Research Article

Effect of litter mixture on litter decomposition and nutrient release of three agroforestry species in Sudano-Guinean savannah of Ngadoundere, Adamawa Cameroon

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Abstract: In order to maintain or improve the soil fertility of agricultural systems in Ngaoundere, an experiment on the decomposition of simple litters and mixtures of Harungana madagascariensis, Vitellaria paradoxa and Syzygium guineense var. macrocarpum was conducted in a field using the litterbag method. This experiment was made of single species and their mixtures of which gave three uneven mixtures (5VP, 5HM and 5SM) and one even mixture (3E) amounting to seven treatments (THM, TVP, TSM, 3E, 5HM, 5VP, and 5SM). The experimental design was a completely randomized block with three replications. 126 samples of 10 g each were introduced in a field for 24 weeks and a deduction of 3 samples was made at 2, 4, 6, 10, 16 and 24 weeks. The remaining dry mass, rates of decomposition, half time and the nutrient release in the soil were determined. The results showed that the remaining dry mass varied from 67.95% in TSM (S. guineense) to 22.02% in TVP (V. paradoxa). The rate of decomposition ranged from 0.033 for 5SM (mixture 50% of S. guineense and 25% for each of the two other species) to 0.055 in 3E with respectively 19, 64 to 12, 56 as a half-time. The initial chemical content and that at the end of the experiment of the simple and mixed litters varied significantly within the treatments. The mixture of litter released more nitrogen and carbon than the individual litter and the pattern was ranged as follow 3E>5VP>5HM>5SM>TVP>THM>TSM. The pattern of phosphorus release in the soil was ranged in the following order: TVP>TSM>THM>5VP>3E>5HM>5SM, indicating that the individual litter released more phosphorus on the soil than their mixture. These preliminary results will not only contribute in the comprehension of the decomposition process mechanism of Ngaoundere but also will permit in choosing the type of the litter and mixture with release more nutrient in the soil for improvement of agricultural system fertility.

Keywords: biodiversity, litter decomposition, litter mixtures, nutrients release, savannas

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Introduction

Litter decomposition represents an important process in biogeochemical cycling (Ibrahima et al., 2008). During this process, in particular N and P, immobilized in the litter are partly released and are made available for plants and soil micro-organisms (Begon et al., 2005). This process is vital for site productivity (Prescott, 2005b) and for regeneration of seedlings and restoration of soil fertility (Ibrahima et al., 2011). The litter decay rate is a factor that largely determines soil fertility (Bossa et al., 2005) and its regulation plays an important role in agro-ecosystem functioning, notably in poor
Effect of litter mixture on litter decomposition and nutrient release of three agroforestry species

soil of Sudano-Guinean savannas of Ngaoundere (Ibrahim et al., 2008). The sustainable management of ecosystem and land degradation like that of Sudano-Guinean savannas of Ngaoundere Cameroon requires knowledge of its structure and functioning, such as phytomass and nutrient cycling, including litter decomposition (Ibrahim et al., 2011).

Litter decomposition involves the mineralization and humification of lignin and cellulose by microorganisms paired simultaneously with the leaching of soluble compounds that allow nitrogen and carbon (and other minerals) to be progressively immobilized or mineralized into the soil (Coûteaux et al., 1995). Litter decomposition is controlled by many factors such as climate (micro and macro), litter quality (physical and chemical composition) and soil organism’s activities (macro-and micro-invertebrates) (Swift et al., 1979). All or any of these factors could be drastically altered due to forest fragmentation or forest conversion, altering the vital process of nutrient cycling (Vanderbilt et al., 2008). Many scientific works related to these factors on litter decomposition have been done. Moore et al. (1999) Mellilo et al. (1982) have shown that litter decomposition was influenced by the physico-chemical factors of litter such as carbon and nitrogen content, thickness, hardness, sclerophyll index of the litter. Coûteaux et al. (1995) study the litter chemical characteristics; Gonzalez and Seastedt (2001), Heneghan et al. (1998), Wall et al. (2008), and Yang and Chen (2009) were interested in the effect of biotic factors on litter decomposition. During the last decade, many studies reported so far on single species analysis (Berg and Mcclaugherthy, 2003). However, in the natural ecosystem, litters fall and decompose in mixture, and physicochemical interactions between decomposing leaves can increase or decrease decomposition up to 30% to their expected mass loss (Hättenschwiler and Gasser, 2005; Tardif et al., 2013). The previous study also shows that various species are often mixed during decomposition and not in single species (King et al., 2002; Wardle et al., 2003; Chapman and Koch, 2007; Leroy et al., 2007). Mixture effect may influence litter decomposition rate (Swan and Palmer, 2004; Kominoski et al., 2007). Mixture litter may have a synergistic effect (Wardle et al., 1997) or antagonistic effect on litter decomposition (Dijkstar et al., 2009). However, in spite of the importance of this factor on litter decomposition process, information about litter mixture on litter decomposition processes in Sudano-Guinean savannah of Ngaoundere is poorly studied and very limited, excepting those Nsowa (2014) on effect litter mixture on the decomposition and leaching of tree species. In this study, we assess the effect of litter mixture on litter decomposition and nutrient release (N, P and C) of three selected agroforestry species after six months of incubation on the field. The influence of litter quality on litter decomposition process is also discussed. This study was carried out on three local species Vitellaria paradoxa, Harungana madagascariensis, and Syzygium guineense var. macrocarpum by using litterbag methods.

Material and methods

Site study

This study was carried out in the locality of Bini-Dang, Guinea savannah highlands of Adamawa region. The Guinea savannah highlands area is approximately 7200 km² and spread between the latitude 7°2′36″ N and 13°34′12″ E. The Bini locality lies in latitude 7°24′ North and longitude 13°32′ East with the average elevation is 1079 m. The soil is rich in ferruginous compounds and composed of red ferralitic developed ancient basalts (Yonkeu et al., 1998). The climate is Guinean type with a humid tendency (Collins, 1985; Suchel, 1987) having a dry season from mid-October to mid-March and a rainy season which starts in April by a period of violent thunder until October. Precipitations are particularly important between July and September. The mean annual temperature is 22.3°C. The vegetation is mainly constituted prairies and shrubby and/or woody savannah with a marked predominance of Daniella oliveri and Lophira lanceolata (Letouzey, 1968) yet, their density has strongly decreased under the influence of human activities (Mapongmetsem et al., 2000). The experimental site is located inside the University of Ngaoundéré (Figure 1). It lies in latitude 7°42′247″ N and longitude 13°53′997″ East with the average elevation is 1096 m.

Species selection

The species used in this study are among the most important socio-economic tree species valued by the populations of the Guinean savannah highlands (Mapongmetsem et al., 2012). They are Harungana madagascariensis Lam. ex poir (Clusiaceae), Vitellaria paradoxa Van Tiegh ex Keay (Sapotaceae), and Syzygium guineense Var. macrocarpum Engl. (Myrtaceae); their distribution areas are located in the upland savanna. The selection of these species was based on the previous study.
Figure 1. Location of the study area.
Local populations prize them because they are sources of income, food, firewood, medicinal substances and soil fertility indicators for farmers of this region and source of honeybees (Yonkeu, 1993; Ibrahima et al., 2008; Mapongmetsem et al., 2012). Concerning the phenology of their leaf we have chosen deciduous broad-leaved trees (Vitellaria paradoxa), deciduous broad-leaved shrubs Syzygium guineense var. macrocarpum and evergreen shrubs (Harungana madagascariensis).

Litter collection

Litters were collected under the tree of each species during their maximal fall period (November to February). For each species, the sample of litter was collected on 3 individuals plants. After the collection of litter sample, other materials like root and sand were removed within the sample, and then litter was dried on the sun for three days before their utilization.

Litterbags experiment

Litterbags method was used for this experiment (Bocock et al., 1960; Ibrahima, 1995). Bags were made up by using nylon material with 2 mm mesh and size according to litter type to avoid leaf material compression and prevent the creation of artificial conditions of litter. The 2 mm mesh size was sufficiently small to prevent losses of litter due to breakage and to permit the access of decomposers (Ibrahima et al., 2002). The experimental design used was randomized complete block design (RCBD) with seven treatments and three replications. In total 126 litterbags (7 treatments × 6 sampling dates × 3 replications). Three replicates of each treatment were removed randomly on each sampling date after 2, 4, 6, 10, 16 and 26 weeks respectively and each litter bags content about 10g± 0.01g of litter.

Chemical analysis

Samples were ground into powder through a small electric grinder to determine nitrogen, phosphorus and carbon content of the litter before and after decomposition process. Nitrogen was analyzed using the Kjeldahl method and titrated with sulphuric acid at 0.01 N. The carbon content was detected by oxidation according to AFNOR method (1982), and phosphorus was analyzed according to Rodier method (1978). Lignin content was measured following the Goering and Van Soest (1970) method.

Statistical analysis

The rate constant of litter decomposition (k) for each species was estimated using the simple negative exponential decay function (Olson, 1963): 

\[ DMR = 100e^{-kt} \]

Where DMR is the litter dry mass remaining. The k value was used to calculate the time required for 50% decomposition or the half-life of litter in the litterbag (Bockheim et al., 1991): 

\[ t_{0.5} = \frac{\ln(0.5)}{-k} = 0.693/-k. \]

The nutrient release in the soil by litter was calculated through a percentage of initial and after decomposition of nutrient content and their dry mass following this equation. 

\[ QR(g) = (Ci*DMI/100)-(Ct*DMf/100), \]

where Q is the nutrient release in the soil by litter after decomposition (g); Ci and Ct are respectively nutrient content at time t and at the initial time; DMt and DM0 are dry mass at time t and at the initial time.

Results and Discussions

Initial litter content

The initial chemicals parameters of the litter and their mixture are represented in Table 1. According to this table, the initial carbon content ranged to 29.19% in H. madagascariensis to 46.73% in the mixture litter of SSM (mixture of 50% S. guineense var. macrocarpum and 25% of V. paradoxa) and 25% of H. madagascariensis). However, all the mixture litter have a higher carbon content than a single. This result is lead to those of Nsowa (2014) who obtained higher carbon content in the mixture of litter. Therefore, for nitrogen, phosphorus and lignin content the value obtained on single litter and their mixture vary according to species and the proportion of mixture. Phosphorus content varies to 0.16% at 0.06% respectively in V. paradoxa and in 5SM (mixture of 50% S. guineense var. macrocarpum and 25% of V. paradoxa and 25% of H. madagascariensis). The higher value of nitrogen was observed in 5VP (mixture of V. paradoxa + 25% of H. madagascariensis + 25% S. guineense var. macrocarpum) and the lower in H. madagascariensis. Concerning lignin content of litter, S. guineense var. macrocarpum has a higher value (3.84%) and V. paradoxa has a lower value (1.20%). Ibrahima et al. (2008) have also obtained a low value of lignin content in the litter of V. paradoxa.

Mass loss dynamic during incubation

In general, the DRM decrease with the time for practically all the treatments (Figure 2) and there a statistically significant difference between all the treatment (F = 26.96 and P-value = 0.0000). At the end of the incubation period of the litter bags on the field, the dried remaining mass of the three monospecific litters fluctuated in average from 67.95% (S. guineense var. macrocarpum) to 22.02% (V. paradoxa) in related to their initial dry
Effect of litter mixture on litter decomposition and nutrient release of three agroforestry species

mass either a loss of mass from 32.05% to 77.98%. According to Mapongmetsem et al. (2005) and Ibrahima et al. (2011), these results suggest that the loss in litter weight varied with the species. This confirms the results, Ibrahima et al. (2000), Baye-Niwah (2001) and Nsowa (2014) concerning the diminution of litter mass of different litters with the time. Between these three litter, the mass loss was slow in S. guineensis var. macrocarpum, this can be explained by their chemical properties particularly lignin content.

Table 1. Initial litter quality.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>C</th>
<th>N</th>
<th>C/N</th>
<th>P</th>
<th>LIGNIN</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSM</td>
<td>31.23±4.23a</td>
<td>1.99±0.2ab</td>
<td>15.72±1.19a</td>
<td>0.14±0.04bc</td>
<td>3.84±0.15b</td>
</tr>
<tr>
<td>TVP</td>
<td>37.06±4.15a</td>
<td>2.13±0.42abc</td>
<td>17.4±3.63ab</td>
<td>0.16±0.01c</td>
<td>1.20±0.80a</td>
</tr>
<tr>
<td>THM</td>
<td>29.19±2.13a</td>
<td>1.83±0.06a</td>
<td>15.92±0.04a</td>
<td>0.11±0.07abc</td>
<td>1.87±0.03a</td>
</tr>
<tr>
<td>5SM</td>
<td>46.73±1.41c</td>
<td>1.93±0.01a</td>
<td>24.21±0.21c</td>
<td>0.06±0.02a</td>
<td>2.11±0.9a</td>
</tr>
<tr>
<td>5VP</td>
<td>42.69±2.27c</td>
<td>2.50±0.27c</td>
<td>17.08±0.03ab</td>
<td>0.12±0.01abc</td>
<td>1.89±0.40a</td>
</tr>
<tr>
<td>5HM</td>
<td>44.14±1.50c</td>
<td>2.03±0.03abc</td>
<td>21.7±0.09c</td>
<td>0.09±0.03ab</td>
<td>2.09±0.8a</td>
</tr>
<tr>
<td>3E</td>
<td>45.36±2.82c</td>
<td>2.42±0.46bc</td>
<td>18.76±1.36b</td>
<td>0.08±0.03ab</td>
<td>2.05±0.05a</td>
</tr>
<tr>
<td>F-ratio</td>
<td>17.01</td>
<td>2.56</td>
<td>12.82</td>
<td>2.42</td>
<td>6.00</td>
</tr>
<tr>
<td>P-value</td>
<td>0.0000</td>
<td>0.069</td>
<td>0.0001</td>
<td>0.08</td>
<td>0.002</td>
</tr>
</tbody>
</table>

N = nitrogen, P = phosphorus, C = Carbon, C/N = ratio of nitrogen to carbon, TSM = Syzygium guineense var. macrocarpum without mixture, TVP = Vitellaria paradoxa without mixture, THM = Harungana madacasriensis without mixture, (5SM) = mixture of 50% of Syzygium guineense var. macrocarpum + 25% Vitellaria paradoxa and 25% Harungana madacasriensis, (5VP) = mixture of 50% Vitellaria paradoxa + 25% Syzygium guineense var. macrocarpum + 25% Harungana madacasriensis, (5HM) = mixture of 50% Harungana madacasriensis + 25% Syzygium guineense var. macrocarpum + 25% Vitellaria paradoxa, 3E = mixture of 33.33% of all the three litter.

Figure 2. Dry mass remaining during the incubation of litter.

DMR = dry mass remaining, TSM = Syzygium guineense var. macrocarpum without mixture, TVP = Vitellaria paradoxa without mixture, THM = Harungana madacasriensis without mixture, (5SM) = mixture of 50% of Syzygium guineense var. macrocarpum + 25% Vitellaria paradoxa and 25% Harungana madacasriensis, (5VP) = mixture of 50% Vitellaria paradoxa + 25% Syzygium guineense var. macrocarpum + 25% Harungana madacasriensis, (5HM) = mixture of 50% Harungana madacasriensis + 25% Syzygium guineense var. macrocarpum + 25% Vitellaria paradoxa, 3E = mixture of 33.33% of all the three litter.

Berg and Mcclaugherty (2008) have reported that the higher presence of recalcitrant components such as lignin decreases the decomposition process. For the mixture, the remaining dry mass after 26 weeks varied from 26.61% for (3E) to 43.53%, for (5SM) either a loss of mass of 73.39% to 56.47% respectively. According to the results of Ibrahima et al. (2008) and Nsowa (2014), this can be due to the particular physical characteristics of each litter in the mixture. In general, the dry mass
remaining of single species was less than those of mixtures excepted on the treatment of *V. paradoxa*. Results of this study corroborate to those of Chapman and Koch (2007) and to those of Pérez Harguindeguy et al. (2008) that have shown that litter decomposition in mixture is faster than in individual litter. We have obtained also that the litter reaming dry mass in *V. paradoxa* was higher than all the mixture treatment. This result overtake to those of Wardle et al. (1997) and those of Dijkstar et al. (2009) who have demonstrated that mixture did not have a synergistic effect on litter decomposition.

**Rate litter decomposition and half-time of decomposition**

A simple exponential function was used to determine the rate of decomposition (k) and the corresponding half time of decomposition. In general, we found a significant difference in rate decomposition between the treatment after 24 weeks of incubation (F = 14.12 and P-value = 0.0000). For the single litter, the values of k ranged from 0.06 for *V. paradoxa* to 0.16 week-1 for *S. guineense var. macrocarpum* corresponding 42.6 and 10.4 weeks of half time. The litter decay constants of the mixture group varied from 0.035 for 5SM (50% mixture of *S. guineense var macrocarpum* and 25% of other two litter) to 0.055 for 3E (a proportional mixture of the three litter) with respectively 19.64 and 12.56 of half-time. We observed the higher rate constant of decomposition in the mixture of the three species within the proportion of *V. paradoxa* were higher, the result can be explained by the fact slow decompose species increase rate decomposition as demonstrated by the study of Hoorens et al. (2010) and Wardle et al. (2003). Indeed, Rheka et al. (2012) showed that when the proportion of the slow decomposing species is higher in the mixture this species could increase or decrease the rate decomposition. In general, all the mixture treatments decompose faster to the single litter of *S. guineense var macrocarpum* and *H. madagasariensis* this means that all the mixture treatment have a synergistic effect or influence positively litter decomposition of these two species. The result of this study overtake to those of Santonja (2011) who reported that litter mixture accelerates the litter decomposition. This result can be also explained by the biotic activities as indicated by Swan and Palmer (2006). According to these authors, biotic fauna focuses their activities to the mixture of litter that has very nutritious. *V. paradoxa* decomposes faster than the mixture treatment which has a high lignin content. This can be explained to their initial nutrient content particular low lignin content and this result confirms that initial litter content was a good predictor of species and mixture decomposition.

**Table 2. Rate and half-time of litter decomposition.**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>K</th>
<th>T(0.5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TVP</td>
<td>0.066±0.001</td>
<td>10.40±0.10</td>
</tr>
<tr>
<td>THM</td>
<td>0.027±0.011</td>
<td>25.40±3.27</td>
</tr>
<tr>
<td>5SM</td>
<td>0.035±0.003</td>
<td>19.64±0.2</td>
</tr>
<tr>
<td>5VP</td>
<td>0.051±0.01</td>
<td>13.42±0.56</td>
</tr>
<tr>
<td>5HM</td>
<td>0.041±0.001</td>
<td>16.50±2.19</td>
</tr>
<tr>
<td>3E</td>
<td>0.055±0.02</td>
<td>12.56±0.07</td>
</tr>
</tbody>
</table>

T(0.5) = half –time of decomposition, K= rate constant of decomposition TSM = *Syzygium guineense var. macrocarpum* without mixture, TVP = *Vitellaria paradoxa* without mixture, THM = *Harungana madacasriensis* without mixture, (5SM) = mixture of 50% of *Syzygium guineense var. macrocarpum* + 25% *Vitellaria paradoxa* and 25% *Harungana madacasriensis* (5VP) = mixture of 50% *Vitellaria paradoxa* + 25% *Syzygium guineense var. macrocarpum* + 25% *Harungana madacasriensis*, (5HM) = mixture of 50% *Harungana madacasriensis* + 25% *Syzygium guineense var. macrocarpum* + 25% *Vitellaria paradoxa*, 3E = mixture of 33.33% of all the three litter.

**Nutrient content and release after 24 weeks of incubation**

After 24 weeks of decomposition, nutrient contents varied significantly according to nutrient and species, and the entire nutrient was release in all species and in their mixture. A similar result has been indicated by Ibrahima et al. (2011). About 24 weeks after incubation of the litters in situ, nitrogen was released in all the litters, and the value of nitrogen ranged to 1.55 for 5VP and 0.98 for THM, corresponding to the supply in the soil of 0.19 g and 0.11 g. The pattern of supply of N in the soil after decomposition by different species and their mixture is ranged as follow 3E>5VP>5HM>5SM>TVP>THM>TSM. The result of nutrient release of litter in the soil showed that the mixture of litter release more nitrogen than the single litter. This may be due to the activity of microorganism who operate more their activities in the mixture litter during the decomposition and allow releasing more nitrogen. Other research like those of Chapman et al. (2013) showed that the presence of a certain substance in mixture might increase the ability of microorganisms to decompose many substrates and to make it available on the soil. However, Schimel and Hättenschwiler (2007) indicated also that the higher transfer of nutrient in the soil by mixture could be explained by the modification of the rate decomposition constant.

**Journal of Degraded and Mining Lands Management**
lower in THM (0.008%). The highest supply on the soil was found in _V. paradoxa_ and the lowest in the mixture of 5SM. The pattern of Phosphorus supply in the soil was ranged in the following order: TVP > TSM > THM > 5VP > 3E > 5HM > 5SM, this order indicated single litter was release more phosphorus on the soil than the mixture. The contrary result was demonstrated by Nsowa (2014) that the phosphorus release in the soil after 24 weeks of decomposition depends on the proportion of the mixture and the quality of each species within the mixture. Carbon content after decomposition varied to 31.56% in _S. guineense var. macrocarpum_ to 16.3% in _V. paradoxa_ corresponding respectively to the supply in the soil of 3.38 g and 2.68 g. The same order of pattern supply of N was also obtained for carbon release in the soil after decomposition this is ranged as follow 3E > 5VP > 5HM > 5SM > TVP > THM > TSM. The result of nutrient release of litter in the soil showed that the litter mixture release more carbon than the individual litter. This result is lead to those of Schimel and Hättenschwiler (2007) who have demonstrated that the higher transfer of nutrient in the soil by mixture can be explained by the modification of the rate decomposition constant by the mixture effect. The nutrient supply given by these litter can allow integrating soil fertility management. Other researchers have mentioned that integrated soil fertility management (ISFM) refers to making best use of inherent soil nutrient stocks given by the litter and other organic matter, locally available soil amendments, and mineral fertilizers to increase land productivity while maintaining or enhancing soil fertility (Muyayabantu et al., 2012).

### Table 3. Nutrient content and nutrient release in the soil after decomposition.

<table>
<thead>
<tr>
<th></th>
<th>TSM</th>
<th>TVP</th>
<th>THM</th>
<th>5SM</th>
<th>5VP</th>
<th>5HM</th>
<th>3E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qt(%)</td>
<td>P</td>
<td>0.010</td>
<td>0.011</td>
<td>0.008</td>
<td>0.04</td>
<td>0.05</td>
<td>0.08</td>
</tr>
<tr>
<td>QR(g)</td>
<td></td>
<td>0.013</td>
<td>0.015</td>
<td>0.010</td>
<td>0.004</td>
<td>0.010</td>
<td>0.006</td>
</tr>
<tr>
<td>Qt(%)</td>
<td>N</td>
<td>1.44</td>
<td>1.32</td>
<td>0.98</td>
<td>1.52</td>
<td>1.85</td>
<td>1.31</td>
</tr>
<tr>
<td>QR(g)</td>
<td></td>
<td>0.09</td>
<td>0.128</td>
<td>0.115</td>
<td>0.130</td>
<td>0.199</td>
<td>0.158</td>
</tr>
<tr>
<td>Qt(%)</td>
<td>C</td>
<td>28.85</td>
<td>16.03</td>
<td>17.4</td>
<td>31.56</td>
<td>23.26</td>
<td>22.89</td>
</tr>
<tr>
<td>QR(g)</td>
<td></td>
<td>0.94</td>
<td>2.68</td>
<td>1.71</td>
<td>3.38</td>
<td>3.63</td>
<td>3.63</td>
</tr>
</tbody>
</table>

QR(g) = nutrient release in the soil after decomposition, Qt(%) = nutrient content after decomposition, P = phosphorus, N = nitrogen and C = carbon, TSM = Syzygium guineense var. macrocarpum without mixture, TVP = Vitellaria paradoxa without mixture, THM = Harungana madacasriensis without mixture, (5SM) = mixture of 50% of Syzygium guineense var. macrocarpum + 25% Vitellaria paradoxa and 25% Harungana madacasriensis, (5VP) = mixture of 50% Vitellaria paradoxa + 25% Syzygium guineense var. macrocarpum + 25% Harungana madacasriensis, (5HM) = mixture of 50% Harungana madacasriensis + 25% Syzygium guineense var. macrocarpum + 25% Vitellaria paradoxa. 3E = mixture of 33.33% of all the three litter.

### Conclusion

In the studies species, the mixture of litter affected decomposition process weakly but significantly according to species and the proportion of mixture of each species within the mixture. The initial quality also influenced the decomposition of single species and mixture decomposition. Nutrient (nitrogen and carbon) release in the soil after 24 weeks of decomposition were higher in the mixture than in the single species, but for phosphorus release, we found that individual species release more phosphorus than their mixture. This result can allow integrating of these species in agroforestry systems for improvement of land or soil degradation in the Adamawa region of Cameroon.

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Effect of litter mixture on litter decomposition and nutrient release of three agroforestry species


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