



**Recovering from forest-to-pasture conversion: leaf decomposition in Central Amazonia, Brazil**

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Review

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4 **Recovering from forest-to-pasture conversion: leaf decomposition in Central**  
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6 **Amazonia, Brazil**

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8 **Running title:** Land use and leaf decomposition in Central Amazonia  
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31 **Abstract:** Land-use change in tropical forests can affect the micro-environment for  
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33 decomposition under modified canopies. In turn, decomposition may have  
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35 consequences for soil fertility and ecosystem sustainability. The effects of the  
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37 conversion from primary forest to pastures on leaf-litter decomposition and its recovery  
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39 in secondary forests 20 y after pasture abandonment were evaluated using litterbags and  
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41 a general mixed model approach. Litterbags containing leaf-litter of two contrasting  
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43 qualities were placed in those three ecosystems and the mass remaining after 90 d was  
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45 quantified. The mass remaining was 50% lower in high- than in low-quality leaves. The  
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47 effects of the decomposition environment depended on the substrate quality. Although  
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49 differences among ecosystems were not significant for low-quality leaves, high-quality  
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51 leaves decomposed more slowly in pastures than in forests (mean dry mass remaining  
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53 was 38% in pastures, 14% in secondary and 12% in primary forest). The decomposition  
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of common substrates did not differ among forests. Results show that the conversion of primary forest to pasture may produce conditions for slower decomposition; however, these conditions appear to be restored to a great extent in 20-y-old secondary forests.

**Keywords:** decomposition-environment, land-use, leaf-litter, mass-loss, rain forest, second-growth

Tropical forests play a substantial role in the global carbon cycle, are projected to experience significant changes in climate (Wieder *et al.* 2009) and are currently experiencing dramatic changes in land-use. For instance, Fearnside & Barbosa (2004) reported a mean annual deforestation rate of 18,000 km<sup>2</sup> y<sup>-1</sup> until 2002 in the Brazilian Amazon. Thus, it is fundamental to understand the consequences of those changes on organic matter decomposition and consequently, in carbon and nutrient cycling, in tropical forests. Decomposition is primarily determined by climate (and microclimate), substrate quality and decomposer activity (Lavelle *et al.* 1993, Wieder *et al.* 2009). In systems where high temperature and rainfall produce near-optimal abiotic conditions for decomposition (Lavelle *et al.* 1993), micro-environmental changes associated with land-use can exert a disproportionate degree of control over litter decomposition (Barlow *et al.* 2007). In these systems, microclimatic conditions are primarily determined by vegetation structure and reductions of leaf-litter quality related to land-use have been reported (Barlow *et al.* 2007, Vasconcelos & Laurance 2005). Changes in microclimate and litter quality may result on a modified micro-environment which, in turn, could affect soil fauna activity and the decomposition process itself.

In Amazonia both increase and decrease in decomposition rates have been reported when comparing pastures with forests and secondary forests with primary ones

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4 (Barlow *et al.* 2007, Koutika *et al.* 1997, 2000; Martius *et al.* 2004, Vasconcelos &  
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6 Laurance 2005). To our knowledge, there are no simultaneous comparisons of  
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8 decomposition between those three ecosystems; despite they are some of the most  
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10 extended land-uses in Amazonia. In this context, our aim was to evaluate if land-use  
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12 change, specifically conversion from primary forest to pastures and subsequent pasture  
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14 abandonment and secondary-forest growth, can produce changes in the micro-  
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16 environment (combined effects of microclimate, nutrient availability/litter quality and  
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18 micro-biota) for decomposition. Through the use of common substrates (the same  
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20 material incubated in all plots), we were able to evaluate micro-environmental  
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22 conditions for decomposers independently of substrate quality (Castanho *et al.* 2012,  
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24 Jenny *et al.* 1949, Orwin *et al.* 2006).  
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30 Our experiment was performed in Central Amazonia (2°24'S; 59°52'W). The  
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32 mean annual temperature is 26°C, and the annual rainfall ranges from 1900 to 3500 mm.  
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34 The dominant vegetation is a primary non-flooded rain forest (canopy 30–35 m high).  
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36 Pasture areas (vegetation 0.4-1 m tall) were clear-cut and burnt at the beginning of the  
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38 1980s; they are partially burned at 3-5-y intervals. Study plots were not burned at least 2  
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40 y before the experiment. Some cattle ranches were abandoned after 4 y of use and 20-y-  
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42 old secondary forest patches (canopy 20-25 m high) were present at the time of our  
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44 study. To evaluate the micro-environment for decomposition, we used 5 × 5-cm  
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46 litterbags of 0.3-mm<sup>2</sup> nylon mesh filled with 1 ± 0.1 g of air-dried senescent leaves of  
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48 two common non-native substrates: a rapidly decomposing species, *Acalypha communis*  
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50 Müll. Arg., Euphorbiaceae, and a slowly decomposing species, *Jarava ichu* Ruiz &  
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52 Pav., Poaceae (Vaieretti *et al.* 2005). For each ecosystem (pasture, secondary and  
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54 primary forest) we placed four plots at least 1 km apart from each other, guaranteeing  
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4 independence for decomposition. On each plot, we placed 40 litterbags, 20 with each  
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6 substrate. We set the experiment up in the field in February 2011 (rainy season) and we  
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8 collected ten litterbags (five from each substrate) per plot and period after 15, 30, 60  
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10 and 90 d. Then, we washed the remaining material in each litterbag, we dried it at 70°C  
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12 to a constant weight and we weighed it. We selected 90 d as an adequate period to  
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14 detect responses to land-use because previous works have, indeed, detected  
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16 decomposition differences related to forest structure over shorter periods near our study  
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18 area (Didham 1998).  
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23 To test the effects of land-use (pasture, secondary and primary forests), substrate  
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25 (high- and low-quality), and incubation period (15, 30, 60 and 90 d) on the  
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27 decomposition (% remaining mass) of two common substrates we used a mixed model  
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29 analysis of variance. Our data showed both linear and quadratic decays, so we created a  
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31 quadratic term (time<sup>2</sup>) to be used as a covariate with time. We considered land-use,  
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33 substrate and incubation period as fixed factors and plot as random factor. We used the  
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35 mean % remaining mass per plot as a response variable. To control the dependence  
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37 among repeated measures, we considered compound symmetry for the co-variance  
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39 matrix (Pinheiros & Bates 2000). We tested the significance of the fixed factors and all  
40  
41 interaction terms. Since the null hypothesis was rejected, we used Fisher's LSD (0.05  
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43 significance level) to identified inter-group differences. We performed all analysis in  
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45 InfoStat version 2011 (InfoStat Group, UNC, Córdoba, Argentina).  
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50 In accordance with their differences in quality (Vaieretti *et al.* 2005), leaf-litter  
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52 of *Acalypha communis* decomposed more rapidly (F = 2170; P < 0.0001) than those of  
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54 *Jarava ichu* in all three ecosystems. During the 90 d of the experiment, the mean dry  
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56 mass remaining was, on average, 50% lower for *Acalypha communis* than for *Jarava*  
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4 *ichu* leaf-litter (Figure 1). The effects of land-use on decomposition depended on the  
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6 substrate ( $F = 60.7$ ;  $P < 0.0001$ ). There were no significant differences in decomposition  
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8 between ecosystems for low-quality leaves (*Jarava ichu*) ( $P \geq 0.05$ ), while high-quality  
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10 leaves (*Acalypha communis*) decomposed slower in pastures than in both forest types  
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12 (Figure 1).  
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16 The slower decomposition of high-quality common substrates in pastures would  
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18 be related to differences in microclimatic conditions between pastures and forests.  
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20 According to the measurements of the nearest microclimatic stations to our sites (which  
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22 are located in the same sites of our experiment in pasture and secondary forests, but 30  
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24 km distant in primary forest), the air temperature was consistently higher in pastures  
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26 than forests during our experiment (Figure 2a). Decreased decomposers activity as a  
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28 result of harsher microclimatic conditions (higher soil temperature and lower soil water  
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30 content) has been found in pastures compared with control forests in Eastern Amazonia  
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32 (Davidson *et al.* 2000). Microclimatic conditions would be similar in secondary and  
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34 primary forests. During our experiment air temperature was only 0.22°C higher in  
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36 secondary forests (Figure 2a) and this did not translate into higher soil temperature, nor  
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38 lower water content. Moreover, this was higher in secondary than primary forests  
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40 (Figure 2b, c). Since primary forest data were recorded about 30 km distant from our  
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42 study sites, these comparisons may be interpreted with caution. However, previous  
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44 works have also reported slight differences in microclimatic conditions that did not  
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46 affect the micro-environment for decomposition in Amazonian secondary and primary  
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48 forest (Barlow *et al.* 2007, Mesquita *et al.* 1998, Vasconcelos & Laurance 2005). This  
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50 would explain the similar decomposition of *Acalypha communis* leaves in 20-y-old  
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52 secondary forests and primary ones (Figure 1).  
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4 We have found leaf characteristics that suggest enhanced decomposability in  
5 abundant species from primary forest compared to species from pastures and secondary  
6 forest (Table 1). This could lead to an enhanced activity of decomposers in primary  
7 forests and consequently, to higher decomposition of common substrates. Higher  
8 decomposability of leaf-litter in primary than secondary-forest species has been reported  
9 previously (Martius *et al.* 2004, Vasconcelos & Laurance 2005). This probably occurs  
10 also in pastures, as it is suggested by previous studies, which have reported nutrient  
11 depletions related to litter quality in pastures compared to forests in Amazonia (Luizão  
12 *et al.* 1999, Markewith *et al.* 2004). Modified microclimatic conditions and reductions  
13 of litter quality seem to cause a harsher micro-environment for decomposition in  
14 Amazonian pastures. While decomposition micro-environment appeared to be similar in  
15 primary and secondary forests, most likely their closed canopies result in a favourable  
16 microclimate for decomposition.  
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33 The lack of differences in decomposition of low-quality *Jarava ichu* leaves  
34 between pastures and forests could be related to the 90-d period of incubation, which  
35 may have been too short to detect differences in this substrate. However, in 90 d *Jarava*  
36 *ichu* leaves lost about 30% of the initial dry mass (Figure 1), which has been shown to  
37 be enough to detect micro-environmental differences associated to ecosystem structure  
38 even in shorter periods (Didham 1998 in tropical forests, Vaieretti *et al.* 2010 in  
39 temperate grasslands). Another possible explanation for the differential responses  
40 between our substrates could be the litter quality itself. The main factor in determining  
41 decomposition is that one which imposes stronger constraints on biological activities  
42 (Castanho *et al.* 2012); therefore, *Jarava ichu* leaves may have been mostly constrained  
43 by their low quality (high C:N ratio, lignin content and LTS; low SLA and N and P  
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4 content; Vaieretti *et al.* 2005). In contrast, the high-quality *Acalypha communis* leaves,  
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6 which impose fewer chemical constraints on decomposers, were affected by the  
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8 modified micro-environment for decomposition under land-use change.  
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11 In conclusion, our results have shown that in Central Amazonia (1) the  
12 decomposition of high-quality leaf-litter is slower in pastures than in secondary and  
13 primary forests, and (2) the micro-environment for decomposition appears to be restored  
14 in 20-y-old secondary forests. However, previous studies have shown that not all  
15 nutrient cycling functions are restored in the long term (Feldpausch *et al.* 2004,  
16 Markewitz *et al.* 2004, Martius *et al.* 2004). Therefore, decomposition experiments with  
17 longer incubation periods should be done to clarify if the effects of microclimatic  
18 patterns are consistent through one and several years, how are these patterns related to  
19 litter production and which are the potential effects of litter mixtures on decomposition  
20 under land-use change.  
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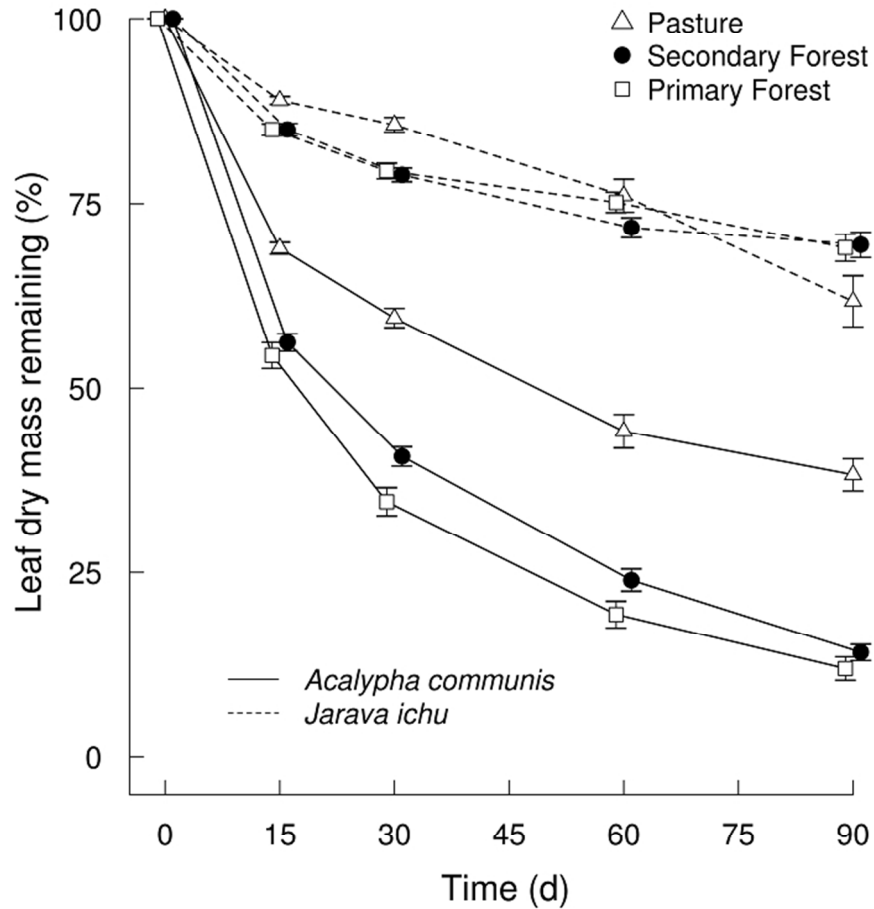
**Table 1.** Mean ( $\pm$  SD) leaf trait values related to leaf-litter decomposability in pastures, 20-y-old secondary forests and primary ones in Central Amazonia. Leaf nitrogen concentration: LNC, specific leaf area: SLA and leaf tensile strength: LTS. The five most abundant species of each ecosystem were considered. For N and C:N in pastures, only the species which sum to more than 80% of community biomass was included.

Stands	LNC (mg g <sup>-1</sup> )	C:N ratio	SLA (m <sup>2</sup> kg <sup>-1</sup> )	LTS (N mm <sup>-1</sup> )
Pasture	11.5 $\pm$ 0.0	37 $\pm$ 0	8.89 $\pm$ 1.16	2.95 $\pm$ 1.16
Secondary forest	15.6 $\pm$ 2.2	32 $\pm$ 4	9.58 $\pm$ 2.10	1.05 $\pm$ 0.20
Primary forest	24.7 $\pm$ 6.1	21 $\pm$ 4	11.8 $\pm$ 1.11	0.75 $\pm$ 0.11

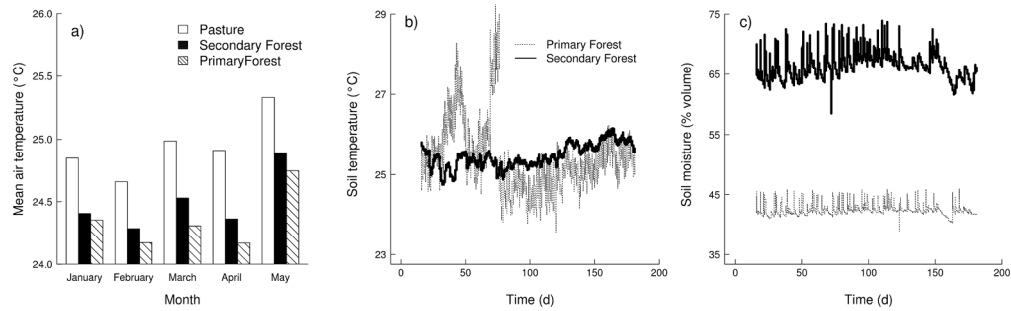
## LEGENDS TO FIGURES

**Figure 1.** Dry mass remaining in litterbags filled with leaves of *Jarava ichu* (*Jar*) (low-quality) and *Acalypha communis* (*Aca*) (high-quality), at four retrieval times during 90 d of placement in areas of pasture, 20-y-old-secondary forest and primary forest in Central Amazonia. Points are means of 20 litterbags (five litterbags on four plots) retrieved per time interval; bars represent standard error.

**Figure 2.** Microclimatic data in pasture, secondary and primary forests from the nearest microclimatic stations to the decomposition experiment: mean monthly air temperature (a), soil temperature (b) and soil moisture (c); soil variables were measured at 10-cm soil depth at 10-m intervals during the first 190 d of 2011. Pasture and secondary forest stations are located in the same sites of the decomposition experiment, but the primary forest one is about 30 km distant. Data from the LBA experiment (<http://daac.ornl.gov/LBA/lba.shtml>).



Dry mass remaining in litterbags filled with leaves of *Jarava ichu* (Jar) (low-quality) and *Acalypha communis* (Aca) (high-quality), at four retrieval times during 90 d of placement in areas of pasture, 20-y-old-secondary forest and primary forest in Central Amazonia. Points are means of 20 litterbags (five litterbags on four plots) retrieved per time interval; bars represent standard error.  
68x68mm (300 x 300 DPI)



Microclimatic data in pasture, secondary and primary forests from the nearest microclimatic stations to the decomposition experiment: mean monthly air temperature (a), soil temperature (b) and soil moisture (c); soil variables were measured at 10-cm soil depth at 10-m intervals during the first 190 d of 2011. Pasture and secondary forest stations are located in the same sites of the decomposition experiment, but the primary forest one is about 30 km distant. Data from the LBA experiment (<http://daac.ornl.gov/LBA/lba.shtml>).  
182x60mm (300 x 300 DPI)