida*

Lorène Siegwart, Isabelle Bertrand, Olivier Roupsard, Maxime Duthoit,
Christophe Jourdan

► To cite this version:

Lorène Siegwart, Isabelle Bertrand, Olivier Roupsard, Maxime Duthoit, Christophe Jourdan. Root litter decomposition in a sub-Saharan agroforestry parkland dominated by *Faidherbia albida*. *Journal of Arid Environments*, 2022, 198, pp.104696. 10.1016/j.jaridenv.2021.104696 . hal-03478845

HAL Id: hal-03478845

<https://hal.inrae.fr/hal-03478845>

Submitted on 8 Jan 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial 4.0 International License

1 **Root litter decomposition in a sub-Saharan agroforestry parkland dominated by *Faidherbia albida***

2 Siegwart Lorène¹, Bertrand Isabelle^{1*}, Roupsard Olivier^{1,2,3}, Duthoit Maxime^{1,2}, Jourdan Christophe^{1,2}

3 ¹- UMR Eco&Sols, Univ Montpellier, CIRAD, INRAE, IRD, Montpellier SupAgro, Montpellier, France

4 ²- CIRAD, UMR Eco&Sols, F-34398 Montpellier, France

5 ³- LMI IESOL, 18524 Dakar, Senegal

6 * Corresponding author: isabelle.bertrand@inrae.fr

7

8 **Abstract** The aim of our study was to measure the decomposition rate of root litter from annual and perennial
9 species according to soil depth and location under or far from trees in a sub-Saharan agroforestry parkland.

10 Soil characteristics under and far from the trees were analysed from topsoil to 200 cm depth. *Faidherbia* tree, pearl
11 millet and cowpea root litter samples were buried in litterbags for 15 months at 20, 40, 90 and 180 cm depths.

12 Root litter decomposition was mainly impacted by soil moisture and soil depth. *Faidherbia* decomposed more
13 slowly ($36 \pm 12\%$ remaining mass after 15 months) than cowpea and pearl millet roots ($23 \pm 7\%$ and $29 \pm 11\%$
14 respectively). Pearl millet aboveground biomass, at harvesting time, was twice as high under (9918 g m^{-2}) than far
15 (4332 g m^{-2}) from the tree, and belowground biomass (0 to 200 cm of depth) was 89 g m^{-2} and 64 g m^{-2} under and
16 far from the tree, respectively. *Faidherbia* fine roots contributed slightly (p -value < 0.1) to higher stocks of C under
17 the tree ($7761 \pm 346 \text{ g m}^{-2}$) than far from it ($5425 \pm 558 \text{ g m}^{-2}$) and from 0 cm down to 200 cm depth.

18 **Key words** Soil organic carbon, soil nutrients, root litter quality, soil depth, *Vigna unguiculata*, *Pennisetum*
19 *glaucum*.

20 **Acknowledgements**

21 We would like to thank both the EU-LEAP-Agri RAMSES II and Agropolis/TOTAL Foundations DSCATT
22 projects for the funding of the experimental setup at the “*Faidherbia*-Flux” platform of Sob, Niakhar district,
23 Senegal (<https://lped.info/wikiObsSN/?Faidherbia-Flux>). Among the technical staff from Senegal, we are
24 extremely indebted to Ibou Diouf from Sob village for extensive help in the field and Patricia Moulin from
25 LAMA/IESOL for conducting all soil analyses.

26

27 **Introduction**

28 In the current context of global warming, soil carbon (C) sequestration can contribute to mitigating the greenhouse
29 effect (Nair et al. 2009a; Nair et al. 2009b; Chenu et al. 2019). In the tropics, C sequestration can more specifically
30 contribute to the improvement of food security and to climate change adaptation (Paustian et al. 2016). Tropical
31 soils are characterized by lower nutrient contents (Feller and Beare 1997) and more rapid C turnover than those in
32 temperate systems (Six et al. 2002). A recent synthesis based on 48 studies performed on tropical soils from 13
33 countries demonstrated that the main determinants of soil organic carbon (SOC) accumulation were C inputs,
34 duration of the experiments and management practices (Fujisaki et al. 2018). However, this synthesis did not
35 consider agroforestry practices due to the lack of references, although agroforestry is assumed to enhance C storage
36 in soils (Smith et al. 2014). Increasing soil C sequestration is a current challenge in highly weathered tropical soils
37 with low C contents, and agroforestry practices may contribute to overcoming this challenge.

38 In agroforestry systems, the diversity of the plant species and new ecological niches for biodiversity (Leaky 1996)
39 lead to an enrichment of aerial, root and microbial biomasses (Nair et al. 2009b; Lagerlöf et al. 2014) with a trade-
40 off between soil fertility improvement and competition for growth resources (Rao et al. 1997). C inputs in
41 agroforestry systems are mostly related to the decomposition of aboveground biomass (tree litterfall and crop
42 residues) and belowground biomass originating from tree and crop root turnover and/or mortality and
43 rhizodeposition (Kuzyakov and Domanski 2000). Cardinael (2015) estimated that tree and crop fine roots each
44 contribute 30% to organic matter input in agroforestry systems. Fine roots are generally more recalcitrant than
45 aerial aboveground biomass to soil microbial decomposition (Rasse et al. 2005; Bertrand et al. 2006; Freschet et
46 al. 2013), and they have the potential to increase soil C stocks. While several studies have demonstrated the
47 chemical characteristics responsible for slow root decomposition rates (Machinet et al. 2009; Cotrufo et al. 2013;
48 Prieto et al. 2016), the impact of soil depth has been less studied, although roots occur at different depths in the
49 soil profile. This is particularly true for agroforestry systems where tree, herbaceous and crop roots colonize
50 different soil layers, especially at depth (Cardinael et al. 2015; Germon et al. 2016; Battie-Laclau et al. 2020).

51 Root litter decomposition depends not only on litter quality but also on pedoclimatic conditions (Makkonen et al.
52 2012) and soil microbial communities and activity (Herman et al. 2012). These biotic and abiotic soil
53 characteristics are strongly impacted by the introduction of trees in arable lands. The introduction of trees causes
54 spatial heterogeneity in soil temperature and humidity (Monteith et al. 1991; Rao et al. 1997; Lin 2007) as well as
55 soil microbial biomass abundance and composition (Chander et al. 1998; Liu et al. 2019, Guillot et al. 2021) and

56 soil C stocks (Cardinael 2015). In a recent study performed in the same area as our study site, Roupsard et al.
57 (2020) demonstrated that the whole pearl millet plant dry mass was 2.2 times higher under the *Faidherbia* tree
58 crown than far from the tree. As a consequence, biomass inputs may be more important near trees, which could
59 induce a modification of the soil chemical and physical properties. While the impact of trees on crop yield, climatic
60 conditions and soil C stocks at a local scale was previously investigated in shallow soil horizons (Oelbermann et
61 al. 2004; Oelbermann and Voroney 2007; Lin 2007; Roupsard et al. 2020), to our knowledge, no studies have
62 investigated the impact of trees on deep soil characteristics or on tree and crop root decomposition.

63 Soil properties may vary with soil depth given that the total organic C content and microbial biomass decrease
64 with depth (Hicks Pries et al. 2018). Soil temperature and moisture tend to be less subject to variations in deeper
65 soil layers than in topsoil. Hicks Pries et al. (2018) showed that slower root decomposition could be responsible
66 for higher stable C stocks at soil depth. A recent meta-analysis by Balesdent et al. (2018) performed on 112
67 grassland, forest and cropland sites demonstrated that the subsoil (30-100 cm depth) stored 47% of the C in the
68 first metre of the soil profile. This deep C storage despite a lower litter input is related to root mortality and
69 rhizodeposition and to the reduced decomposition rates at depth (Guenet et al. 2013). Data are lacking on root
70 litter dynamics and C stocks in deep soil horizons, especially for tropical areas.

71 The aim of our study was thus to measure soil characteristics, including soil C stocks and the root decomposition
72 rate, according to soil depth in a sub-Saharan agroforestry park dominated by *Faidherbia albida* trees and to
73 account for the tree effect.

74 We hypothesized that (i) soil fertility, indicated by the C and nutrient contents, would be higher in the topsoil than
75 in deeper soil layers and under trees than far from the trees due to the presence of leguminous tree species;(ii) the
76 root litter decomposition rate would mainly depend on the plant species (i.e., root tissue quality), roots would
77 decompose faster under trees and (iii) root litter would decompose more slowly in deep soil layers than in topsoil
78 because of the stable pedoclimatic conditions.

79

80 **Materials and methods**

81 Study site

82 The “Faidherbia-Flux” collaborative observatory for greenhouse gas balance and ecosystem services
83 (<https://lped.info/wikiObsSN/?Faidherbia-Flux>) is located in the natural agro-silvo-pastoral parkland of Sob
84 (14°29'45N, 16°27'13W), 135 km East of Dakar, on the Bambey-Fatick transect, West Senegal, (Roupsard et al.
85 2020). The climate is sub-Saharan, with an average annual rainfall of 500 mm (Lalou et al. 2019) and an average
86 temperature of 29.6°C (Ndiaye et al. 2001). The soil temperature (°C) was measured with thermocouples buried
87 at 0, 2, 5, 15, 30, 60, 100, 150 and 200 cm. The soil volumetric water content ($m^3_{H_2O} m^3_{soil}$) was measured with
88 TDR (time domain reflectometry) moisture sensors buried at 15, 30, 50, 75, 100, 125, 150, 175 and 200 cm in an
89 open area of the plot (far from the trees and close to the weather station). The rainfall was measured on site with
90 an automatic tipping bucket (Texas Electronics, model TE525 mm). Data were recorded every 30 minutes over
91 the entire study period. The average daily temperature and soil moisture and sum of rainfall were calculated (Fig.
92 1). The soil is a sandy tropical ferrallitic soil (Maignien 1965); it is classified as an Arenosol (IUSS Working group
93 WRB 2014). The water table is located at approximately 5-6 m depending on the season.

94 The studied agroforestry system was composed mainly of *Faidherbia albida* trees (85% occurrence), with a density
95 of 6.8 trees/ha, which represents an average canopy cover of 5.14% measured over an area of 15 ha (Roupsard et
96 al. 2020; Rahimi et al. 2021). *Faidherbia* trees were associated with groundnut (*Arachis hypogaea*) or pearl millet
97 (*Pennisetum glaucum*) according to annual rotations. In June 2018, pearl millet was manually sown in the studied
98 plot at a distance of 80 cm between each sowing pocket. Cowpea (*Vigna unguiculata*) was sown at the same time
99 in a neighbouring plot with the same soil type and climatic conditions. There was no amendment applied to these
100 plots, and harvesting was conducted in October 2018.

101 Above- and belowground biomass sampling

102 The biomass sampling campaign was conducted in October 2018, immediately before the pearl millet crop harvest.
103 According to the large volume of soil to excavate and sieve (each pit was 8 m³), only 2 pits could be prepared, one
104 under and one far from a tree. We sampled 3 walls in each pit, thereby assuming independence of the results. The
105 pit under the tree was chosen under a *Faidherbia* individual representative of the tree population (Diatta 2021),
106 with a height of 13.5 m and a circumference at breast height of 2.84 m.

107 The aboveground parts of pearl millet were collected in two subplots, each measuring 2 m × 2 m. One subplot was
108 located under the selected *Faidherbia* tree crown (1.5 m from the trunk, crown radius of 5 m), whereas the second
109 subplot was located far from any tree and at a minimum distance of 30 m from the first subplot. The subplots used
110 for biomass quantification were at the same location as the pits. Each subplot included four pearl millet pockets.

111 The vegetative biomass was split into ears, stems, leaves and stumps. All samples were oven-dried for 48 hours at
112 65°C before weighing.

113 After the aboveground biomass was sampled, two pits of 2 m × 2 m × 2 m were dug at the same locations. For
114 each pit, roots were sorted by manually sieving the soil at 2 mm from a total soil volume of 8 m³ and split according
115 to the plant species (pearl millet and *Faidherbia* tree) and the corresponding soil layer (0 – 40 cm, 40 – 100 cm,
116 100 – 150 cm and 150 – 200 cm). Given the small quantity of pearl millet roots found at great depth, the root
117 biomasses of pearl millet in soil layers 100 – 150 and 150 – 200 cm were summed for each profile. Then, *Faidherbia*
118 roots were sorted manually, and their diameter (D) was measured with a digital calliper to separate fine roots (D
119 < 2 mm) from medium roots (10 mm > D ≥ 2 mm). All samples were washed on a 0.5 mm sieve and oven-dried
120 for 48 hours at 65°C before weighing. The belowground biomass was assessed for 2 subplots × 2 plant species ×
121 4 soil layers (× 2 root diameter categories for *Faidherbia*) after correction for the ash content. To this end, a
122 subsample of 1 g of the washed root sample was burned at 500°C for 4 hours to remove organic matter, and the
123 remaining mineral ash was weighed and deducted from the dry root mass.

124 Supplementary roots were collected between 0 and 40 cm depth in the neighbouring plot planted with cowpea and
125 prepared as described above for millet and *Faidherbia* roots.

126 Litterbag experiment

127 We performed a 464-day root litter decomposition experiment with fine roots of *Faidherbia* tree, cowpea and pearl
128 millet. A subsample of 1.5 g root litter was inserted in 10 × 20 cm nylon mesh screens of 1 mm (Diatex), hereafter
129 referred to as root litterbags. The mesh size of 1 mm allowed all decomposer communities, including small
130 invertebrates, to penetrate the nylon mesh and establish themselves on the decomposing roots (Handa et al.
131 2014). On October 15th, 2018, corresponding to the harvest period, three litterbag replicates per plant species
132 (*Faidherbia* tree, pearl millet or cowpea) were buried at four soil depths (20, 40, 90 and 180 cm) on 3 different
133 walls (east, north and west walls) in each subplot (located under and far from the tree). The litterbags were buried
134 at approximately 50 cm perpendicular to the pit walls to prevent desiccation or temperature fluctuations as much
135 as possible. Each hole made to insert the litterbags perpendicular to the pit wall was filled with soil from the same
136 hole. Each litterbag was replicated five times to allow five sampling campaigns (d1 to d5), which were scheduled
137 after 1.5, 3, 6, 9 and 15 months of root decomposition. The first months of decomposition corresponded to the dry
138 season (d1 to d3), while the wet season started immediately before the fourth litterbag sampling (see Fig. 1). The
139 last sampling occurred during the next dry season (d5).

140 In total, 3 plant species \times 2 locations (subplots) \times 4 soil depths \times 3 pit walls \times 5 sampling dates = 360 litterbags
141 were buried. However, due to a shortage in the initial sampling of root biomass encountered in the pits, cowpea
142 and Faidherbia litter samples were not buried at 40 and 90 cm and thus were not collected on all dates (see Fig. 2).

143 After litterbag collection, the remaining root litter was carefully retrieved, and the soil adhering to the decomposed
144 roots was carefully removed by shaking by hand before being oven-dried for 48 hours at 65°C. Ash corrections
145 were made on a subsample to remove soil particle contamination as previously described. The relative humidity
146 of the soil around the litterbags was measured from the oven-dried soil samples. The remaining dry mass in each
147 litterbag was calculated as

$$148 \quad RDM = \frac{M_f}{M_i} \times 100$$

149 where *RDM* is the remaining dry mass (%), M_i is the initial litter dry mass (g) and M_f is the final litter dry mass
150 (g).

151 The remaining root dry mass according to a time axis for each species at each location and each soil depth gave
152 the decomposition kinetics, where the Y intercept was named *d0*. The time axis was expressed on standardized
153 days depending on the soil temperature at each soil depth. The time was normalized by temperature using the
154 method published by Mary et al. (1999) at a reference temperature of 25°C, arbitrarily chosen as commonly used
155 by Balesdent and Recous (1997):

$$156 \quad D_{corr25} = \frac{D_{meas}}{e^{-K \times (T - T_{ref})}}$$

157 where D_{corr25} (days) is the time normalized at T_{ref} , T_{ref} (°C) is the reference temperature (25°C), D_{meas} is the
158 measured time (days), T (°C) is the average soil temperature of each day, and K is the thermal coefficient ($K =$
159 0.115 for kinetics of SOC decomposition at 25°C (Balesdent and Recous 1997)). Then, for each root species at
160 each location and each soil depth, the decomposition kinetics were determined by a regression between the
161 remaining dry mass and standardized time. To better fit our data, two linear regressions were applied for individual
162 decomposition kinetics: the first regression with a $k1$ coefficient was based on the first sampling date (from *d0* to
163 *d1*), and the second regression had a $k2$ coefficient (from *d1* to *d5*). Two linear regressions \times 3 root species \times 2
164 locations \times 4 soil depths = 48 coefficients were obtained. Regressions with an R-squared value lower than 50%
165 were removed from the dataset.

166 Initial litter quality

167 Initial root chemical qualities were determined for the three plant species (pearl millet, cowpea and Faidherbia
168 tree). C fractions (soluble compounds, cellulose, hemicellulose and lignin) were assessed with a fibre analyser
169 (Fibretherm®, Gerhardt) on a 500 mg root litter subsample following the Van Soest protocol (Goering and Van
170 Soest 1970). Root C and N elemental composition was determined with an automatic elemental analyser (Flash
171 2000, ThermoFisher Scientific) on 3 mg subsamples of root litter. For the total root P content, 50 mg of litter
172 powder was mixed with 65% HNO₃ and mineralized for 15 min at 200°C in a Milestone Ethos Easy microwave
173 under standard and blank conditions. The total P content was quantified colorimetrically with the yellow
174 vanadomolybdate assay (Koenig and Johnson 1942).

175 The proportion of C originating from roots and remaining in the soil after 15 months of decomposition was
176 calculated for 2 species (pearl millet and Faidherbia fine roots) at both locations (under and far from the tree) and
177 at 3 depths (0 – 40, 40 – 100 and 100 – 200 cm, which matched the root biomass sampling and litterbag
178 experimental setup) by multiplying the root carbon content (%) and the remaining mass at d5 (%). Decomposition
179 data were missing at 90 cm depth for Faidherbia, and an average proportion of C at 20 and 180 cm was thus used.
180 Then, this calculated proportion was multiplied by the living root carbon stocks (gC m⁻³) to give the amount of
181 remaining C originating from roots and remaining in the soil after 15 months of decomposition for each species
182 and at each depth. For pearl millet as an annual crop, the totality of the root carbon entered the soil at each harvest
183 and thus at each year. For Faidherbia as a perennial tree, we considered that 0.56% of the root carbon was entering
184 the soil each year according to the acacia root turnover (Jha and Prasad Mohapatra 2010). This calculation was not
185 performed for cowpea because the root biomass in the soil profile was not assessed for pearl millet or for
186 Faidherbia.

187 Soil sampling and analyses

188 The soil sampling campaign was conducted in late October 2018 immediately after the pits were dug. In each pit
189 (under and far from the tree), in three out of four faces (taken as replicates), soil samples were collected at different
190 depths (0 – 10 cm, 10 – 20 cm, 20 – 40 cm, 40 – 70 cm, 70 – 100 cm, 100 – 130 cm, 130 – 160 cm, 160 – 200
191 cm). The soil sampling was more detailed than the experimental design of the litterbags to obtain a precise
192 characterization of the soil profile. Soil was sampled where the litterbags were buried. Each sample was analysed
193 by the LAMA laboratory (IRD-US Imago, Dakar, Senegal) for total soil C and N contents by dry combustion
194 (Matejovic 1997). The mineral C content was assumed to be insignificant, and the measured total soil C was thus

195 associated with soil organic C. Soil pH was measured in a 1:2.5 soil-water suspension. Available phosphorus was
196 determined according to the Olsen method and was measured by the malachite green method (Ohno and Zibilske
197 1991). Soil mineral N was extracted with a 1:4 soil-1 M KCl solution, NO₃ and NH₄ were determined by
198 continuous flow colorimetry (SKALARSA 3000 flow analyser), and the sum of NO₃ and NH₄ represented the
199 mineral soil N content. Soil texture was determined based on five fractions (clay, silt (fine + coarse), sand (fine +
200 coarse)).

201 The soil bulk density was assessed according to the cylinder method (Blake and Hartge 1986) in each pit (under
202 and far from the tree) on two out of four faces (as replicates) at ten soil depths (10, 20, 40, 60, 80, 100, 120, 140,
203 160 and 180 cm).

204 SOC stocks were calculated at each location (under and far from the tree) and each soil depth following the 'M1'
205 method described by Poeplau et al. (2017) as follows:

$$206 \quad C_{stock_{i,j}} = BD_{mean} \times C_{tot} \times w$$

207 where $C_{stock_{i,j}}$ is the soil C stock at location j in soil layer i (g m^{-2}), w is the width of soil layer i (m), BD_{mean} is
208 the mean bulk density of soil layer i (g m^{-3}) and C_{tot} is the amount of total soil C measured in soil layer i at location
209 j (g g^{-1} soil). To compare the surface soil layers with the deep layers while the compaction was different due to
210 ploughing of the topsoil layers, we also calculated the C stock at an equivalent soil mass following the method
211 presented by Ellert and Bettany (1995).

212 The total SOC stock in the whole soil profile was calculated for each location as the sum of the SOC stock in each
213 layer.

214 Statistical analyses

215 For each measurement, data are presented as the mean values \pm standard deviation of 3 replicates. Whenever the
216 location (far from and under the tree) had no significant effect according to the methods described below, the
217 average value of 6 replicates was calculated instead. All statistical analyses were processed with R Software
218 (version 4.0.2) (R Core Team 2020).

219 To analyse the effect of depth and location on soil characteristics, linear mixed models were applied to each soil
220 variable, with soil depth and location as fixed factors and the 3 replicated profiles as random factors. Data from
221 the same soil profile were considered dependent on each other. Post hoc Tukey tests allowed us to determine the

222 significance of the differences between each category of soil depth and location. C stocks in both locations were
223 compared for each soil layer with Wilcoxon rank sum tests, as required for comparisons between 2 populations
224 with 3 individuals each.

225 The initial difference in the quality of the root litter from the three plant species was analysed with one-way
226 analysis of variance for each variable (soluble fraction, hemicellulose, cellulose, lignin, total C, total N, and total
227 P contents and C:N). To analyse the variations in the humidity of the soil in contact with the litterbags, a linear
228 mixed model was applied to the relative humidity, with location, soil depth, plant root species and sampling date
229 as fixed factors and the 3 replicated profiles as random factors. To analyse the effect of location, soil depth and
230 plant species on root litter decomposition, linear mixed models were applied to the remaining litter dry mass on
231 each sampling date and to the k1 and k2 decomposition rates, with soil depth, location and plant species as fixed
232 factors and the 3 replicated profiles as random factors.

233 To analyse the carbon inputs from the roots (Fig. 10), linear mixed models were applied to the soil C stocks, to the
234 tree living fine root C stocks, to the pearl millet living root C stocks and to the remaining C in the soil after 15
235 months of decomposition (all data in gC m^{-3}), with location, soil depth and plant root species as fixed factors and
236 the 3 replicated profiles as random factors. For all the linear mixed models and analyses of variance, *lme4* and *car*
237 packages were used. The normality of the residues was always verified with a Shapiro-Wilk test, and the
238 homogeneity of the variances was verified with a Bartlett test. When necessary (p-values < 5%), Box-Cox (*boxcox*)
239 or Yeo Johnson (*jtrans*) transformations were applied.

240 A simple ordination of all the variables was conducted for a principal component analysis with the “*vegan*” and
241 “*factoextra*” packages. Among the soil depths that were analysed for the initial soil characterization, only 4 depths
242 were selected for this analysis (10 – 20, 20 – 40, 70 – 100 and 100 – 130 cm) to match the experimental design of
243 the litterbags. Wilk’s tests allowed the identification of qualitative variables (location, depth and plant species)
244 that significantly separated the individuals with the “*FactoInvestigate*” package.

245

246 **Results**

247 Effects of depth and location on soil characteristics

248 The soil texture was globally very sandy, with more than 70% sand in every sample (Fig. 3), but the texture was
249 significantly impacted by soil depth (Supplementary Table 1), with soils richer in clay and lower in coarse sand in
250 the deeper layers (Fig. 3a). Location impacted only fine sand, with a higher content far from the tree (p-value =
251 1.94×10^{-2}), while an interaction between soil depth and location was observed for the silt content (p-value = 7.63
252 $\times 10^{-5}$ combined with soil depth).

253 The total C and N contents were not significantly impacted by location (Supplementary Table 1). However, the
254 soil total C and total N contents tended to be higher under the tree than far from the tree (Fig. 4a and 4b). In this
255 poor Arenosol, the total soil C did not exceed 0.45% in the surface layer. At both locations, soil depth strongly
256 affected the total C ($F = 30.17$, p-value = 3.0×10^{-11}) and N contents ($F = 11.30$, p-value = 1.2×10^{-6}) with a strong
257 decrease from a depth of 30 cm. The C:N ratio, soil pH, and soil available phosphorus and mineral N contents
258 were impacted by the interaction of depth and location, while only the mineral N and C:N ratios were significantly
259 affected by soil depth (Supplementary Table 1). In the first 20 cm, the C:N ratios increased from 12.7 to 14.0 far
260 from the tree and then decreased to 8.7 at 180 cm, while under the tree, the C:N ratios increased from 11.0 at the
261 surface to 14.3 at a depth of 1 m (Fig. 4c). Soil pH presented values ranging between 6 and 7 in the topsoil. Below
262 40 cm, soil under the tree presented higher pH values (6.9 ± 0.6 between 40 and 180 cm) than those far from the
263 tree (5.7 ± 0.3) (Fig. 4d). As often occurs in tropical soils, available phosphorus was very low (less than 3 mg kg^{-1})
264 and significantly higher under than that far from the tree ($F = 3.77$, p-value = 5.6×10^{-3} , Supplementary Table
265 1). The available phosphorus decreased with depth to less than 1 mg kg^{-1} at 180 cm for both locations (Fig. 4f).
266 Mineral N presented similar patterns, with average values of 5.5 ± 2.8 and $9.4 \pm 3.1 \text{ mg kg}^{-1}$ in the topsoil far from
267 and under the tree and decreasing to 5.0 ± 3.6 and $3.3 \pm 0.1 \text{ mg kg}^{-1}$ at 180 cm, respectively (Fig. 4e).

268 Despite important differences in total C stocks within the whole profile under the tree ($7761 \pm 346 \text{ g m}^{-2}$, $n = 3$)
269 compared to far from the tree ($5425 \pm 558 \text{ g m}^{-2}$, $n = 3$), the samples at each soil depth did not differ significantly
270 between locations under and far from the tree (Table 1).

271 Above- and belowground biomass

272 Pearl millet biomass was higher under the tree than far from the tree (Fig. 5). The difference was mainly noteworthy
273 for the aboveground parts, resulting in a lower R:S ratio (0.03 compared to 0.05 far from the tree). At both

274 locations, millet roots were concentrated in the first 40 cm depth whereas under the tree, *Faidherbia* fine roots were
275 concentrated below 40 cm depth. Far from the tree, tree roots were rare between 0 and 200 cm depth (Fig. 6).

276 Root litter quality, soil moisture and decomposition rates

277 *Faidherbia* litter was significantly enriched in lignin compared to cowpea and pearl millet litter (Table 2). Pearl
278 millet roots presented a similar amount of lignin as in cowpea, while their soluble fraction was lower. However,
279 the cellulose content was higher in pearl millet than in cowpea, while hemicellulose was not significantly different
280 between the two crops. Large differences in the N content explained the important variations in C:N ratios, which
281 varied from 13.0 for *Faidherbia* fine roots to 30.2 and 32.5 for cowpea and pearl millet roots, respectively.

282 The relative humidity of the soil in contact with the litterbags significantly increased with soil depth ($F = 337.9$, p -
283 value $< 2.2 \times 10^{-16}$, Table 3), and it was higher under the tree than far from the tree ($F = 24.9$, p -value $= 7.3 \times 10^{-3}$,
284 Table 3). The soil humidity was still high on d1 ($9.0 \pm 5.9 \text{ m}^3 \text{H}_2\text{O m}^{-3} \text{soil}$) from the previous wet season and decreased
285 significantly from d1 to d3 ($F = 100.5$, p -value $= < 2.2 \times 10^{-16}$, Table 3). The wet season that started immediately
286 before d4 increased the humidity of the soil in contact with the litterbags on d4 and d5.

287 Regarding root litter decomposition, no significant effect of location was observed on any date (Supplementary
288 Table 2); thus, data were compiled for both locations.

289 After 15 months of the experiment, neither the crop nor the tree fine roots reached an asymptote; therefore, we
290 described decomposition with 2 slopes k_1 and k_2 (linear fitting) rather than with one extinction coefficient
291 (exponential fitting). After 1.5 months of fine root decomposition, i.e., d1, the root litterbags had lost almost half
292 of their initial dry mass; then, with the dry season, the remaining fine root mass decreased more slowly from d1 to
293 d5 and reached approximately 25% of the initial mass at the end of the experiment (Fig. 7). The remaining fine
294 root mass on d2 (pearl millet only) was significantly impacted by depth ($F = 3.8$, p -value $= 4.8 \times 10^{-2}$), with a
295 lower fine root remaining mass at a depth of 20 cm than at 40 cm and a lower fine root remaining mass at a depth
296 of 90 cm than at 180 cm (Fig. 8a). On d5, the remaining mass was significantly higher for *Faidherbia* than for
297 cowpea fine roots ($F = 3.9$, p -value $= 3.5 \times 10^{-2}$, Fig. 8b).

298 The k_1 coefficient of the first decomposition stage was significantly impacted by the plant species ($F = 3.9$, p -
299 value $= 3.5 \times 10^{-2}$, data not shown), with higher coefficients for cowpea and lower coefficients for *Faidherbia*. The
300 rate of fine root decomposition was also significantly impacted by soil depth in the case of pearl millet ($F = 7.4$,
301 p -value $= 4.54 \times 10^{-3}$, Table 4), with lower values at 180 cm than at 20 cm depth. The cowpea fine root

302 decomposition rate also decreased with soil depth but to a lesser extent than that of pearl millet ($F = 7.7$, p -value
303 $= 2.13 \times 10^{-2}$, Table 4), while the fine root decomposition rate of the *Faidherbia* tree was only slightly impacted
304 by depth (Table 4).

305 Relationships between fine root decomposition, soil characteristics and litter quality

306 The contribution of the main soil variables and the fine root decomposition rate to differences among soil depths
307 is represented by the PCA (Fig. 9), which explained 50.5% of the dataset's variability. Individuals at each soil
308 depth were well separated with no overlap between 95% confidence ellipses of three distinguished groups: 0-40
309 cm, 90 cm and 180 cm (Fig. 9, p -value $= 2.20 \times 10^{-9}$ for Wilk's test). The variables that best explained the
310 separation between soil depths were C:N, sand, Olsen P and clay. The k_1 coefficient increased with these variables.
311 These variables were not correlated (orthogonal) with k_2 , the soil pH or silt content (Fig. 9). Therefore, the first
312 axis of the PCA best described variables that correlated with k_1 , and the second axis variables correlated with k_2 .
313 Importantly, k_1 and k_2 were not correlated.

314

315 **Discussion**

316 Impact of *Faidherbia albida* trees on soil characteristics

317 As expected for this type of soil, the total C and N contents were quite low (less than 0.5 and 0.05%, respectively),
318 as previously described (Barthès et al. 2006; Tounkara et al. 2020). The C and N contents decreased with soil
319 depth and were higher under than far from the tree, as expected according to other agroforestry studies (Felix et
320 al. 2018; Nair et al. 2009b), especially with *Faidherbia albida* (Dilla et al. 2019), but these differences were
321 surprisingly not significant (considering p -value > 0.05). In the 0 – 40 cm soil layer, the soil C:N ratio was higher
322 far from than that under the tree, whereas in the deeper layers, the opposite was true. These changes were associated
323 with a large standard deviation, probably due to the low N concentration. Because *Faidherbia* leaf litter was shown
324 to release high amounts of nutrients, especially N, during decomposition (Mubarak et al. 2008), the long-term
325 effects of this litter may have contributed to a decrease in the surface soil C:N ratio, likely by increasing the
326 bacterial pathway of decomposition (Rousk and Bååth 2007).

327 At a depth of 40 – 180 cm, the higher C:N ratio under the tree than far from it was also related to a lower soil
328 mineral N content, while the yield of the pearl millet was almost 3 times higher under tree (Roupsard et al. 2020;

329 Leroux et al. 2020). Due to higher pearl millet above- and belowground production, more mineral N could be taken
330 up by the crop under the tree. However, with respect to pearl millet root distribution, the main difference between
331 the locations under and far from the tree occurred in the topsoil (0 – 40 cm), and millet did not invest biomass at
332 great depth under the tree, which is in agreement with the higher root:total biomass ratio far from the tree. Another
333 possible explanation is that microorganisms may immobilize soil mineral N following an N-mining strategy (Chen
334 et al. 2014) to mineralize soil organic matter or plant litter with a high C:N ratio. The total amounts of soil C and
335 N were not influenced by tree presence, suggesting that the nature of the litter entering the soil instead of the soil
336 organic matter (C and N) differed under and far from the tree and would be responsible for the hypothetical N-
337 mining strategy. We did not separate roots or aboveground plant parts according to their location (under or far
338 from the tree) before assessing their C and N contents. However, the fine and medium roots of *Faidherbia* were
339 particularly abundant under the tree below a depth of 40 cm and had a low C:N ratio of 13. The low root C:N ratio
340 can be explained by the high N availability in this N-fixing species, which would prevent a lack of N and thus
341 hamper the N-mining strategy. However, the presence of N-binding materials such as lignin and polyphenols could
342 restrict N accessibility and lead to a microbial N immobilization phase, as described during the leaf decomposition
343 of a N-fixing tree by Teklay and Malmer (2004). Furthermore, the slow decomposition of *Faidherbia* roots due to
344 the high lignin content could favour the development of K-strategy microorganisms dominated by fungi (Chen et
345 al. 2014). However, without more information on the importance and nature of the soil microbial communities in
346 comparison to total soil C, we cannot conclude the origin of the soil C/N changes.

347 Several soil fertility indicators, such as mineral N and Olsen P, were higher in the topsoil (0 – 40 cm) than at depth
348 (40 – 200 cm) under the tree. The enrichment of nutrients in the topsoil under the *Faidherbia albida* tree was in
349 agreement with the results found by Yengwe et al. (2018) and explained the higher crop yield under this tree. No
350 remaining detritus of *Faidherbia* leaves was observed on the soil surface during the sampling period. This was due
351 to the active livestock in this silvo-agro-pastoral system removing the leaves, twigs and fruits from the ground
352 during the litterfall season (April to July) due to the reverse phenology of this tree (Roupsard et al. 1999). However,
353 ruminants tend to stand under trees, where excrement is deposited, which enriches the topsoil nutrient content
354 under trees. At a depth of 50 cm, the lack of nutrients under trees compared to that far from trees could come from
355 the increase in *Faidherbia* root biomass at the same depth and thus the increase in nutrient uptake at depth compared
356 to the topsoil.

357 A significant interaction between the soil depth and location impacted the soil pH. Indeed, the higher soil pH under
358 the tree compared with that far from the tree occurred mostly below a depth of 40 cm, while no significant

359 differences were observed in the topsoil, as previously reported by Félix et al. (2018) for *Piliostigma* shrubs in
360 Burkina Faso. In the 40 – 90 cm horizon, soil pH tended to increase under the tree (from 6.7 to 7.3), as found by
361 Rao et al. (1997), while acidification (from 6.5 to 5.7) was recorded far from the tree. Sandy soils are poorly
362 buffered (Wezel et al. 2000), and pH is sensitive to small variations in acid-basic reactions. Although our study
363 did not allow us to conclude the mechanisms to explain the increase in pH under the tree, acidification of the soil
364 profile far from the tree is an indicator of fertility degradation. Acidic soils are indeed known for their relatively
365 low microbial abundance and diversity and low cation exchange capacity (Robson 2012) and could affect millet
366 productivity.

367 Impact of soil depth on root litter decomposition

368 Due to the climatic conditions in the study area, root decomposition occurred rapidly after crop harvest (end of
369 October 2018), while the soil was still moist from the previous wet season, and lasted for two months thereafter
370 (January 2019). Then, the soil dried progressively from $9.0 \pm 5.9 \text{ m}^3_{\text{H}_2\text{O}} \text{ m}^{-3}_{\text{soil}}$ on d1 to $2.6 \pm 2.8 \text{ m}^3_{\text{H}_2\text{O}} \text{ m}^{-3}_{\text{soil}}$ on
371 d3, as no rain occurred until the next wet season, which started in July 2019. Faster decomposition in wetter soils
372 confirmed a previous report by Duthoit et al. (2020) regarding soil respiration. This moisture regime leads to two
373 contrasting kinetics of decomposition, with a relatively rapid first phase (k1) and a slower second phase (k2),
374 following the same time scale, similar to the few other studies conducted under similar environmental conditions
375 (Mubarak et al. 2008; Mubarak et al. 2012). This result suggested that the labile part of the root litter decomposed
376 quickly during the first phase of decomposition (k1) when the soil was very wet. Then, the decomposition slowed
377 (k2) as the soil dried.

378 Soil moisture is a key factor controlling root decomposition and seems to be the main driver of decomposition
379 kinetics after litter species, i.e., quality (Arrouays et al. 2002; Butenschoen et al. 2011). Because the humidity of
380 the root litterbags was significantly higher for the individuals located under the tree due to tree shading, which
381 reduced soil evaporation (Hasselquist et al. 2018), greater soil water infiltration (Faye et al. 2020), the reduction
382 of water runoff under the tree crown (Lal 1989) and the potential benefit of hydraulic redistribution through the
383 *Faidherbia* root system (Bayala and Prieto 2020), we expected a slower fine root decomposition rate far from the
384 tree than under the tree. This was not confirmed here. However, the lack of tree replicates may bias our results,
385 and the study would need to be extended to a wider area of the park, including different tree sizes representing the
386 local diversity of the parkland.

387 Root litter quality was the main factor controlling the rate of decomposition. *Faidherbia albida* roots decomposed
388 more slowly than cowpea roots due to less soluble compounds and high lignin contents, as reported in Mubarak et
389 al. (2012), while the root N content (higher in *Faidherbia* fine roots) did not seem to influence k_1 . Over a short
390 period of time, soluble C drives the decomposition of plant residues (Bertrand et al. 2006; Bertrand et al. 2009;
391 Moorhead et al. 2016; Liang et al. 2018), while the litter N content (C:N ratio) has no impact unless N limits
392 decomposition (Recous et al. 1995; Bertrand et al. 2006), which does not seem to be the case here.

393 The remaining C after 15 months of decomposition accounted for root C inputs (Fig. 10) for 2 plant species
394 (*Faidherbia* fine roots and pearl millet), at both locations (under and far from the tree) and at 3 soil layers (0 – 40,
395 40 – 100 and 100 – 200 cm of depth). The effect of all combined factors was significant ($F = 10.3$, $p\text{-value} = 5.4$
396 $\times 10^{-3}$, Supplementary Table 2). Under the tree, *Faidherbia* root biomass was higher than far from the tree, and low
397 decomposition rates of this perennial root litter were observed in the litterbags. Both of these factors resulted in
398 higher C inputs from *Faidherbia* root litter under (6.2 gC m^{-2} between 0 and 200 cm of depth, Fig. 10) than far
399 from the tree (0.2 gC m^{-2}), which could explain the tendency of higher soil C stocks under than far from the tree
400 (Fig. 10, Table 1). Furthermore, the root C input was higher at depth than at the surface; between 100 and 200 cm
401 depths, the amount of remaining C after 15 months of decomposition originating from *Faidherbia* root litter under
402 the tree was 7 times higher than that at 20 cm. No significant C inputs from the *Faidherbia* root litter were
403 noteworthy far from the tree. Due to a different root distribution, pearl millet presented the opposite trend. Pearl
404 millet root C inputs were significantly higher at the soil surface than at depth, with no difference between the 2
405 locations (Fig. 10). The pearl millet crop provided 5.7 gC m^{-3} at 0 – 40 cm of depth through its roots. This amount
406 is very low compared to the soil C stocks at the same depth (4708 gC m^{-3} far from the tree and 6429 gC m^{-3} under
407 the tree), but it is repeated every growing season. The role in the soil carbon stocks of pearl millet in topsoil and
408 of *Faidherbia* fine roots at depth was in agreement with that described by Jackson et al. (2017), attesting that fine
409 roots contribute substantially to soil organic carbon storage. Future studies should prospect deeper soil depths to
410 take into account a more representative cross-section of the tree root system. We hypothesized that soil depth
411 would slow the fine root decomposition rate due to reduced microbial activity and moisture and temperature
412 buffering, which was confirmed for the first phase of decomposition (k_1 was higher at 20 cm than at soil depths
413 of 40, 90 and 180 cm for the three species). We did not measure microbial biomass C; however, several studies
414 have reported its close relationships with the organic C content in soils (Insam and Domsch 1988; Webster et al.
415 2001; Ng et al. 2014). In the topsoil, more abundant microbial biomass and activity as well as drying/rewetting
416 cycles that create a flush of C and microbial activity may explain the quicker decomposition rates (Miller et al.

417 2005; Sun et al. 2013). According to the PCA, the soil characteristics that best explained k_1 were sand, the Olsen
418 P content and the soil C:N ratio, suggesting that the very low amount of P may have decreased the microbial
419 activity at depth.

420 **Conclusion**

421 Root litter decomposition varied mostly according to soil depth, with litter quality and soil moisture being the main
422 factors related to the decomposition coefficient k_1 in the first 1.5 months. Organic C originating from roots would
423 be stored for a longer time period at depth than in the topsoil. Furthermore, tree root litter tended to be more
424 recalcitrant than annual crop root litter and was more abundant below 40 cm, while annual roots were concentrated
425 in the topsoil. Therefore, slow tree root decomposition at depth could play a role in increasing belowground C
426 inputs and sequestration. In contrast, pearl millet induced root C inputs mainly in the topsoil and it did not depend
427 on the location. The root decomposition rate was not affected by the location, but the tree fine root biomass and
428 pearl millet vegetative production were higher under the tree than far from the tree. This difference resulted in
429 higher soil carbon stocks under the tree than far from it.

430 In agroforestry systems, the diversity of plant species induces a great diversity of root qualities and thus various
431 decomposition kinetics. Introducing trees in arable lands would globally increase root litter inputs while slowing
432 root decomposition, especially at depth, and would thus increase the soil carbon storage potential of the system.
433 Further research should focus on this aspect with replicated trees and different distances from the trees according
434 to a gradient to confirm the influence of tree presence on root decomposition kinetics.

435

436

- 437 Arrouays D, Balesdent J, Germon J-C, Jayet P-A, Soussana J-F, Stengel P (2002) Contribution à la lutte contre
438 l'effet de serre. Stocker du carbone dans les sols agricoles de France ?
- 439 Balesdent J, Recous S (1997) Les temps de résidence du carbone et le potentiel de stockage de carbone dans
440 quelques sols cultivés français. *Can J Soil Sci* 77(2):187–193. <https://doi.org/10.4141/S96-109>
- 441 Barthès BG, Brunet D, Ferrer H, Chotte J-L, Feller C (2006) Determination of Total Carbon and Nitrogen Content
442 in a Range of Tropical Soils Using near Infrared Spectroscopy: Influence of Replication and Sample
443 Grinding and Drying. *Journal of Near Infrared Spectroscopy* 14(5):341–348.
444 <https://doi.org/10.1255/jnirs.686>
- 445 Battie-Laclau P, Taschen E, Plassard C, Dezette D, Abadie J, Arnal D, Benezech P, Duthoit M, Pablo A-L, Jourdan
446 C, Laclau J-P, Bertrand I, Taudière A, Hinsinger P (2020) Role of trees and herbaceous vegetation
447 beneath trees in maintaining arbuscular mycorrhizal communities in temperate alley cropping systems.
448 *Plant Soil* 453(1–2):153–171. <https://doi.org/10.1007/s11104-019-04181-z>
- 449 Bayala J, Prieto I (2020) Water acquisition, sharing and redistribution by roots: applications to agroforestry
450 systems. *Plant Soil* 453(1–2):17–28. <https://doi.org/10.1007/s11104-019-04173-z>
- 451 Bertrand I, Chabbert B, Kurek B, Recous S (2006) Can the Biochemical Features and Histology of Wheat Residues
452 Explain their Decomposition in Soil? *Plant Soil* 281(1–2):291–307. <https://doi.org/10.1007/s11104-005-4628-7>
- 453
- 454 Bertrand I, Prevot M, Chabbert B (2009) Soil decomposition of wheat internodes of different maturity stages:
455 Relative impact of the soluble and structural fractions. *Bioresource Technology* 100(1):155–163.
456 <https://doi.org/10.1016/j.biortech.2008.06.019>
- 457 Blake GR, Hartge KH (1986) Bulk Density. In: Klute A (ed) SSSA Book Series. Soil Science Society of America,
458 American Society of Agronomy, Madison, WI, USA, pp 363–375
- 459 Butenschoen O, Scheu S, Eisenhauer N (2011) Interactive effects of warming, soil humidity and plant diversity
460 on litter decomposition and microbial activity. *Soil Biology and Biochemistry* 43(9):1902–1907.
461 <https://doi.org/10.1016/j.soilbio.2011.05.011>
- 462 Cardinael R (2015) Stockage de carbone et dynamique des matières organiques des sols en agroforesterie sous
463 climat méditerranéen et tempéré. Thesis, Université Paris-Saclay (ComUE)
- 464 Cardinael R, Mao Z, Prieto I, Stokes A, Dupraz C, Kim JH, Jourdan C (2015) Competition with winter crops
465 induces deeper rooting of walnut trees in a Mediterranean alley cropping agroforestry system. *Plant Soil*
466 391(1–2):219–235. <https://doi.org/10.1007/s11104-015-2422-8>
- 467 Chander K, Goyal S, Nandal DP, Kapoor KK (1998) Soil organic matter, microbial biomass and enzyme activities
468 in a tropical agroforestry system. *Biol Fertil Soils* 27(2):168–172.
469 <https://doi.org/10.1007/s003740050416>
- 470 Chen R, Senbayram M, Blagodatsky S, Myachina O, Dittert K, Lin X, Blagodatskaya E, Kuzyakov Y (2014) Soil
471 C and N availability determine the priming effect: microbial N mining and stoichiometric decomposition
472 theories. *Global Change Biology* 20(7):2356–2367. <https://doi.org/10.1111/gcb.12475>
- 473 Chen C, Angers DA, Barré P, Derrien D, Arrouays D, Balesdent J (2019) Increasing organic stocks in agricultural
474 soils: Knowledge gaps and potential innovations. *Soil and Tillage Research* 188:41–52.
475 <https://doi.org/10.1016/j.still.2018.04.011>
- 476 Cotrufo MF, Wallenstein MD, Boot CM, Deneff K, Paul E (2013) The Microbial Efficiency-Matrix Stabilization
477 (MEMS) framework integrates plant litter decomposition with soil organic matter stabilization: do labile
478 plant inputs form stable soil organic matter? *Global Change Biology* 19(4):988–995.
479 <https://doi.org/10.1111/gcb.12113>

- 480 Diatta S (2021) Estimation du stock et du stockage annuel de carbone dans la biomasse aérienne de *Faidherbia*
481 *albida* du parc agroforestier de Sob (Observatoire de Niakhar, Sénégal) : approches par inventaires et
482 dendrochronologie.
- 483 Dilla AM, Smethurst PJ, Barry K, Parsons D (2019) Preliminary estimate of carbon sequestration potential of
484 *Faidherbia albida* (Delile) A.Chev in an agroforestry parkland in the Central Rift Valley of Ethiopia.
485 *Forests, Trees and Livelihoods* 28(2):79–89. <https://doi.org/10.1080/14728028.2018.1564146>
- 486 Duthoit M, Roupsard O, Crequy N, Sauze J, Van Den Meersche K (2020) Conception d'un dispositif automatisé
487 de chambres de mesures d'échanges gazeux du sol à fermeture horizontale. *Cahier des Techniques de*
488 *l'INRA*
- 489 Ellert BH, Bettany JR (1995) Calculation of organic matter and nutrients stored in soils under contrasting
490 management regimes. *Can J Soil Sci* 75(4):529–538. <https://doi.org/10.4141/cjss95-075>
- 491 Faye W, Fall AN, Orange D, Do F, Roupsard O, Kane A (2020) Climatic variability in the Sine-Saloum basin and
492 its impacts on water resources: case of the Sob and Diohine watersheds in the region of Niakhar. *Proc*
493 *IAHS* 383:391–399. <https://doi.org/10.5194/piahs-383-391-2020>
- 494 Félix GF, Clermont-Dauphin C, Hien E, Groot JCJ, Penche A, Barthès BG, Manlay RJ, Tittonell P, Cournac L
495 (2018) Ramial wood amendments (*Piliostigma reticulatum*) mitigate degradation of tropical soils but
496 do not replenish nutrient exports. *Land Degrad Dev* 29(8):2694–2706. <https://doi.org/10.1002/ldr.3033>
- 497 Feller C, Beare MH (1997) Physical control of soil organic matter dynamics in the tropics. *Geoderma* 79(1):69–
498 116. [https://doi.org/10.1016/S0016-7061\(97\)00039-6](https://doi.org/10.1016/S0016-7061(97)00039-6)
- 499 Freschet GT, Cornwell WK, Wardle DA, Elumeeva TG, Liu W, Jackson BG, Onipchenko VG, Soudzilovskaia
500 NA, Tao J, Cornelissen JHC (2013) Linking litter decomposition of above- and below-ground organs to
501 plant-soil feedbacks worldwide. *J Ecol* 101(4):943–952. <https://doi.org/10.1111/1365-2745.12092>
- 502 Fujisaki K, Chevallier T, Chapuis-Lardy L, Albrecht A, Razafimbelo T, Masse D, Ndour YB, Chotte J-L (2018)
503 Soil carbon stock changes in tropical croplands are mainly driven by carbon inputs: A synthesis.
504 *Agriculture, Ecosystems & Environment* 259:147–158. <https://doi.org/10.1016/j.agee.2017.12.008>
- 505 Germon A, Cardinael R, Prieto I, Mao Z, Kim J, Stokes A, Dupraz C, Laclau J-P, Jourdan C (2016) Unexpected
506 phenology and lifespan of shallow and deep fine roots of walnut trees grown in a silvoarable
507 Mediterranean agroforestry system. *Plant Soil* 401(1–2):409–426. <https://doi.org/10.1007/s11104-015-2753-5>
- 509 Goering HK, Van Soest PJ (1970) Forage Fiber Analyses: Apparatus, Reagents, Procedures, and Some
510 Applications
- 511 Hasselquist NJ, Benegas L, Roupsard O, Malmer A, Ilstedt U (2018) Canopy cover effects on local soil water
512 dynamics in a tropical agroforestry system: Evaporation drives soil water isotopic enrichment.
513 *Hydrological Processes* 32(8):994–1004. <https://doi.org/10.1002/hyp.11482>
- 514 Herman DJ, Firestone MK, Nuccio E, Hodge A (2012) Interactions between an arbuscular mycorrhizal fungus and
515 a soil microbial community mediating litter decomposition. *FEMS Microbiol Ecol* 80(1):236–247.
516 <https://doi.org/10.1111/j.1574-6941.2011.01292.x>
- 517 Hicks Pries CE, Sulman BN, West C, O'Neill C, Poppleton E, Porras RC, Castanha C, Zhu B, Wiedemeier DB,
518 Torn MS (2018) Root litter decomposition slows with soil depth. *Soil Biology and Biochemistry*
519 125:103–114. <https://doi.org/10.1016/j.soilbio.2018.07.002>
- 520 Insam H, Domsch KH (1988) Relationship between soil organic carbon and microbial biomass on
521 chronosequences of reclamation sites. *Microb Ecol* 15(2):177–188. <https://doi.org/10.1007/BF02011711>
- 522 IUSS Working group WRB (2014) World reference base for soil resources 2014: international soil classification
523 system for naming soils and creating legends for soil maps. FAO, Rome

- 524 Jackson RB, Lajtha K, Crow SE, Hugelius G, Kramer MG, Piñeiro G (2017) The Ecology of Soil Carbon: Pools,
525 Vulnerabilities, and Biotic and Abiotic Controls. *Annual Review of Ecology, Evolution, and Systematics*
526 48(1):419–445. <https://doi.org/10.1146/annurev-ecolsys-112414-054234>
- 527 Jha P, Prasad Mohapatra K (2010) Leaf litterfall, fine root production and turnover in four major tree species of
528 the semi-arid region of India. *Plant Soil* 326(1–2):481–491. <https://doi.org/10.1007/s11104-009-0027-9>
- 529 Koenig R, Johnson C (1942) Colorimetric Determination of Phosphorus in Biological Materials. *Ind Eng Chem*
530 *Anal Ed* 14(2):155–156. <https://doi.org/10.1021/i560102a026>
- 531 Kuzyakov Y, Domanski G (2000) Carbon input by plants into the soil. Review. *Journal of Plant Nutrition and Soil*
532 *Science* 163(4):421–431. [https://doi.org/10.1002/1522-2624\(200008\)163:4<421::AID-](https://doi.org/10.1002/1522-2624(200008)163:4<421::AID-)
533 [JPLN421>3.0.CO;2-R](https://doi.org/10.1002/1522-2624(200008)163:4<421::AID-JPLN421>3.0.CO;2-R)
- 534 Lagerlöf J, Adolfsson L, Börjesson G, Ehlers K, Vinyoles GP, Sundh I (2014) Land-use intensification and
535 agroforestry in the Kenyan highland: Impacts on soil microbial community composition and functional
536 capacity. *Applied Soil Ecology* 82:93–99. <https://doi.org/10.1016/j.apsoil.2014.05.015>
- 537 Lal R (1989) Agroforestry systems and soil surface management of a tropical alfisol: I: Soil moisture and crop
538 yields. *Agroforest Syst* 8(1):7–29. <https://doi.org/10.1007/BF00159066>
- 539 Lalou R, Sultan B, Muller B, Ndonky A (2019) Does climate opportunity facilitate smallholder farmers' adaptive
540 capacity in the Sahel? *Palgrave Communications* 5(1):1–11. <https://doi.org/10.1057/s41599-019-0288-8>
- 541 Leaky R (1996) Definition of agroforestry revisited. *Agroforestry Today* 8:5–7
- 542 Leroux L, Falconnier GN, Diouf AA, Ndao B, Gbodjo JE, Tall L, Balde AA, Clermont-Dauphin C, Bégué A,
543 Affholder F, Rouspard O (2020) Using remote sensing to assess the effect of trees on millet yield in
544 complex parklands of Central Senegal. *Agricultural Systems* 184:102918.
545 <https://doi.org/10.1016/j.agsy.2020.102918>
- 546 Liang Z, Elsgaard L, Nicolaisen MH, Lyhne-Kjærbye A, Olesen JE (2018) Carbon mineralization and microbial
547 activity in agricultural topsoil and subsoil as regulated by root nitrogen and recalcitrant carbon
548 concentrations. *Plant Soil* 433(1):65–82. <https://doi.org/10.1007/s11104-018-3826-z>
- 549 Lin BB (2007) Agroforestry management as an adaptive strategy against potential microclimate extremes in coffee
550 agriculture. *Agricultural and Forest Meteorology* 144(1):85–94.
551 <https://doi.org/10.1016/j.agrformet.2006.12.009>
- 552 Liu C, Jin Y, Hu Y, Tang J, Xiong Q, Xu M, Bibi F, Beng KC (2019) Drivers of soil bacterial community structure
553 and diversity in tropical agroforestry systems. *Agriculture, Ecosystems & Environment* 278:24–34.
554 <https://doi.org/10.1016/j.agee.2019.03.015>
- 555 Machinet GE, Bertrand I, Chabbert B, Recous S (2009) Decomposition in soil and chemical changes of maize
556 roots with genetic variations affecting cell wall quality. *European Journal of Soil Science* 60(2):176–185.
557 <https://doi.org/10.1111/j.1365-2389.2008.01109.x>
- 558 Maignien R (1965) Notice explicative : carte pédologique du Sénégal au 1/1.000.000. :71
- 559 Makkonen M, Berg MP, Handa IT, Hättenschwiler S, Ruijven J van, Bodegom PM van, Aerts R (2012) Highly
560 consistent effects of plant litter identity and functional traits on decomposition across a latitudinal
561 gradient. *Ecology Letters* 15(9):1033–1041. <https://doi.org/10.1111/j.1461-0248.2012.01826.x>
- 562 Mary B, Beaudoin N, Justes E, Machet JM (1999) Calculation of nitrogen mineralization and leaching in fallow
563 soil using a simple dynamic model. *Eur J Soil Science* 50(4):549–566. <https://doi.org/10.1046/j.1365->
564 [2389.1999.00264.x](https://doi.org/10.1046/j.1365-2389.1999.00264.x)
- 565 Matejovic I (1997) Determination of carbon and nitrogen in samples of various soils by the dry combustion.
566 *Communications in Soil Science and Plant Analysis* 28(17–18):1499–1511.
567 <https://doi.org/10.1080/00103629709369892>

- 568 Miller A, Schimel J, Meixner T, Sickman J, Melack J (2005) Episodic rewetting enhances carbon and nitrogen
569 release from chaparral soils. *Soil Biology and Biochemistry* 37(12):2195–2204.
570 <https://doi.org/10.1016/j.soilbio.2005.03.021>
- 571 Monteith JL, Ong CK, Corlett JE (1991) Microclimatic interactions in agroforestry systems. *Forest Ecology and*
572 *Management* 45(1):31–44. [https://doi.org/10.1016/0378-1127\(91\)90204-9](https://doi.org/10.1016/0378-1127(91)90204-9)
- 573 Moorhead DL, Sinsabaugh RL, Hill BH, Weintraub MN (2016) Vector analysis of ecoenzyme activities reveal
574 constraints on coupled C, N and P dynamics. *Soil Biology and Biochemistry* 93:1–7.
575 <https://doi.org/10.1016/j.soilbio.2015.10.019>
- 576 Mubarak AR, Abdalla MH, Nortcliff S (2012) Millet (*Pennisetum typhoides*) yield and selected soil attributes as
577 influenced by some tree types of the semi-arid tropics of Sudan. *Journal of Arid Environments* 77:96–
578 102. <https://doi.org/10.1016/j.jaridenv.2011.10.008>
- 579 Mubarak AR, Elbashir AA, Elamin LA, Daldoum DMA, Steffens D, Benckiser G (2008) Decomposition and
580 Nutrient Release from Litter Fall in the Semi-arid Tropics of Sudan. *Communications in Soil Science and*
581 *Plant Analysis* 39(15–16):2359–2377. <https://doi.org/10.1080/00103620802292574>
- 582 Nair PKR, Kumar BM, Nair VD (2009a) Agroforestry as a strategy for carbon sequestration. *Journal of Plant*
583 *Nutrition and Soil Science* 172(1):10–23. <https://doi.org/10.1002/jpln.200800030>
- 584 Nair PKR, Nair VD, Kumar BM, Haile SG (2009b) Soil carbon sequestration in tropical agroforestry systems: a
585 feasibility appraisal. *Environmental Science & Policy* 12(8):1099–1111.
586 <https://doi.org/10.1016/j.envsci.2009.01.010>
- 587 Ndiaye O, Le Hesran J-Y, Etard J-F, Diallo A, Simondon F, Neil Ward M, Robert V (2001) Variations climatiques
588 et mortalité attribuée au paludisme dans zone de Niakhar, Sénégal, de 1984 à 1996. *Cahiers santé* 11:25–
589 33
- 590 Ng E-L, Patti AF, Rose MT, Scheffe CR, Wilkinson K, Smernik RJ, Cavagnaro TR (2014) Does the chemical
591 nature of soil carbon drive the structure and functioning of soil microbial communities? *Soil Biology and*
592 *Biochemistry* 70:54–61. <https://doi.org/10.1016/j.soilbio.2013.12.004>
- 593 Oelbermann M, Paul Voroney R, Gordon AM (2004) Carbon sequestration in tropical and temperate agroforestry
594 systems: a review with examples from Costa Rica and southern Canada. *Agriculture, Ecosystems &*
595 *Environment* 104(3):359–377. <https://doi.org/10.1016/j.agee.2004.04.001>
- 596 Oelbermann M, Voroney RP (2007) Carbon and nitrogen in a temperate agroforestry system: Using stable isotopes
597 as a tool to understand soil dynamics. *Ecological Engineering* 29(4):342–349.
598 <https://doi.org/10.1016/j.ecoleng.2006.09.014>
- 599 Ohno T, Zibilske LM (1991) Determination of Low Concentrations of Phosphorus in Soil Extracts Using
600 Malachite Green. *Soil Science Society of America Journal* 55(3):892–895.
601 <https://doi.org/10.2136/sssaj1991.03615995005500030046x>
- 602 Paustian K, Lehmann J, Ogle S, Reay D, Robertson GP, Smith P (2016) Climate-smart soils. *Nature* 532(7597):49–
603 57. <https://doi.org/10.1038/nature17174>
- 604 Poeplau C, Vos C, Don A (2017) Soil organic carbon stocks are systematically overestimated by misuse of the
605 parameters bulk density and rock fragment content. *SOIL* 3(1):61–66. [https://doi.org/10.5194/soil-3-61-](https://doi.org/10.5194/soil-3-61-2017)
606 2017
- 607 Pries CEH, Sulman BN, West C, O'Neill C, Poppleton E, Porras RC, Castanha C, Zhu B, Wiedemeier DB, Torn
608 MS (2018) Root litter decomposition slows with soil depth. *Soil Biology and Biochemistry* 125:103–114.
609 <https://doi.org/10.1016/j.soilbio.2018.07.002>
- 610 Prieto I, Stokes A, Roumet C (2016) Root functional parameters predict fine root decomposability at the
611 community level. *Journal of Ecology* 104(3):725–733. <https://doi.org/10.1111/1365-2745.12537>

- 612 R Core Team (2020) R: A Language and Environment for Statistical Computing. R Foundation for Statistical
613 Computing, Vienna, Austria
- 614 Rahimi J, Ago EE, Ayantunde A, Berger S, Bogaert J, Butterbach-Bahl K, Cappelaere B, Demarty J, Diouf AA,
615 Falk U, Haas E, Hiernaux P, Kraus D, Roupsard O, Scheer C, Srivastava AK, Tagesson T, Grote R (2021)
616 Modelling Gas Exchange and Biomass Production in West African Sahelian and Sudanian Ecological
617 Zones. *Geoscientific Model Development Discussions* :1–39. <https://doi.org/10.5194/gmd-2020-417>
- 618 Rao MR, Nair PKR, Ong CK (1997) Biophysical interactions in tropical agroforestry systems. *Agroforestry*
619 *Systems* 38(1/3):3–50. <https://doi.org/10.1023/A:1005971525590>
- 620 Rasse DP, Rumpel C, Dignac M-F (2005) Is soil carbon mostly root carbon? Mechanisms for a specific
621 stabilisation. *Plant Soil* 269(1):341–356. <https://doi.org/10.1007/s11104-004-0907-y>
- 622 Recous S, Robin D, Darwis D, Mary B (1995) Soil inorganic N availability: Effect on maize residue
623 decomposition. *Soil Biology and Biochemistry* 27(12):1529–1538. [https://doi.org/10.1016/0038-0717\(95\)00096-W](https://doi.org/10.1016/0038-0717(95)00096-W)
624
- 625 Robson A (2012) *Soil Acidity and Plant Growth*. Elsevier
- 626 Roupsard O, Audebert A, Ndour AP, Clermont-Dauphin C, Agbohessou Y, Sanou J, Koala J, Faye E, Sambakhe
627 D, Jourdan C, le Maire G, Tall L, Sanogo D, Seghieri J, Cournac L, Leroux L (2020) How far does the
628 tree affect the crop in agroforestry? New spatial analysis methods in a *Faidherbia* parkland. *Agriculture,*
629 *Ecosystems & Environment* 296:106928. <https://doi.org/10.1016/j.agee.2020.106928>
- 630 Roupsard O, Ferhi A, Granier A, Pallo F, Depommier D, Mallet B, Joly HI, Dreyer E (1999) Reverse phenology
631 and dry-season water uptake by *Faidherbia albida* (Del.) A. Chev. in an agroforestry parkland of
632 Sudanese west Africa. *Functional Ecology* 13(4):460–472. <https://doi.org/10.1046/j.1365-2435.1999.00345.x>
633
- 634 Rousk J, Bååth E (2007) Fungal and bacterial growth in soil with plant materials of different C/N ratios. *FEMS*
635 *Microbiol Ecol* 62(3):258–267. <https://doi.org/10.1111/j.1574-6941.2007.00398.x>
- 636 Six J, Feller C, Deneff K, Ogle S, Joao Carlos De Moraes Sa, Albrecht A (2002) Soil organic matter, biota and
637 aggregation in temperate and tropical soils - Effects of no-tillage. *Agronomie* 22(7–8):755–775.
638 <https://doi.org/10.1051/agro:2002043>
- 639 Smith P, Bustamante M, Ahammad H, Clark H, Dong H, Elsiddig EA, Haberl H, Harper R, House J, Jafari M,
640 Masera M (2014) *Climate Change 2014 Mitigation of Climate Change: Working Group III Contribution*
641 *to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University
642 Press, Cambridge, United Kingdom and New York, NY, USA
- 643 Sun Y, Yan F, Liu F (2013) Drying/rewetting cycles of the soil under alternate partial root-zone drying irrigation
644 reduce carbon and nitrogen retention in the soil–plant systems of potato. *Agricultural Water Management*
645 128:85–91. <https://doi.org/10.1016/j.agwat.2013.06.015>
- 646 Teklay T, Malmer A (2004) Decomposition of leaves from two indigenous trees of contrasting qualities under
647 shaded-coffee and agricultural land-uses during the dry season at Wondo Genet, Ethiopia. *Soil Biology*
648 *and Biochemistry* 36(5):777–786. <https://doi.org/10.1016/j.soilbio.2003.12.013>
- 649 Van Soest PJ (1963) Use of detergents in the analysis of fibrous feeds. 2. A rapid method for the determination of
650 fiber and lignin. *Journal of the Association of Official Agricultural Chemists* 829–835
- 651 Webster EA, Hopkins DW, Chudek JA, Haslam SFI, Šimek M, Pícek T (2001) The Relationship between
652 Microbial Carbon and the Resource Quality of Soil Carbon. *Journal of Environmental Quality* 30(1):147–
653 150. <https://doi.org/10.2134/jeq2001.301147x>
- 654 Wezel A, Rajot J-L, Herbrig C (2000) Influence of shrubs on soil characteristics and their function in Sahelian
655 agro-ecosystems in semi-arid Niger. *Journal of Arid Environments* 44(4):383–398.
656 <https://doi.org/10.1006/jare.1999.0609>

657 Yengwe J, Gebremikael MT, Buchan D, Lungu O, De Neve S (2018) Effects of *Faidherbia albida* canopy and leaf
658 litter on soil microbial communities and nitrogen mineralization in selected Zambian soils. *Agroforest*
659 *Syst* 92(2):349–363. <https://doi.org/10.1007/s10457-016-0063-4>

660

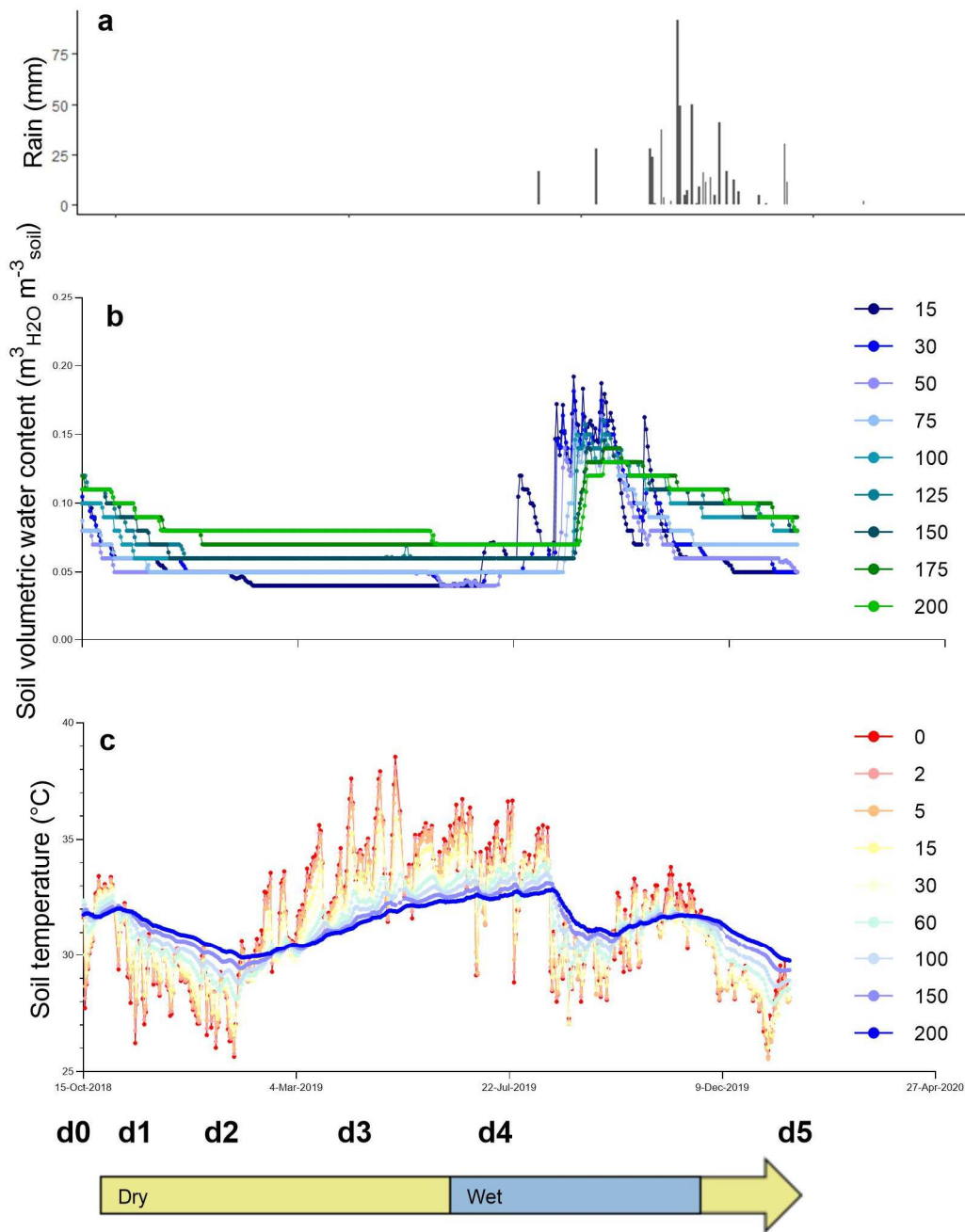


Fig. 1 Dynamics of rainfall (a), volumetric soil water content (b) and soil temperature (c) over time according to soil depth (from the topsoil to 200 cm deep) from the beginning (d0:– 10/15/18) to the end of the experiment (d5: 01/22/20). On the x-axis, d0 to d5 correspond to the sampling dates after 1.5 (d1), 3 (d2), 6 (d3), 9 (d4) and 15 (d5) months of decomposition. Data are presented as daily averages. The wet season is represented in blue, and the dry season is represented in yellow.

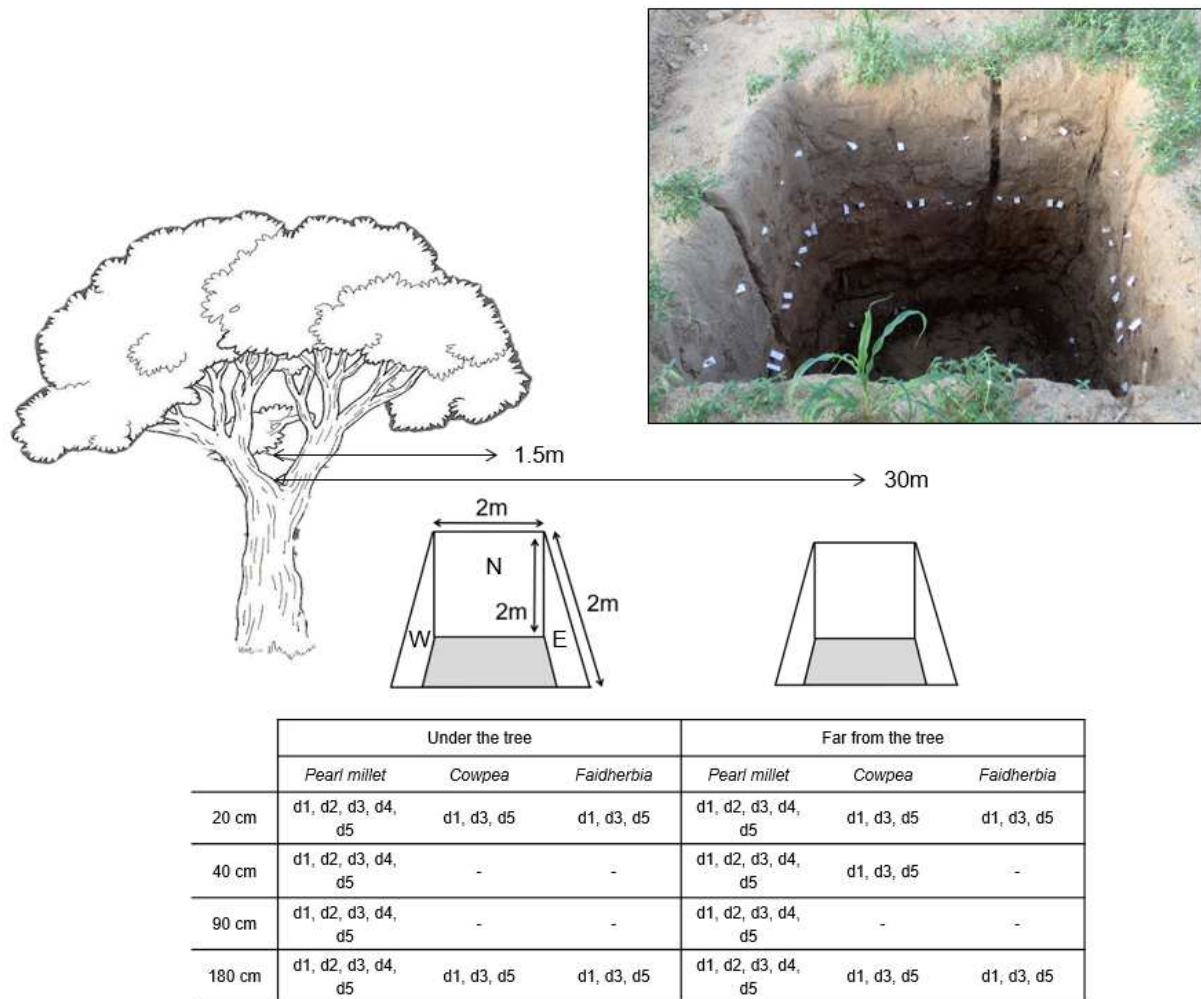


Fig. 2 Sampling strategy in the two pits (far from and under the tree), for each root litter type (pearl millet, cowpea and Faidherbia), at four depths (20, 40, 90 and 180 cm) and for five sampling dates (after 1.5 (d1), 3 (d2), 6 (d3), 9 (d4) and 15 (d5) months). Each litterbag was replicated on three pit walls (northern (N), eastern (E) and western (W) soil profiles). Missing treatments are due to root sample shortages.

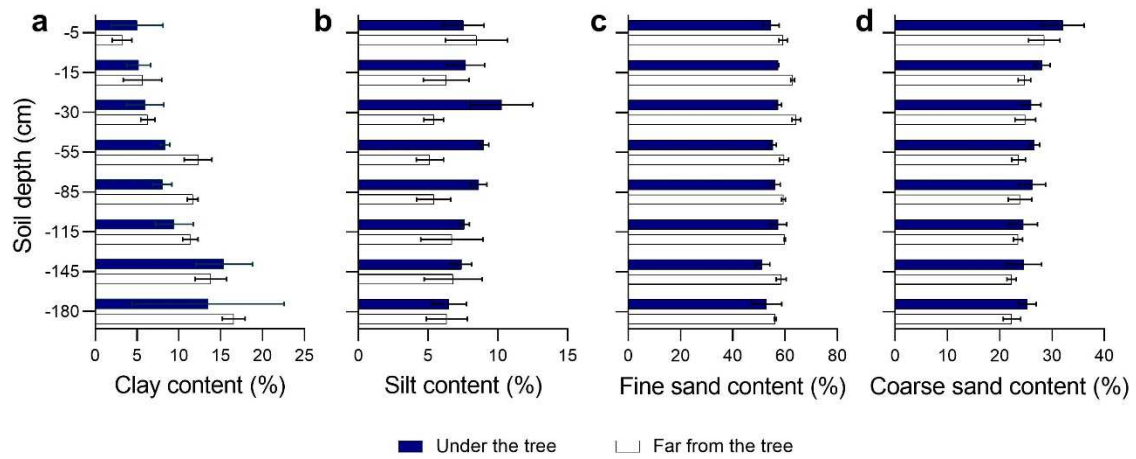


Fig. 3 Comparison of soil texture (%) variations in clay (a), silt (b), fine sand (c) and coarse sand (d) in the soil profile from topsoil to a depth of 180 cm in the pits under (dark) and far from the *Faidherbia* tree (white). Data are mean values from 3 pit walls, and error bars represent the standard deviation ($n = 3$).

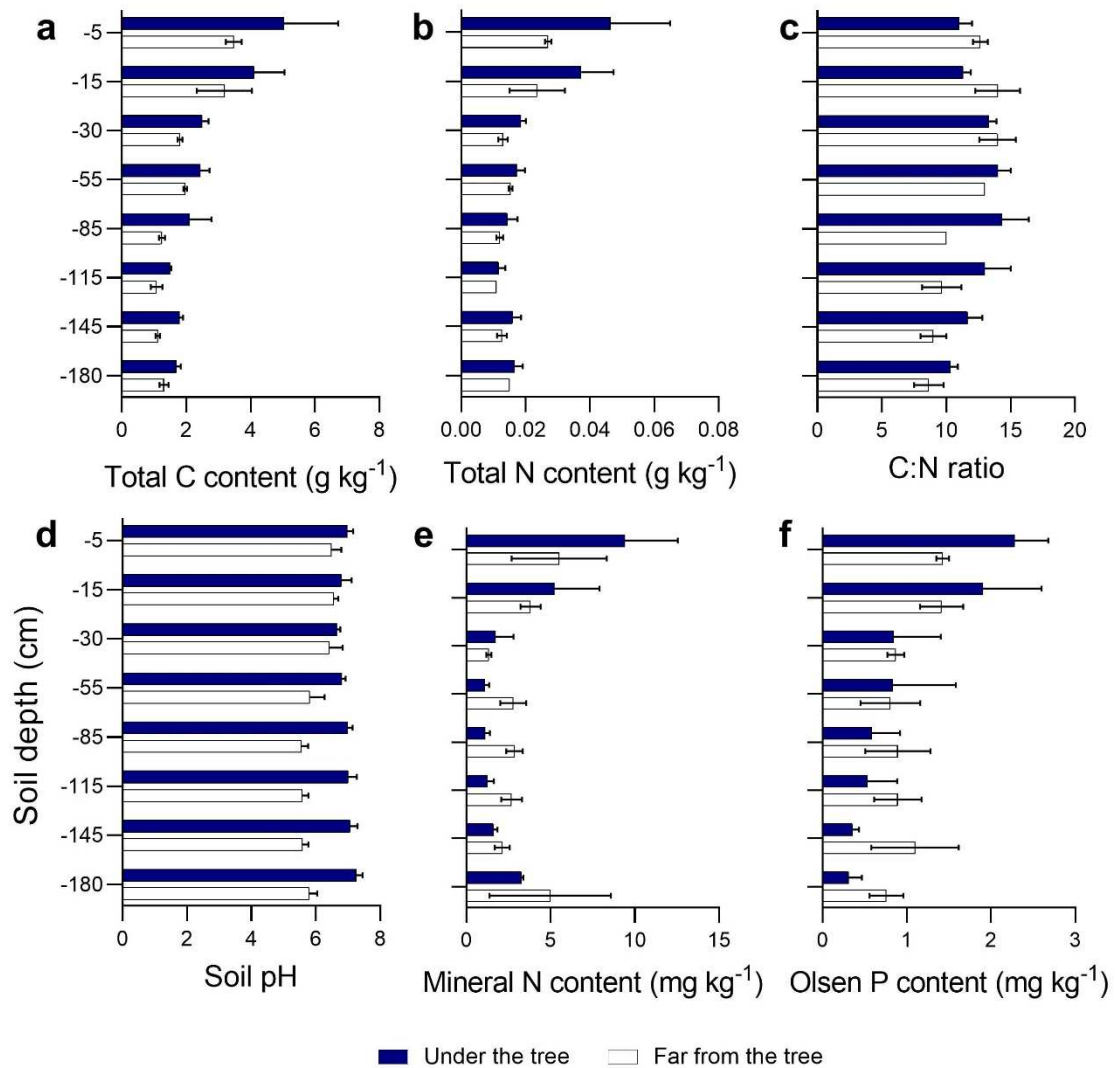


Fig. 4 Total C content (a), total N content (b), C:N ratio (c), soil pH (d), mineral N content (e) and available phosphorus content (f) in the soil profile from topsoil to a depth of 180 cm in the pits under (dark) and far from the tree (white). Data are mean values from 3 pit walls, and error bars represent the standard deviation ($n = 3$).

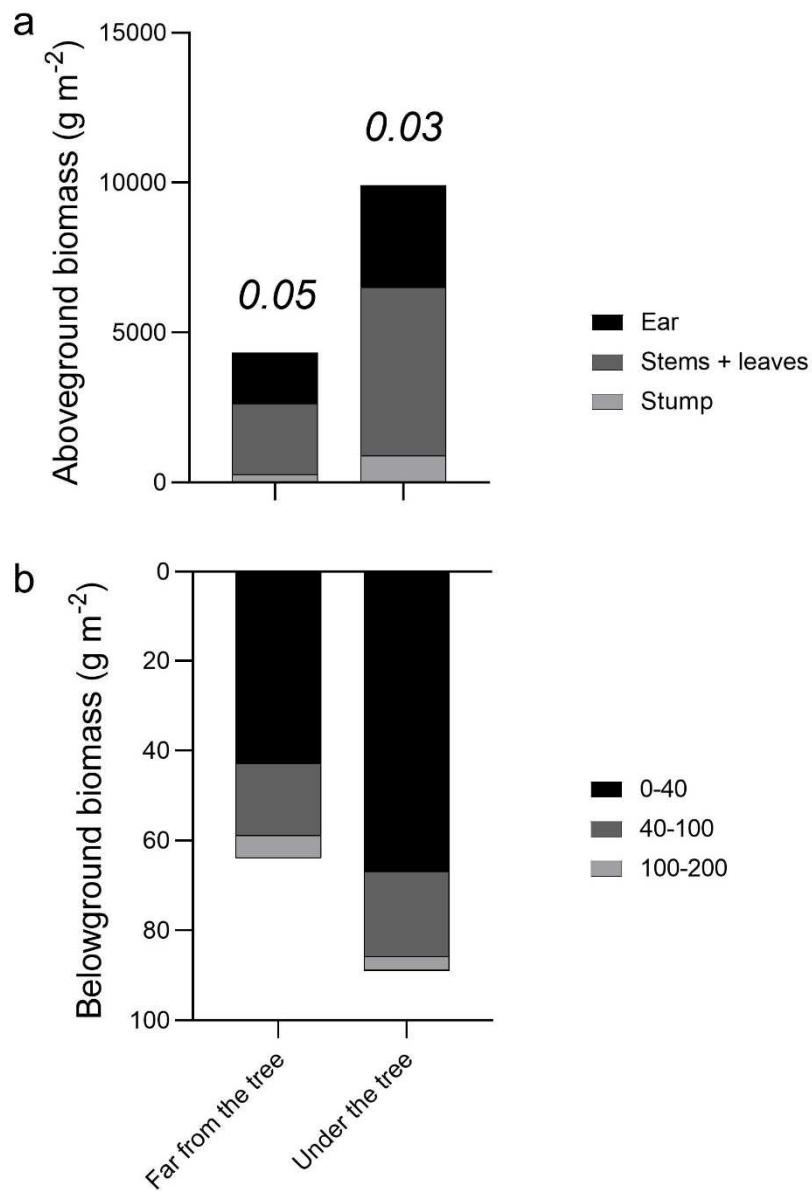


Fig. 5 Above- (a) and belowground (b) biomasses of pearl millet under (right) and far (left) from the Faidherbia tree according to organs (ears and grains, stems and leaves, stump) and soil depths (0 – 40, 40 – 100 and 100 – 200 cm). For each location, R:S ratios are indicated in italics.

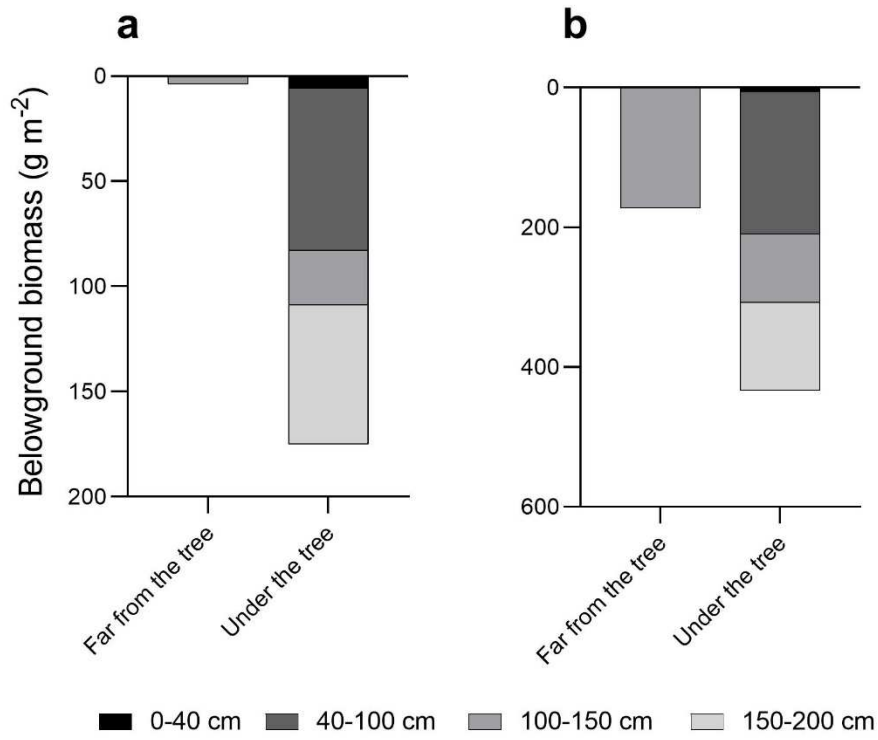


Fig. 6 Comparison of fine (a) and medium (b) root biomasses of *Faidherbia* under (right) and far (left) from the tree according to soil depth (0 – 40, 40 – 100, 100 – 150 and 150 – 200 cm).

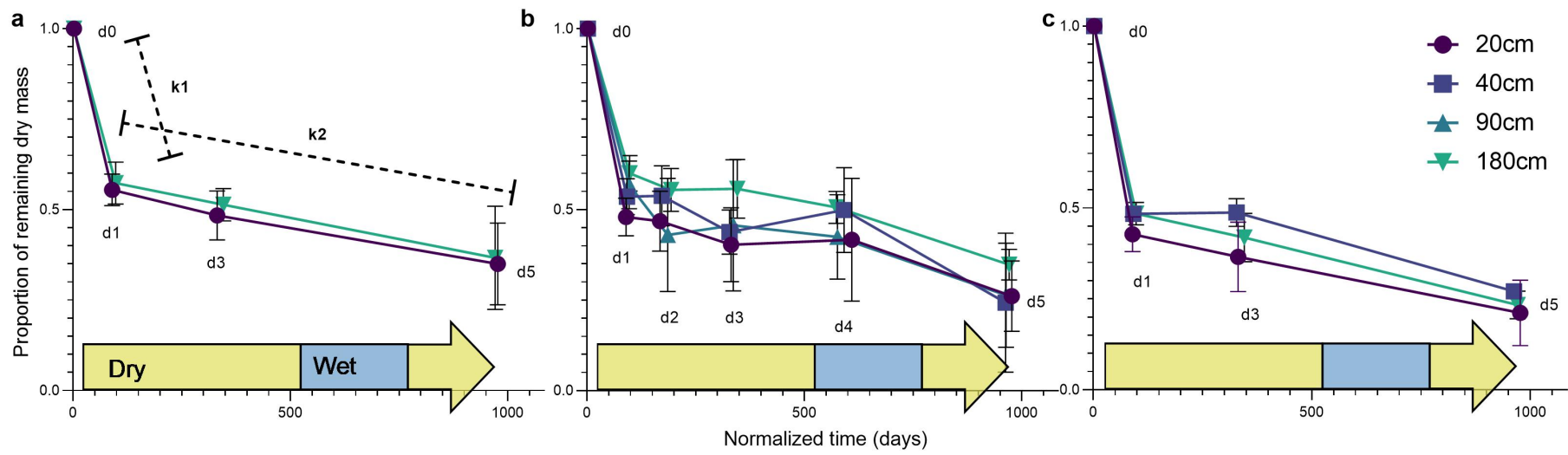


Fig. 7 Dynamics of root litter decomposition (after 1.5, 3, 6, 9 and 15 months) for the three plant species (Faiderbia tree (a), pearl millet (b) and cowpea (c)) at four soil depths (20, 40, 90, 180 cm). The wet season is represented in blue, and the dry season is represented in yellow. Data are mean values, and error bars are standard deviations ($n = 6$). Coefficients k_1 and k_2 are shown only on the left plot but were calculated for each regression.

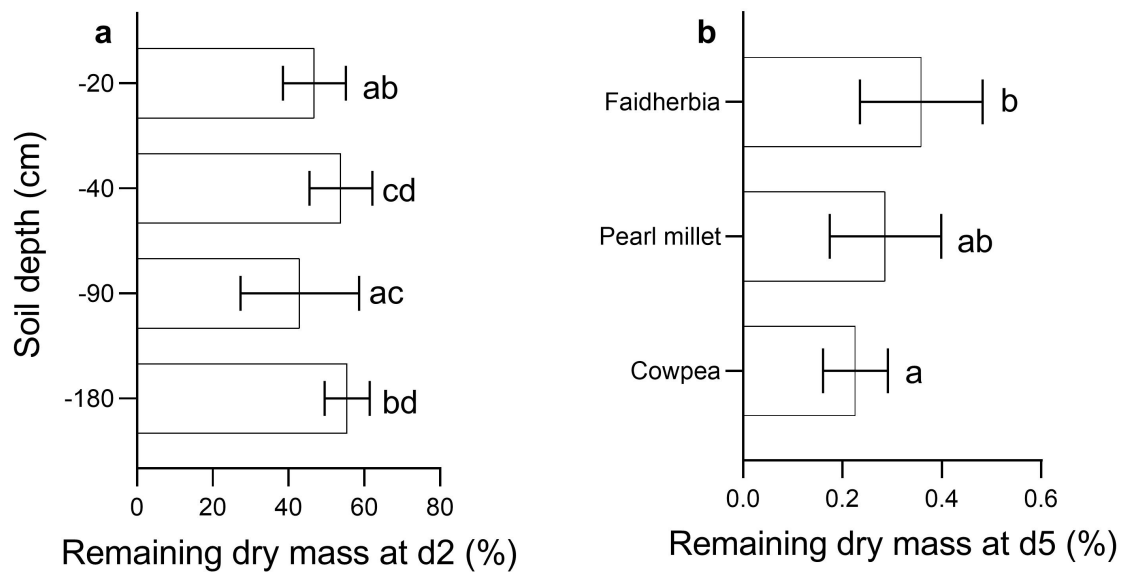


Fig. 8 Final root litter remaining mass (a) on d2 (01/17/2019) for pearl millet at four soil depths (20, 40, 90 and 180 cm) and (b) on d5 (01/22/2020) for three plant species (Faidherbia tree, pearl millet and cowpea) at all soil depths. Data are mean values, and error bars are standard deviations (n=3). The different letters indicate significant differences in remaining dry mass for each soil depth (A) or for each plant species (B).

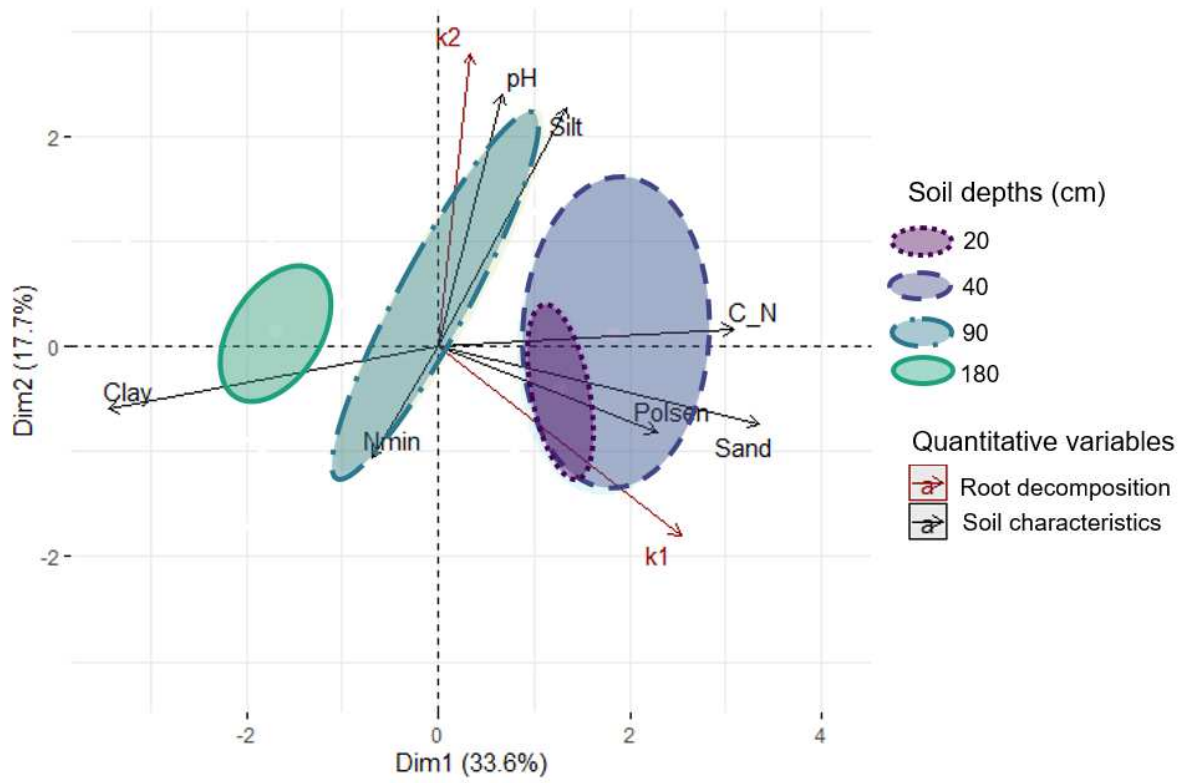


Fig. 9 Relationships between soil characteristics (clay, silt, sand, available P (as P_{Olsen}) and mineral N (as N_{min}) contents, pH and the C:N ratio) and root decomposition (k_1 and k_2), according to the soil depth (20, 40, 90, 180 cm).

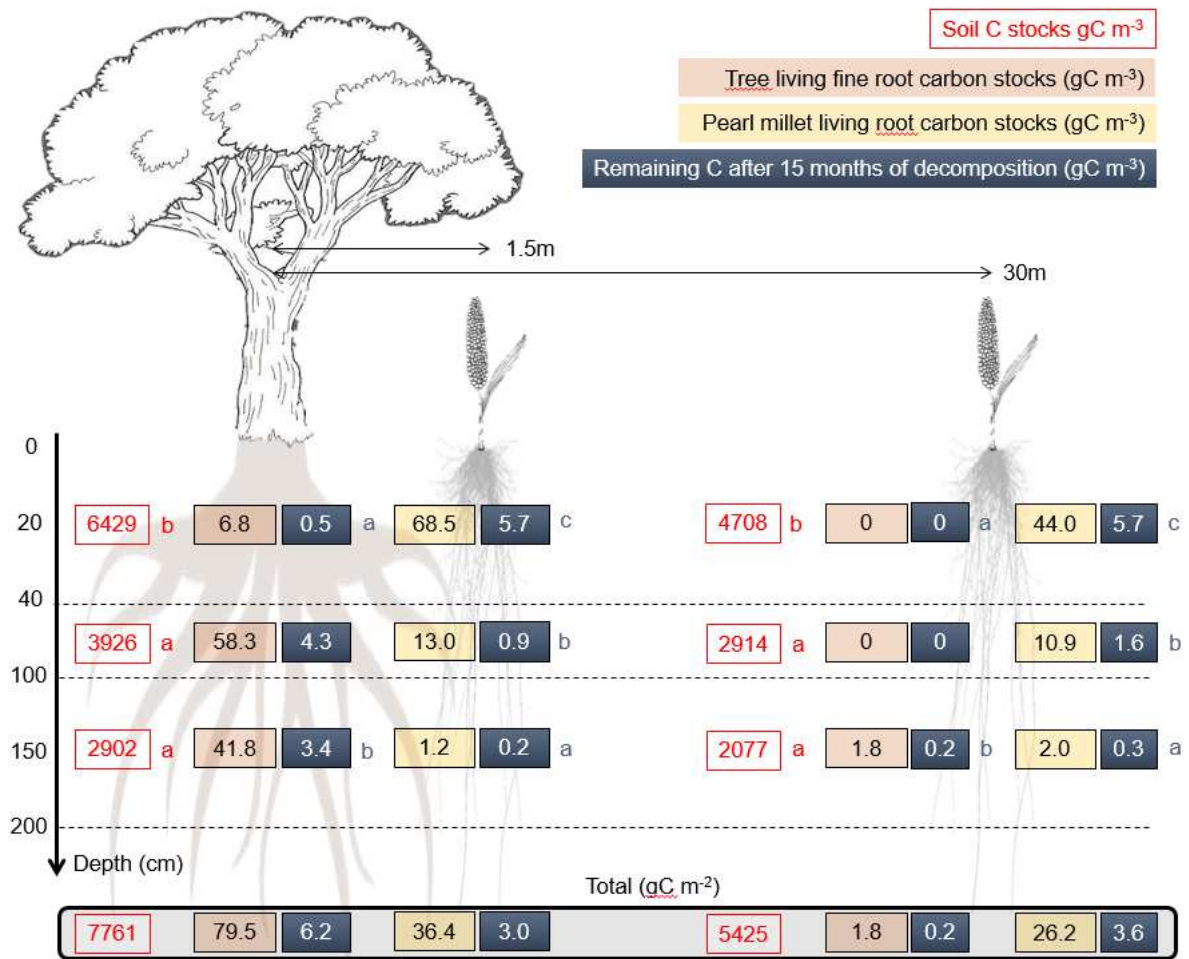


Fig. 10 Potential root C contribution to soil C stocks in one cultural season for *Faidherbia* and pearl millet according to the soil depth and at two locations: under (left) and far (right) from the tree. For each location, the different letters indicate significant differences in soil C stocks and in remaining C between the soil depths.

Table 1 Total soil carbon stocks (g m^{-2}) of equivalent soil mass according to location (under or far from the tree) at different soil depths down to 200 cm. Data are mean values \pm standard deviation ($n = 3$). Significant differences between both locations for each soil layer were tested with Wilcoxon tests.

Soil depth	Carbon stocks on equivalent soil mass (g m^{-2})		Results of the tests of Wilcoxon	
	Under tree	Far from tree	W	p-value
0 – 10 cm	883 \pm 295	634 \pm 44	6	0.66
10 – 20 cm	712 \pm 164	543 \pm 145	8	0.2
20 – 40 cm	907 \pm 73	634 \pm 25	6	0.2
40 – 70 cm	1272 \pm 147	1064 \pm 30	9	0.1
70 – 100 cm	1083 \pm 353	684 \pm 52	9	0.1
100 – 130 cm	769 \pm 23	536 \pm 88	9	0.1
130 – 160 cm	920 \pm 57	623 \pm 34	9	0.1
160 – 200 cm	1214 \pm 101	919 \pm 97	9	0.1
Total stock	7761 \pm 346	5425 \pm 558	9	0.1

Table 2 Initial values of biochemical qualities of the fine root litter added to the litterbags. Data are mean values \pm standard deviation (n = 3). Significant differences between root litter types were tested with one-way analyses of variance. ***, ** and * indicate the significance of the impact of the studied effects on litter quality with p-values < 0.001, 0.01, and 0.05, respectively. Letters indicate differences between the 3 types of litter.

	Initial values			Statistics	
	Faidherbia	Pearl millet	Cowpea	F-value	p-value
Carbon fractions (% DM)					
Soluble fraction	14.5 \pm 2.7 ^a	13.9 \pm 2.2 ^a	27.1 \pm 2.2 ^b	29.3	8.1 $\times 10^{-4}$ ***
Cellulose	19.4 \pm 2.4 ^a	37.9 \pm 2.4 ^b	21.3 \pm 4.4 ^a	29.9	7.6 $\times 10^{-4}$ ***
Hemicellulose	14.2 \pm 1.9 ^a	27.4 \pm 2.2 ^{ab}	34.3 \pm 9.8 ^b	8.9	1.6 $\times 10^{-2}$ *
Lignine	51.9 \pm 4.1 ^b	20.8 \pm 2.1 ^a	17.3 \pm 4.4 ^a	82.6	4.3 $\times 10^{-5}$ ***
Elemental composition (% DM)					
C	45.4 \pm 0.1 ^c	40.9 \pm 0.7 ^a	42.9 \pm 0.8 ^b	37.9	4.0 $\times 10^{-4}$ ***
N	3.5 \pm 0.1 ^c	1.3 \pm 0.0 ^a	1.4 \pm 0.0 ^b	1779	4.8 $\times 10^{-9}$ ***
P	0.09 \pm 0.0 ^{ab}	0.07 \pm 0.01 ^a	0.11 \pm 0.01 ^b	12.0	8.0 $\times 10^{-3}$ **
C:N	13.0 \pm 0.3 ^a	32.5 \pm 0.9 ^c	30.2 \pm 0.3 ^b	981	2.8 $\times 10^{-8}$ ***

Table 3A Differences in the volumetric humidity ($\text{m}^3_{\text{H}_2\text{O}} \text{m}^{-3}_{\text{soil}}$) of the soil in contact with the litterbags among soil depths (20, 40, 90 and 180 cm), plant species (pearl millet, Faidherbia tree, cowpea), locations (far from and under the tree) and sampling dates (d1 to d5). Data are mean values \pm standard deviation. The different lowercase letters indicate significant differences between the modalities, and ns indicates the absence of a significant effect.

	Soil volumetric humidity ($\text{m}^3_{\text{H}_2\text{O}} \text{m}^{-3}_{\text{soil}}$)					Statistics	
						F-value	P-value
Soil depth (cm)	20	40	90	180			
	0.020 \pm 0.018 ^a	0.027 \pm 0.024 ^b	0.045 \pm 0.036 ^b	0.110 \pm 0.051 ^c		337.9	< 2.2 $\times 10^{-16}$
Root species	Faidherbia	Pearl millet	Cowpea				
	0.060 \pm 0.054	0.049 \pm 0.046	0.051 \pm 0.057				ns
Location	Far	Under					
	0.039 \pm 0.036 ^a	0.069 \pm 0.061 ^b				103.5	4.4 $\times 10^{-4}$
Sampling date	d1	d2	d3	d4	d5		
	0.090 \pm 0.059 ^d	0.058 \pm 0.042 ^c	0.026 \pm 0.028 ^a	0.042 \pm 0.040 ^b	0.051 \pm 0.053 ^{bc}	100.5	< 2.2 $\times 10^{-16}$

Table 3B Differences in the volumetric humidity ($\text{m}^3_{\text{H}_2\text{O}} \text{m}^{-3}_{\text{soil}}$) of the soil in contact with the litterbags between each location (far from and under the tree) on each sampling date (d1 to d5). Data are mean values \pm standard deviation. The different lowercase letters indicate significant differences between the modalities, and ns indicates the absence of a significant effect.

	d1		d2		d3		d4		d5	
	Far	Under	Far	Under	Far	Under	Far	Under	Far	Under
	0.069 \pm 0.039 ^a	0.113 \pm 0.069 ^b	0.043 \pm 0.029 ^a	0.070 \pm 0.048 ^b	0.018 \pm 0.021 ^a	0.035 \pm 0.032 ^b	0.030 \pm 0.019 ^a	0.051 \pm 0.049 ^b	0.032 \pm 0.033	0.072 \pm 0.063
	F = 16.9		F = 12.6		F = 15.2		F = 14.6			
	p-value = 1.41 $\times 10^{-2}$		p-value = 2.22 $\times 10^{-2}$		p-value = 1.72 $\times 10^{-2}$		p-value = 1.68 $\times 10^{-2}$			ns

Table 4 The k1 coefficient for each plant species (Faidherbia tree, pearl millet and cowpea) according to soil depth (20, 40, 90, 180 cm). Data are mean values (n = 6). The different lowercase letters indicate significant differences between the soil depths accompanied by their p-values for each plant species, and ns indicates the absence of a significant effect of soil depth.

	Soil depths (cm)				Statistics	
	20	40	90	180	F-value	P-value
Faidherbia	5.08×10^{-3}	-	-	4.44×10^{-3}		ns
Pearl millet	5.93×10^{-3} b	5.17×10^{-3} a	4.55×10^{-3} a	4.16×10^{-3} a	7.4	4.54×10^{-3}
Cowpea	6.53×10^{-3} b	5.75×10^{-3} a	-	5.37×10^{-3} a	7.7	2.13×10^{-2}