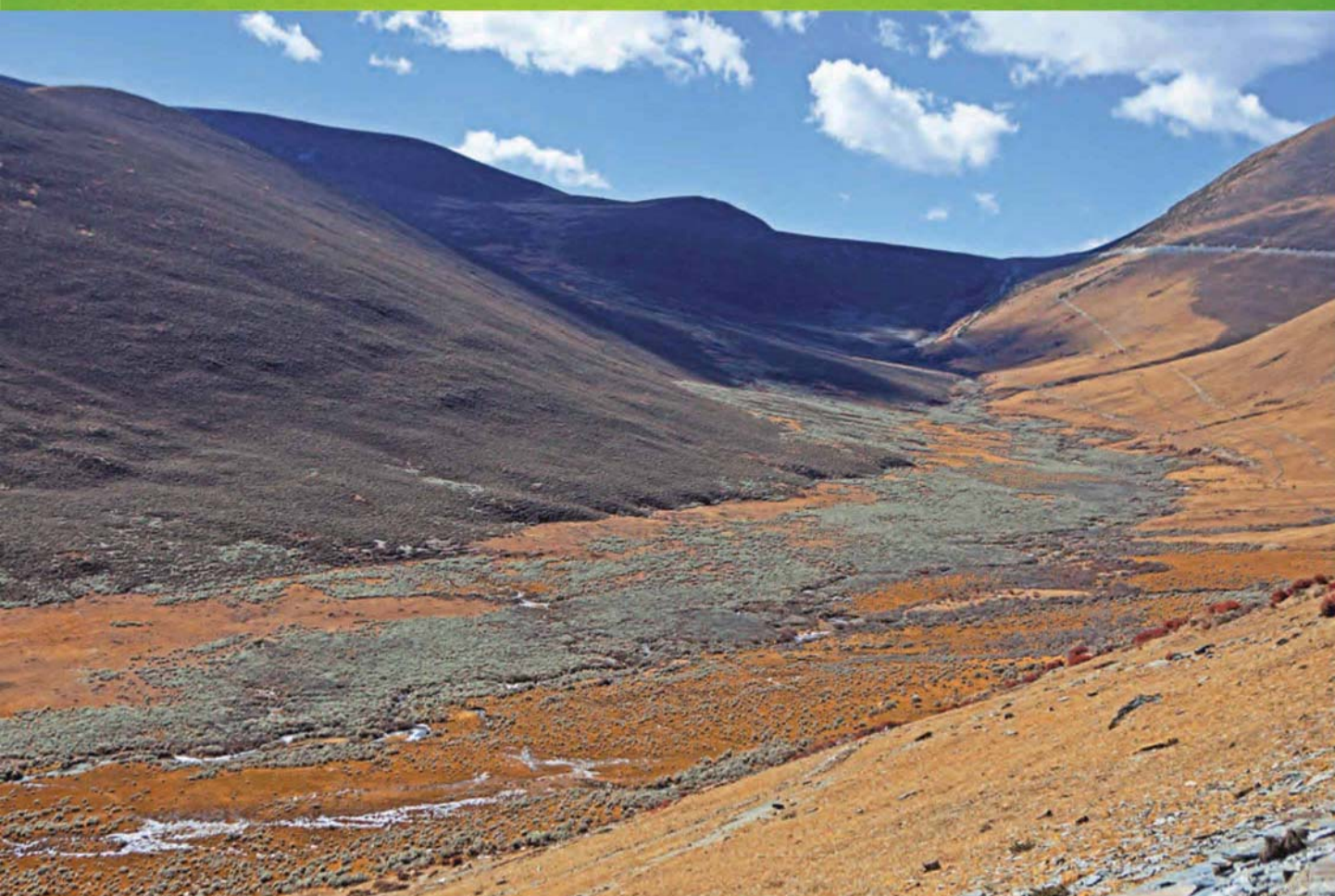


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# 生态学报

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**封面图说:** 川西高山地带土壤及植被——青藏高原东缘川西的高山地带坡面上为草地, 沟谷地带由于低平且水分较充足, 生长有很多灌丛。川西地区大约在海拔 4000m 左右为林线, 以下则分布有亚高山森林。亚高山森林是以冷、云杉属为建群种或优势种的暗针叶林为主体的森林植被。作为高海拔低温生态系统, 高山-亚高山地带土壤碳被认为是我国重要的土壤碳库。有研究表明, 易氧化有机碳含量与海拔高度呈显著正相关, 显示高海拔有利于土壤碳的固存。因而, 这里的表层土壤总有机碳含量随着海拔的升高而增加。

**彩图及图说提供:** 陈建伟教授 北京林业大学 E-mail: cites.chenjw@163.com

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Wang W J, Yang W Q, Tan B, Liu R L, Wu F Z. The dynamics of soil fauna community during litter decomposition at different phenological stages in the subtropical evergreen broad-leaved forests in Sichuan basin. Acta Ecologica Sinica, 2013, 33(18): 5737-5750.

## 四川盆地亚热带常绿阔叶林不同物候期凋落物分解 与土壤动物群落结构的关系

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**摘要:** 为了解植物生长不同物候时期凋落物分解过程中土壤动物群落结构动态及其与凋落物分解的关系, 以四川盆地亚热带常绿阔叶林典型人工林树种马尾松和柳杉, 次生林树种香樟和麻栎凋落物为研究对象, 采用凋落物分解袋试验研究, 凋落物分解过程中土壤动物的群落特征。4 种凋落物分解袋共获得土壤动物 8047 只, 其中, 柳杉 (2341 只) > 香樟 (2105 只) > 马尾松 (2046 只) > 麻栎 (1555 只)。其中, 秋末落叶期、萌动期和展叶期, 马尾松凋落物袋中主要以捕食性土壤动物为优势类群, 而后以菌食性土壤动物为主; 香樟凋落物袋中除秋末落叶期和叶衰期以菌食性土壤动物为主要优势类群外, 其他各时期均以捕食性土壤动物为主要优势类群; 柳杉凋落物分解各时期均以菌食性土壤动物为主要优势类群; 麻栎凋落物分解在前 3 个时期以菌食性为主, 而后以植食性土壤动物为主要优势类群。相关分析表明, 在秋末落叶期和萌动期土壤动物的个体密度主要和氮、磷含量及其格局密切相关, 叶衰期主要和难分解组分木质素显著相关。除在秋末落叶期土壤动物对凋落物分解的贡献率与土壤动物的个体密度显著相关外, 其余主要物候关键时期均与土壤动物的类群密度及其食性显著相关。

**关键词:** 土壤动物群落结构; 功能类群; 常绿阔叶林; 物候时期; 凋落物分解

## The dynamics of soil fauna community during litter decomposition at different phenological stages in the subtropical evergreen broad-leaved forests in Sichuan basin

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**Abstract:** Litter decomposition is one of the essential processes in terrestrial forest ecosystems, which could contribute to material turnover and plant productivity. Although primary decomposition of litter is ultimately the result of the catabolic activities of soil microbes, soil faunas have been well known that they can accelerate the rates of litter decomposition and nutrient cycling in forest ecosystems. Soil faunas have body sizes large enough to disrupt physical structure of litter directly by fragmenting and comminuting of litter, and promote litter decomposition indirectly by altering litter surface and regulating microbial activities. However, both litter quality and microclimate play important roles of soil fauna communities during litter decomposition. The annual critical phenological stages in plant growth do not only represent the change of climate environment, but also indicate the nutrients needs in plant growing. Therefore, in order to understand the relationships between litter decomposition and plant growth, the structure dynamics of soil fauna community were studied at plant phenological stages, including leave falling stage, leave budding stage, leaf expanding stage, leave maturing stage, leave graving period and leave senescing stage according to local plant phenology from November 2011 to October 2012. Four kinds of foliar litter were sampled as *Pinus massoniana* and *Cryptomeria fortune* from their plantations, and *Cinnamomum*

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*camphora* and *Quercus acutissima* from their secondary ecosystems in subtropical regions of Sichuan basin in southwestern China, respectively. Litterbags with different mesh sizes (0.04 mm and 3 mm) were used to exclude soil fauna during litter decomposition. We captured a total of 8047 soil fauna individuals in all litterbags, which belonged to 22 orders and 73 families. Soil fauna individuals showed: *C. fortunei* (2341) > *C. camphora* (2105) > *P. massoniana* (2046) > *Q. acutissima* (1555). Soil fauna community structure was significantly varied with different litter substrate at different key stages as litter decomposition proceeding, indicating litter quality could have close relationships to soil fauna during litter decomposition. The leave falling stage, leave budding stage and leaf expanding stage, predatory soil fauna dominated soil fauna community during *P. massoniana* litter decomposition, and fungivore dominated the other stages. Fungivore also dominated soil fauna community at leave falling stage and leave senescing stage during *C. camphora* decomposition, but predatory dominated the other stages. In contrast, soil fauna community during *C. fortunei* litter decomposition was dominated by fungivore at all investigated stages. Although fungivore dominated soil fauna community at early three stages during *Q. acutissima* litter decomposition, phytophagy dominated the later stages. Correlation analysis showed that the individual density of soil fauna was significantly related to Nitrogen and Phosphorus content in leave falling stage and leave budding stage, but which closely related to lignin content at leave senescing stage. Moreover, the contribution of soil fauna to litter decomposition showed a significantly relationships with the individual density of soil fauna at leave falling stage, which significantly related to the group density and the soil faunal functional group at other critical stages during litter decomposition.

**Key Words:** soil fauna community structure; functional group; evergreen broad-leaved forest; phenological period; litter decomposition

土壤动物是森林生态系统中不可分割的重要组成部分<sup>[1-2]</sup>,可通过破碎、采食、混合和湿润等直接作用,以及通过改变凋落物质量和影响土壤微生物群落结构与活性等间接作用,贡献于凋落物分解的生态过程<sup>[3-5]</sup>。然而,温湿度等环境因子<sup>[6-7]</sup>以及凋落物分解过程中质量变化<sup>[8-9]</sup>可能显著影响土壤动物的群落结构,从而影响凋落物分解。大量的凋落物一般形成于秋末冬初<sup>[10]</sup>,这些新鲜凋落物可为土壤动物提供丰富的食物来源<sup>[3]</sup>,但冬季相对较低的温度可能抑制土壤动物的活动<sup>[11]</sup>;春季温度的增加,可能促进土壤动物的生长繁育<sup>[7]</sup>,但前期凋落物易分解组分大量流失以及植物生长对养分的竞争<sup>[12]</sup>,导致凋落物分解过程中土壤动物群落动态及其与凋落物分解关系的不确定性。凋落物分解是自然生态系统中植物生长的重要养分来源,不同物候时期植物养分需求存在差异,因此凋落物分解对不同时期植物生长具有不同作用,但由于已有研究很少关注到不同物候时期凋落物分解过程,更缺乏对凋落物分解不同时期土壤动物的贡献等关键过程的关注,极大地限制了人们对植物生长与凋落物分解相互关系的理解。

四川盆地亚热带常绿阔叶林位于人口稠密区,为当地人提供了其赖以生存的物质基础,但近几十年来该区人类活动频繁,自然森林植被受到严重破坏,正在被大面积的人工林和次生林逐渐取代。由于受到人类活动干扰的森林生态系统更为脆弱,土壤动物受人类活动的影响更为强烈,使得土壤动物作用于凋落物分解释放养分供给于植物生长的生态过程尤为重要,且强烈的人类活动干扰必然显著改变植物的生长环境及其对土壤动物群落结构的作用<sup>[13-14]</sup>,进而影响凋落物分解过程及其与植物生长过程的关系。因此,以典型人工林树种马尾松和柳杉,次生林树种香樟和麻栎凋落物为研究对象,根据植物物候动态,研究凋落物分解不同关键时期土壤动物的群落特征,以期深入认识四川盆地常绿阔叶林凋落物分解过程,为合理调控凋落物分解等物质循环过程,以更好地作用于植物生长及区域亚热带常绿阔叶林可持续管理提供一定的理论依据。

## 1 研究区域和研究方法

### 1.1 研究区自然概况

选取四川盆地常绿阔叶林4种典型森林群落,马尾松(*Pinus massoniana*)人工林和香樟(*Cinnamomum camphora*)次生林位于四川省高县来复镇(104°32'—104°34' E, 28°34'—28°36' N, 海拔412—567 m),地处长江上游和四川盆地南缘,属中亚热带湿润季风气候,年平均气温18.1℃,最高气温(7月)36.8℃,最低气温(1月)7.8℃,年均降雨量1021 mm。林下灌木为梨叶悬钩子(*Rubus pirifolius*)、枹栎(*Quercus serrate*)、油樟(*C. longepaniculatum*)、野桐(*Mallotus japonicas*)、铁仔(*Myrsine africana*)、茶茱萸(*Viburnum setigerum*)、展毛野牡丹(*Melastoma normale*)等;草本为蕨(*Miscanthus sinensis*)、金星蕨(*Parathelypteris glanduligera*)、芒(*Miscanthus sinensis*)、芒萁(*Dicranopteris dichotoma*)、皱叶狗尾草(*Setaria plicata*)、淡竹叶(*Lophatherum gracile*)等。土壤为发育在砂岩上的山地黄壤,土层厚度40—60 cm, pH值4.3±0.4,总有机碳(16.3±1.5) g/kg,全氮(0.7±0.1) g/kg,全磷(2.0±0.3) g/kg。

柳杉(*Cryptomeria fortunei*)人工林和麻栎(*Quercus acutissima*)次生林位于成都平原与川西北山地接合部的都江堰灵岩山(103°34′—103°36′ E, 31°01′—31°01′ N, 海拔 896—1320 m), 亚热带气候类型, 年平均气温 15.2 ℃, 最高气温(7 月) 31.6 ℃, 最低气温(1 月) -1.4 ℃, 年降水量 1243 mm。林下灌木主要有光叶海桐(*Pittosporum glabratum*)、胡枝子(*Lespedeza bicolor*)、针刺悬钩子(*Rubus pungens* Camb)、野花椒(*Zanthoxylum simulans*)和十大功劳(*Mahonia fortunei*)。草本主要为扁竹根(*Iris japonica*)、欧洲蕨(*Pteridium aquilinum*)、麦冬(*Ophiopogon japonicus*)、莎草(*Cyperus rotundus*)和芒萁(*Dracopis dichotome*)等。土壤为发育在沙岩上的黄壤, 土层厚度一般为 70—100 cm, pH 值 4.9±0.3, 有机碳(19.8±1.2) g/kg, 全氮(1.4±0.2) g/kg, 全磷(0.9±0.1) g/kg。

## 1.2 样地设置和样品处理.

基于背景调查, 在四个森林群落内各设置一个代表性样地, 于 2011 年 10 月凋落物高峰期在样地内搜集其代表性树种马尾松、香樟、柳杉和麻栎凋落叶, 带回实验室在自然条件下风干。将风干后的凋落叶分别装入表层孔径为 0.04 mm (基本排除土壤动物)<sup>[15]</sup>和 3 mm (基本允许所有土壤动物进入)<sup>[16]</sup>, 贴地面层均为 0.04 mm 孔径, 大小为 20 cm×20 cm 的封口尼龙网分解袋中, 每袋装入样品量为 10 g。分别另取不同树种凋落物各约 50 g 用于同步测定凋落物初始干重及养分元素含量。

表 1 不同林分凋落物初始质量

Table 1 Initial quality of litters in different investigated forests

| 林型<br>Forest type        | 马尾松<br><i>P. massoniana</i> | 香樟<br><i>C. camphora</i> | 柳杉<br><i>C. fortunei</i> | 麻栎<br><i>Q. acutissima</i> |
|--------------------------|-----------------------------|--------------------------|--------------------------|----------------------------|
| 碳 Carbon /(g/kg)         | 496.99a±14.64               | 461.22b±17.70            | 480.73ab±20.34           | 490.49a±24.13              |
| 氮 Nitrogen /(g/kg)       | 12.18a±0.37                 | 11.03b±0.56              | 10.66b±0.48              | 13.23c±0.70                |
| 磷 Phosphorus /(g/kg)     | 0.87a±0.06                  | 0.66b±0.05               | 0.85a±0.07               | 0.92a±0.05                 |
| 木质素 Lignin /%            | 24.80a±0.72                 | 27.02b±0.55              | 19.58c±0.60              | 24.05d±0.09                |
| 纤维素 Cellulose /%         | 16.78a±0.57                 | 16.92a±0.49              | 19.32b±0.31              | 14.90c±0.61                |
| 碳/氮 Carbon/Nitrogen      | 40.80a±0.46                 | 41.86a±1.19              | 45.10b±0.39              | 37.07c±0.66                |
| 碳/磷 Carbon/Phosphorus    | 576.09a±29.12               | 703.68b±28.99            | 567.52a±22.06            | 536.26c±9.64               |
| 氮/磷 Nitrogen/Phosphorus  | 14.12a±0.66                 | 16.81b±0.61              | 12.58c±0.44              | 14.47a±0.33                |
| 木质素/氮 Lignin/Nitrogen    | 20.37a±0.27                 | 24.54b±0.97              | 18.38c±0.37              | 18.21c±0.92                |
| 木质素/纤维素 Lignin/Cellulose | 1.48a±0.01                  | 1.60b±0.03               | 1.01c±0.01               | 1.62b±0.05                 |

同行不同字母表示差异显著 ( $P<0.05$ )

2011 年 11 月 13 日凋落叶秋季高峰期, 分别在各自物种林地地表放置各自凋落物袋, 每个样地内按树种放置 0.04 mm 和 3 mm 孔径的凋落物分解袋各 30 袋, 即总袋数为 5 重复×4 林型×6 次取样×2 孔径=240 个凋落物袋。另分别在各区域内设钮扣式温度传感器连续监测空气温度, 1 h 记录 1 次数据。为探讨凋落物与叶片生长过程的相互关系, 根据前期对该区叶片物候的观察和已有研究资料<sup>[17]</sup>, 于 2011 年 12 月 27 日秋末落叶期, 2012 年 3 月 7 日萌动期, 2012 年 4 月 27 日展叶期, 2012 年 6 月 16 日叶片成熟期, 2012 年 8 月 25 日盛叶期, 2012 年 10 月 30 日叶衰期采集不同树种两种孔径的分解袋各 5 袋, 所采的分解袋分为有土壤动物和移除土壤动物两种, 将有土壤动物样品装入透气的收集袋低温保存, 迅速带回实验室, 用 Tullgren 漏斗(4 mm)分离收集的中小型土壤节肢动物, 分离周期为 48 h。采用体视解剖镜和生物显微镜镜检计数和分类, 参照《中国土壤动物检索图鉴》<sup>[18]</sup>、《昆虫分类检索》<sup>[19]</sup>等进行鉴定(科水平)。测定分离土壤动物后的凋落物和移除土壤动物的凋落物干重及养分元素含量, 凋落物全碳采用重铬酸钾外加热法测定; 全氮采用半微量凯氏定氮法测定; 全磷采用钼锑钒比色法测定; 木质素和纤维素采用改进的 Van Soest 中性洗涤纤维(NDF)及酸性洗涤纤维(ADF)方法测定<sup>[20]</sup>。2011 年 11 月初到 2012 年 10 月末样地空气温度变化特征如图 1 所示。

## 1.3 计算与统计分析

(1) Shannon-Wiener 多样性指数<sup>[21]</sup>  $H = -\sum P_i \ln P_i$

式中,  $P_i = n_i/N$ ,  $n_i$  为每个类群的个体数,  $N$  为总的个体数。

(2) Pielou 均匀性指数<sup>[22]</sup>  $j = H/\ln s$

式中,  $H$  为 Shannon-Wiener 多样性指数,  $s$  为类群数。

(3) Simpson 优势度指数<sup>[23]</sup>  $C = \sum (n_i/N)^2$

式中,  $n_i$  为每个类群的个体数,  $N$  为总的个体数。

(4) Margalef 丰富度<sup>[24-25]</sup>  $E = (S-1)/\ln N$

式中,  $S$  为类群数,  $N$  为全部类群的个体总数。

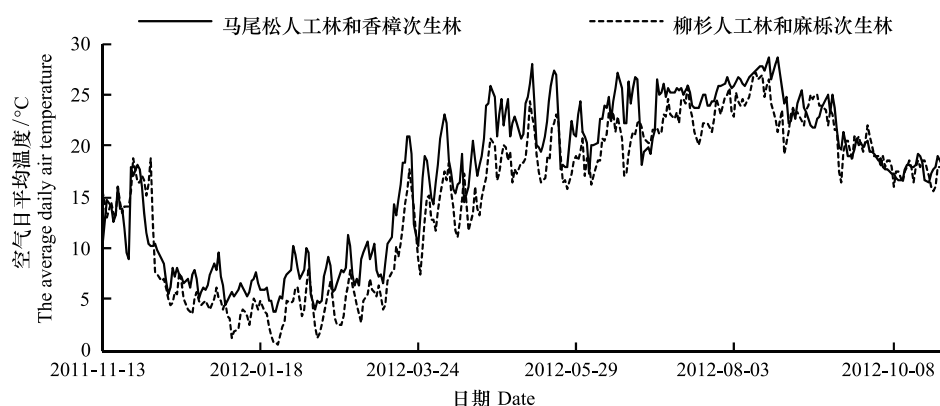


图1 采样期间样地空气温度动态变化

Fig.1 Dynamic changes of air temperature in the sampling sites during the sampling date

(5) Jaccard 相似性指数<sup>[26-27]</sup>

$$q = c / (a + b - c)$$

式中,  $a$ 、 $b$  分别为群落 A 和群落 B 的类群数,  $c$  为两群落的共有类群数

当  $0 < q < 0.25$  时, 极不相似; 当  $0.25 \leq q < 0.50$  时, 中等不相似; 当  $0.50 \leq q < 0.75$  时, 中等相似; 当  $0.75 \leq q < 1.00$  时, 极相似。

(6) 土壤动物对每阶段凋落物失重的贡献率 ( $P_{\text{fau}}$ )<sup>[28-29]</sup>:

$$L_t = (M_{t-1} - M_t) / M_0 \times 100\%$$

$$C_{\text{fau}} = L_{\text{bt}} - L_{\text{st}}$$

$$P_{\text{fau}} = C_{\text{fau}} / L_{\text{bt}} \times 100\%$$

式中,  $L_t$  为各孔径内凋落物的绝对失重率,  $M_0$  为分解初始干质量,  $M_{t-1}$  为前一次凋落物残留量,  $M_t$  为当次凋落物残留量,  $C_{\text{fau}}$  土壤动物作用的凋落物失重率,  $L_{\text{bt}}$  为当次大孔径凋落物袋内凋落物的绝对失重率,  $L_{\text{st}}$  为当次小孔径凋落物袋内凋落物的绝对失重率。

根据原始捕获量占捕获总量的百分比来划分各类群数量等级, 即个体数量大于捕获总量的 10.0% 以上者为优势类群, 占 1.0%—10.0% 者为常见类群, 不足 1.0% 者为稀有类群<sup>[11]</sup>。

数据统计与分析采用 SPSS 20.0 和 Excel 完成, 相关性分析 (Pearson) 和最小显著差异法 (LSD) 分析土壤动物各指标之间的差异性、土壤动物对凋落物分解的贡献率与凋落物质量之间的相关关系。

## 2 结果和分析

### 2.1 土壤动物的群落组成和功能类群

4 种凋落物分解袋共获得土壤动物 8047 只, 分别隶属于 22 目 73 科 (附表 1)。其中, 柳杉 (2341 只) > 香樟 (2105 只) > 马尾松 (2046 只) > 麻栎 (1555 只)。植物生长的秋末落叶期、萌动期和展叶期, 马尾松凋落物袋中主要以捕食性土壤动物大翼甲螨科、懒甲螨科为主要优势类群, 而在叶片成熟期、盛叶期和叶衰期以菌食性土壤动物棘跳科和等节跳科为主要优势类群; 香樟凋落物分解过程中除秋末落叶期和叶衰期以菌食性等节跳科为主要优势类群, 盛叶期未出现优势类群外, 其他各时期均以捕食性懒甲螨科为主要优势类群; 柳杉凋落物分解过程中各时期均以菌食性土壤动物等节跳科为主要优势类群; 麻栎凋落物分解过程中在前 3 个时期以菌食性的等节跳科和棘跳科为主要优势类群, 而后叶片成熟期和叶衰期以植食性的蚁科为主, 盛叶期又以捕食性土革螨科为主要优势类群 (附表 2, 图 2)。

### 2.2 土壤动物密度和群落特征的动态变化

从图 3 可以看出, 马尾松和香樟凋落物分解过程中的土壤动物个体密度和类群密度表现出一致的变化趋势, 均在展叶期降到最小值, 其他各时期差异相对较小。柳杉和麻栎凋落物分解过程中土壤动物的个体密度也具有相似的变化趋势, 但柳杉凋落物中的土壤动物个体密度在展叶期显著高于麻栎, 两种凋落物分解过程中土壤动物的类群密度变化趋势较为接近, 且各物候时期差异不明显。

从图 4 可以看出, 多样性指数、均匀度指数、优势度指数在不同物候时期的差异并不明显, 丰富度指数在马尾松、香樟和柳杉凋落物分解过程中展叶期均出现最低值。统计分析结果表明, 各多样性指数在不同物候时期差异均不显著, 不同凋落物间多样性指数、均匀度指数、优势度指数差异也不显著, 但丰富度指数在不同凋落物间表现出显著差异 ( $P < 0.05$ )。

相似性分析表明 (表 2), 除马尾松凋落物分解过程中的土壤动物在叶片成熟期和秋末落叶期、萌动期、展叶期为极相似, 而在萌动期和展叶期却极不相似外, 土壤动物在其它物种凋落物分解过程中不同关键时期相似性差异均为中等相似或中等不相似。

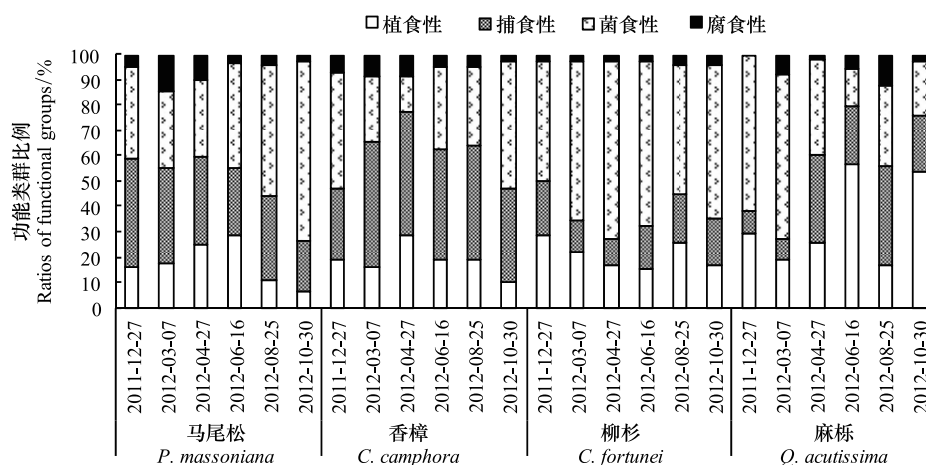


图2 四川盆地亚热带常绿阔叶林带4种典型森林群落各物候时期凋落物分解过程中土壤捕食性、植食性、菌食性和腐食性动物功能类群动态

Fig.2 Dynamics of soil fauna functional groups (predators, phytophaga, fungivore and saprozoic) during litter decomposition at different phenological stages in four kinds of typical forest community in the subtropical evergreen broad-leaved forest in Sichuan basin

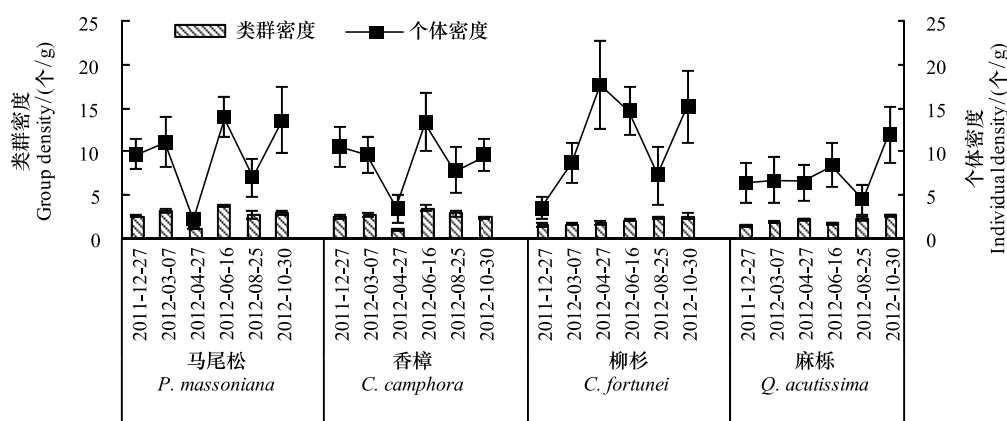


图3 四川盆地亚热带常绿阔叶林带4种典型森林群落各物候时期分解袋中土壤动物的个体和类群相对密度的变化(平均值±标准误,  $n=5$ )

Fig.3 Individual and taxa relative density of soil fauna in litterbags during litter decomposition at different phenological stages in four kinds of typical forest community in the subtropical evergreen broad-leaved forest in Sichuan basin (mean±SE,  $n=5$ )

对同一地区不同凋落物分解过程中的土壤动物进行相似性分析发现,马尾松林和香樟林除在展叶期土壤动物中等不相似外,其他各时期均表现为中等相似,而柳杉和麻栎林中仅在秋末落叶期和展叶期中等相似,其他各时期均表现为中等不相似(表3)。

### 2.3 土壤动物指标与分解过程中凋落物质量、环境因子的相关性分析

凋落物第一年的分解过程中,在秋末落叶期和萌动期土壤动物的个体密度主要和氮、磷含量及其格局相关性密切,在展叶期仅与木质素含量和氮/磷显著( $P<0.05$ )相关,在叶片成熟期和盛叶期与除碳外的其他所调查的指标均密切相关,其中,在叶衰期主要和木质素含量相关性显著。与土壤动物的个体密度具有一定的相似性,土壤动物的类群密度在秋末落叶期和萌动期也与氮、磷含量及其格局密切相关,不同的是在展叶期土壤动物的类群密度与纤维素含量显著相关,在一年的分解过程中与木质素的含量都无明显的相关性,且在盛叶期和叶衰期与除木质素以外的其他被测指标均有一定程度的相关性。此外,在叶衰期土壤动物类群密度与氮、磷含量呈极显著( $P<0.01$ )正相关,而其他时期均为负相关(附表3,表4)。

在凋落物分解过程中,土壤动物的类群密度极显著( $P<0.01$ )正相关于时期均温和降水量,此外土壤动物的个体密度和丰富度指数也与降水量密切相关(表5)。

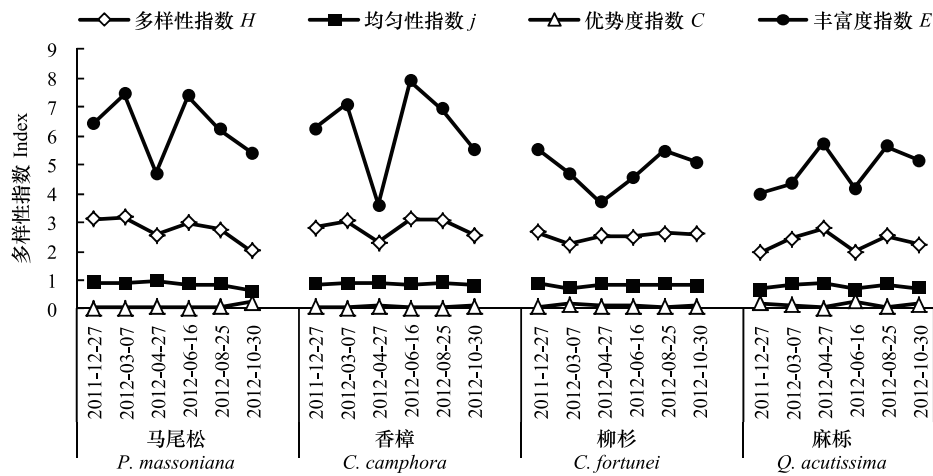


图 4 四川盆地亚热带常绿阔叶林带 4 种典型森林群落各物候时期凋落物分解过程中土壤动物群落多样性动态

Fig.4 Dynamics of diversity index of soil fauna community during litter decomposition at different phenological stages in four kinds of typical forest community in the subtropical evergreen broad-leaved forest in Sichuan basin

表 2 各林型土壤动物群落相似性指标

Table 2 Similarity index of soil animal community in each forest type

| 凋落物<br>Litter species    | 采样时间 Sampling time |            |            |            |            |            |
|--------------------------|--------------------|------------|------------|------------|------------|------------|
|                          |                    | 2011-12-27 | 2012-03-07 | 2012-04-27 | 2012-06-16 | 2012-08-25 |
| 马尾松 <i>P. massoniana</i> | 2012-10-30         | 0.38       | 0.44       | 0.39       | 0.51       | 0.67       |
|                          | 2012-08-25         | 0.37       | 0.36       | 0.33       | 0.48       |            |
|                          | 2012-06-16         | 0.79       | 0.78       | 0.87       |            |            |
|                          | 2012-04-27         | 0.29       | 0.24       |            |            |            |
|                          | 2012-03-07         | 0.61       |            |            |            |            |
| 香樟 <i>C. camphora</i>    | 2012-10-30         | 0.56       | 0.53       | 0.32       | 0.37       | 0.53       |
|                          | 2012-08-25         | 0.43       | 0.55       | 0.37       | 0.62       |            |
|                          | 2012-06-16         | 0.42       | 0.62       | 0.41       |            |            |
|                          | 2012-04-27         | 0.28       | 0.34       |            |            |            |
|                          | 2012-03-07         | 0.67       |            |            |            |            |
| 柳杉 <i>C. fortunei</i>    | 2012-10-30         | 0.33       | 0.45       | 0.34       | 0.39       | 0.35       |
|                          | 2012-08-25         | 0.50       | 0.34       | 0.52       | 0.47       |            |
|                          | 2012-06-16         | 0.45       | 0.59       | 0.52       |            |            |
|                          | 2012-04-27         | 0.70       | 0.48       |            |            |            |
|                          | 2012-03-07         | 0.52       |            |            |            |            |
| 麻栎 <i>Q. acutissima</i>  | 2012-10-30         | 0.43       | 0.29       | 0.48       | 0.46       | 0.48       |
|                          | 2012-08-25         | 0.37       | 0.37       | 0.43       | 0.46       |            |
|                          | 2012-06-16         | 0.40       | 0.40       | 0.52       |            |            |
|                          | 2012-04-27         | 0.48       | 0.38       |            |            |            |
|                          | 2012-03-07         | 0.55       |            |            |            |            |

表 3 同一区域土壤动物群落相似性指标

Table 3 Similarity index of soil animal community in the same area

| 林型<br>Forest type                                     | 采样时间 Sampling time |            |            |            |            |            |
|-------------------------------------------------------|--------------------|------------|------------|------------|------------|------------|
|                                                       |                    | 2011-12-27 | 2012-03-07 | 2012-04-27 | 2012-06-16 | 2012-08-25 |
| 马尾松和香樟<br><i>P. massoniana</i> and <i>C. camphora</i> |                    | 0.53       | 0.63       | 0.42       | 0.53       | 0.61       |
| 柳杉和麻栎 <i>C. fortune</i> and <i>Q. acutissima</i>      |                    | 0.54       | 0.36       | 0.56       | 0.43       | 0.40       |

表 4 土壤动物群落结构与凋落物质量的相关关系  
Table 4 Correlation analyses among community structure of soil faunal and litter quality

|                    |            | 碳<br>Carbon<br>/(g/kg) | 氮<br>Nitrogen<br>/(g/kg) | 磷<br>Phosphorus<br>/(g/kg) | 木质素<br>Lignin<br>/% | 纤维素<br>Cellulose<br>/% | 碳/氮<br>Carbon/<br>Nitrogen | 碳/磷<br>Carbon/<br>Phosphorus | 氮/磷<br>Nitrogen/<br>Phosphorus | 木质素/氮<br>Lignin/<br>Nitrogen | 木质素/<br>纤维素<br>Lignin/<br>Cellulose |
|--------------------|------------|------------------------|--------------------------|----------------------------|---------------------|------------------------|----------------------------|------------------------------|--------------------------------|------------------------------|-------------------------------------|
| 个体密度               | 2011-12-27 | 0.03                   | -0.79 **                 | -0.57 **                   | -0.08               | -0.44                  | 0.87 **                    | 0.45 *                       | 0.08                           | 0.73 **                      | 0.46 *                              |
| Individual density | 2012-03-07 | -0.21                  | -0.48 *                  | -0.55 *                    | -0.19               | -0.01                  | 0.34                       | 0.10                         | 0.66 **                        | 0.27                         | -0.05                               |
|                    | 2012-04-27 | -0.41                  | -0.38                    | -0.40                      | -0.47 *             | -0.18                  | 0.04                       | 0.24                         | 0.74 **                        | -0.21                        | -0.13                               |
|                    | 2012-06-16 | -0.13                  | -0.84 **                 | -0.61 **                   | 0.23                | -0.68 **               | 0.89 **                    | 0.32                         | -0.35                          | 0.77 **                      | 0.57 **                             |
|                    | 2012-08-25 | -0.13                  | -0.51 *                  | -0.77 **                   | -0.76 **            | 0.56 *                 | 0.45 *                     | 0.75 **                      | 0.70 **                        | 0.02                         | -0.85 **                            |
|                    | 2012-10-30 | -0.57 **               | 0.37                     | 0.31                       | 0.55 *              | 0.27                   | -0.46 *                    | -0.37                        | -0.19                          | 0.03                         | -0.17                               |
| 类群数量               | 2011-12-27 | -0.07                  | -0.86 **                 | -0.63 **                   | -0.18               | -0.40                  | 0.93 **                    | 0.48 *                       | 0.09                           | 0.88 **                      | 0.49 *                              |
| No. of groups      | 2012-03-07 | -0.44                  | -0.50 *                  | -0.47 *                    | -0.28               | 0.42                   | 0.47 *                     | 0.22                         | 0.27                           | 0.31                         | -0.43                               |
|                    | 2012-04-27 | -0.54 *                | -0.09                    | -0.18                      | -0.21               | -0.46 *                | -0.16                      | 0.02                         | 0.56 **                        | -0.17                        | 0.22                                |
|                    | 2012-06-16 | -0.28                  | -0.55 *                  | -0.62 **                   | -0.13               | -0.11                  | 0.53 *                     | 0.62 **                      | 0.20                           | 0.36                         | 0.02                                |
|                    | 2012-08-25 | 0.21                   | -0.85 **                 | -0.71 **                   | -0.43               | 0.64 **                | 0.86 **                    | 0.65 **                      | 0.56 **                        | 0.62 **                      | -0.77 **                            |
|                    | 2012-10-30 | -0.78 **               | 0.91 **                  | 0.66 **                    | 0.10                | 0.30                   | -0.86 **                   | -0.74 **                     | -0.45 *                        | -0.72 **                     | -0.40                               |

\* 表示存在显著相关性 ( $P<0.05$ ); \*\* 表示存在极显著相关性( $P<0.01$ )

表 5 气候因子与土壤动物群落相关性分析  
Table 5 Correlation analysis among the climatic factors and the soil fauna community

|                                                   | 个体密度<br>Individual<br>density | 类群密度<br>Group density | 多样性指数<br>$H$ | 均匀度指数<br>$j$ | 优势度指数<br>$C$ | 丰富度指数<br>$E$ |
|---------------------------------------------------|-------------------------------|-----------------------|--------------|--------------|--------------|--------------|
| 时期均温<br>Average daily temperature during sampling | 0.10                          | 0.30 **               | 0.01         | -0.05        | -0.02        | 0.15         |
| 降水量 Precipitation                                 | 0.18 *                        | 0.45 **               | 0.04         | -0.17        | 0.00         | 0.25 **      |

\* 表示存在显著相关性 ( $P<0.05$ ); \*\* 表示存在极显著相关性( $P<0.01$ )

在凋落物分解过程中,除在秋末落叶期土壤动物对凋落物分解的贡献率( $P_{\text{fau}}$ )与土壤动物的个体密度显著( $P<0.05$ )相关,叶衰期  $P_{\text{fau}}$  与土壤动物个体和群落密度均无显著相关外,其余各物候关键时期  $P_{\text{fau}}$  均与土壤动物的类群密度显著( $P<0.05$ )相关(表 6)。同时,除秋末落叶期和叶片成熟期  $P_{\text{fau}}$  与土壤动物的食性无显著相关外,其他物候关键时期  $P_{\text{fau}}$  与土壤动物的食性均显著相关。

表 6 土壤动物对凋落物分解的贡献率  $P_{\text{fau}}$  与土壤动物群落相关性分析  
Table 6 Correlation analyses among the soil fauna community and the contribution rate of soil fauna

|                         | 土壤动物的贡献率 The contribution rate of soil fauna ( $P_{\text{fau}}$ ) |          |           |           |           |            |
|-------------------------|-------------------------------------------------------------------|----------|-----------|-----------|-----------|------------|
|                         | 2011-12-27                                                        | 2012-3-7 | 2012-4-27 | 2012-6-16 | 2012-8-25 | 2012-10-30 |
| 个体密度 Individual density | 0.53 *                                                            | -0.26    | -0.22     | 0.00      | -0.11     | 0.19       |
| 类群密度 Group density      | 0.39                                                              | -0.44 *  | 0.48 *    | -0.60 **  | -0.46 *   | 0.01       |
| 植食性 Phytophaga          | -0.04                                                             | -0.83 ** | -0.16     | 0.00      | 0.05      | 0.96 **    |
| 捕食性 Predators           | 0.19                                                              | -0.45 *  | 0.59 **   | -0.26     | -0.39     | -0.51 *    |
| 菌食性 Fungivore           | -0.02                                                             | 0.08     | -0.45 *   | -0.30     | -0.70 **  | -0.70 **   |
| 腐食性 Saprozoic           | 0.07                                                              | -0.54 *  | -0.69 **  | -0.03     | 0.70 **   | -0.14      |

\* 表示存在显著相关性 ( $P<0.05$ ); \*\* 表示存在极显著相关性( $P<0.01$ )

3 讨论

土壤动物是影响凋落物分解的重要生物因子,但由于其受人类活动的干扰<sup>[13-14]</sup>和食性差异的限制<sup>[30-32]</sup>,使得次生林和人工林较天然林土壤动物群落结构发生变化<sup>[13,33]</sup>,尤其是在植物生长的不同物候时期,环境条件和凋落物质量的变化可能显著影响土壤动物群落结构及其对凋落物分解的贡献,然而相关研究尚不足。本研究发现在 1a 的植物生长过程中,马尾松和香樟凋落物在萌动期和展叶期以捕食性土壤动物懒甲螨科所占比例较大,而随着凋落物分解菌食性等节跳科和棘跳科所占比例上

升,逐渐成为主要优势类群,柳杉凋落物分解过程中菌食性土壤动物等节跳科一直为主要优势类群,并占有绝对优势地位,麻栎凋落物在秋末落叶期、萌动期和展叶期以菌食性等节跳科和棘跳科为主要优势类群,而后植食性蚁科和捕食性土革螨科比例上升,开始占主导地位。在凋落物分解过程中除柳杉土壤动物的个体密度高峰在展叶期出现外,其他3种凋落物的土壤动物个体密度高峰均出现在叶片成熟期和叶衰期。相关性分析的结果表明在凋落物分解过程中,凋落物的质量变化是影响土壤动物群落动态变化的重要因素,在秋末落叶期和萌动期土壤动物的个体密度主要和氮、磷含量及其格局密切相关,在叶衰期主要和难分解组分木质素显著相关,土壤动物的类群密度与个体密度具有相似性,但其与木质素在各时期相关性均不显著。此外,除在秋末落叶期土壤动物对凋落物分解的贡献率与土壤动物的个体密度显著相关外,其余主要物候关键时期均与土壤动物的类群密度及其食性显著相关。

亚热带常绿阔叶林具有与环境条件相适应的生物小循环节律,在凋落物分解过程中表现为:在干季(11月至翌年4月)多数树种换叶,凋落物数量达到高峰<sup>[10]</sup>;雨季(5—10月)地表凋落物进入快速分解期,为植物生长提供养分<sup>[17]</sup>。环境条件成为影响土壤动物功能类群的制约因子,并且有些类群较之其他类群有着明显的旱季和雨季之分,除柳杉凋落物分解过程中植食性土壤动物在各时期所占比例差异不大外,其他凋落物分解过程中植食性土壤动物均表现为在降水量较多的展叶期和叶片成熟期所占比例较高,在降水量较少的秋末落叶期和萌动期所占比例较低,且菌食性土壤动物呈现出与植食性土壤动物相反的变化趋势。土壤动物群落结构随着凋落物的数量、质量及植物生长对养分需求程度而变化,主要体现在土壤动物优势类群相对数量分布上,四种凋落物分解的秋末落叶期均以菌食性等节跳科和若甲螨科土壤动物所占比例较高,而随着凋落物的分解不同树种土壤动物的群落结构表现出较大差异,其中马尾松和香樟在萌动期和展叶期主要以捕食性懒甲螨科为主要优势类群而后叶片成熟期、盛叶期和叶衰期菌食性等节跳科所占比例逐渐上升,至叶衰期已成为主要优势类群。柳杉和麻栎凋落物分解过程中萌动期和展叶期仍以菌食性等节跳科和棘跳科为主要优势类群,其中柳杉以菌食性等节跳科为优势类群持续至叶衰期,而麻栎在叶片成熟期以植食性蚁科所占比例最大,盛叶期被捕食性土革螨科超越,叶衰期植食性蚁科又成为主要优势类群。

值得关注的是,本研究马尾松和香樟凋落物分解过程中土壤动物的个体密度在展叶期最少,叶片成熟期最大,与已有研究春季土壤动物密度的变化趋势相一致<sup>[34]</sup>。这主要和以下两方面原因有关,第一,凋落物质量是影响土壤动物群落结构的重要因子,凋落物氮、磷、碳/氮和碳/磷较高时,更有利于土壤动物的类群数和个体数的发展<sup>[12]</sup>。相关性结果表明展叶期土壤动物的个体密度和类群数与凋落物氮、磷含量相关性不显著,可能是由于展叶期凋落物的大量分解,土壤动物食物来源匮乏,且凋落物易分解(碳、氮、磷)组分减少,难分解组分(木质素)比例增加,不利于土壤动物进食,从而影响土壤动物数量;第二,叶片成熟期温湿度较高,环境条件适宜土壤动物生存<sup>[6-7]</sup>,土壤动物种类和数量迅速增加,另外,由于该时期凋落物已分解到一定程度,物理破碎作用逐渐减小,菌食性土壤动物比例增加。而在柳杉和麻栎凋落物分解过程中土壤动物在各时期的分布规律与马尾松和香樟略有不同,这主要是由于受湿度条件的影响,过高或过低的湿度都不利于土壤动物的生存,在雨季的初期(叶片成熟期)和末期(叶衰期)柳杉和麻栎凋落物袋中土壤动物的个体密度相对较高,而在雨季中期(盛叶期)土壤动物的个体密度明显偏低,柳杉凋落物袋中土壤动物个体密度在展叶期达到最大,主要是由于该时期降水量逐渐增加,有利于土壤动物数量增长需求所致。另外,次生林较人工林具有更稳定的生态环境<sup>[33]</sup>,可能是导致次生林凋落物分解过程中土壤动物的个体密度波动范围较人工林小的一个重要原因。

物种多样性是反映群落组成的复杂程度,评价群落生态组织水平的指标。高的多样性指数和均匀度意味着在生态系统中,有更长的食物链和更多的共生现象,从而增加群落结构的稳定性<sup>[34]</sup>。本实验马尾松和香樟凋落物袋内的土壤动物多样性指数和均匀度指数均高于柳杉和麻栎,说明马尾松和香樟的凋落物分解过程中土壤动物的群落结构稳定性更高。土壤动物丰富度指数是表彰生境优越与否的参数,而丰富度指数在不同树种之间的差异较大,说明不同树种生境条件差异较大。优势度指数相对于已有研究<sup>[33]</sup>普遍偏小,说明研究区域土壤动物优势类群所占比例相对较低。

在凋落物分解的不同关键时期土壤动物群落结构具有一定程度的差异性,而相关分析结果表明土壤动物对凋落物分解的贡献率与土壤动物群落结构具有显著相关性,这可能是导致凋落物分解的不同关键时期土壤动物对凋落物分解的贡献率产生差异的原因。柳杉和麻栎第1年的凋落物分解过程中土壤动物对凋落物分解的贡献大于香樟和马尾松,这主要可能是由于土壤动物种类和数量存在差异以及与之相应的土壤动物食性差异造成的,香樟一年的凋落物分解过程中以捕食性土壤动物为主,马尾松凋落物中捕食性土壤动物所占比例也较高,因此,在该区域捕食性土壤动物可能起到了限制土壤动物参与凋落物分解的作用,而柳杉林和麻栎林土壤动物以菌食性和植食性土壤动物为主,加速了凋落物的分解<sup>[35]</sup>。此外,菌食性土壤动物是对凋落物分解影响最大的土壤动物类群,其个体数量在不同基质的凋落物中的差异显著,可能是导致相似环境条件下土壤动物对不同基质凋落物分解速率差异的主要原因<sup>[36-37]</sup>。对凋落物分解各关键时期土壤动物的功能类群比较还发现,马尾松林土壤动物功能类群的结构组成在各物候时期相对稳定,这可能是导致马尾松林土壤动物在各物候时期对凋落物分解贡献率差异相对较小的主要原因。相关性分析结果表明在凋落物分解的秋末落叶期,土壤动物的贡献和土壤动物的个体密度显著正相关,而其他时期与土壤动物的食性密切相关,这主要是由于凋落物分解初期土壤动物主要通过机械破碎分解凋落物,土壤动物的数量决定了凋落物的分解速度,而后期土壤动物主要通过采食作用分解凋落物<sup>[3-5]</sup>。在凋落物分解的展叶期土壤动物的贡献与土壤动物

的类群密度呈显著正相关,而在叶片成熟期和盛叶期却呈显著负相关,说明土壤动物种类过多反而抑制其对凋落物的分解。

综上所述,在凋落物分解的不同关键时期土壤动物的群落结构存在明显差异,尤其表现在土壤动物优势类群分布上,此外,相同时期不同种凋落物的土壤动物优势类群也不相同,但在相似的环境条件下,土壤动物的群落结构具有一定的相似性。相关性分析结果表明土壤动物的群落结构变化显著影响凋落物的分解,在秋末落叶期和萌动期土壤动物的个体密度主要和氮、磷含量及其格局密切相关,叶衰期主要和难分解组分木质素显著相关,土壤动物的类群密度与个体密度具有相似性,但其与木质素在各时期相关性均不显著。此外,除在秋末落叶期土壤动物对凋落物分解的贡献率与土壤动物的个体密度显著相关外,其余主要物候关键时期均与土壤动物的类群密度及其食性显著相关。这些结果不仅表明土壤动物的群落结构与叶片物候阶段密切相关,也对深入认识土壤动物对凋落物分解的贡献与植物生长的关系具有重要意义,而且为深入理解区域亚热带人工林和次生林生态系统凋落物分解等物质循环过程提供了一定的基础数据。

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附表 1 不同林型下土壤动物的平均密度(个/袋)

| Appendix 1 The average density of soil animals under different forest types (ind./bag) |                      |     |                          |            |            |            |            |            |                       |            |            |            |            |            |                       |            |            |            |            |            |                         |            |            |            |            |            |                           |     |            |            |            |            |            |            |    |    |
|----------------------------------------------------------------------------------------|----------------------|-----|--------------------------|------------|------------|------------|------------|------------|-----------------------|------------|------------|------------|------------|------------|-----------------------|------------|------------|------------|------------|------------|-------------------------|------------|------------|------------|------------|------------|---------------------------|-----|------------|------------|------------|------------|------------|------------|----|----|
| 土壤动物类群<br>Soil fauna groups                                                            |                      |     | 马尾松 <i>P. massoniana</i> |            |            |            |            |            | 香樟 <i>C. camphora</i> |            |            |            |            |            | 柳杉 <i>C. fortunei</i> |            |            |            |            |            | 麻栎 <i>Q. acutissima</i> |            |            |            |            |            | 功能类群<br>Functional groups |     |            |            |            |            |            |            |    |    |
|                                                                                        |                      |     | 2011-12-27               | 2012-03-07 | 2012-04-27 | 2012-06-16 | 2012-08-25 | 2012-10-30 | 2011-12-27            | 2012-03-07 | 2012-04-27 | 2012-06-16 | 2012-08-25 | 2012-10-30 | 2011-12-27            | 2012-03-07 | 2012-04-27 | 2012-06-16 | 2012-08-25 | 2012-10-30 | 2011-12-27              | 2012-03-07 | 2012-04-27 | 2012-06-16 | 2012-08-25 | 2012-10-30 |                           |     | 2011-12-27 | 2012-03-07 | 2012-04-27 | 2012-06-16 | 2012-08-25 | 2012-10-30 |    |    |
| 线蚓目 Tubificida                                                                         | 线蚓科 Enchytraeidea    | 0   | 0                        | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 1.2        | 0                     | 0.8        | 0          | 0          | 0          | 1.4        | 0                       | 0          | 0          | 0          | 0          | 0          | 0                         | 0   | 0          | 0          | 0          | 0          | 0          | S          |    |    |
|                                                                                        | 隐翅甲科 Staphylinidae   | 0   | 0.8                      | 0          | 0.8        | 0.2        | 0.8        | 1.6        | 0.8                   | 0          | 1.6        | 0          | 0          | 0          | 0                     | 0.8        | 0.8        | 0.8        | 1.6        | 0.8        | 0                       | 1.6        | 1.6        | 0.8        | 0.8        | 0          | 0                         | 0   | 1.6        | 1.6        | 0.8        | 0.8        | 0          | 0          | PR |    |
| 鞘翅目 Coleoptera                                                                         | 蚁甲科 Pselaphidae      | 0   | 0.8                      | 0          | 0.8        | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0                     | 0.8        | 0          | 0          | 0          | 0          | 0                       | 0          | 0.8        | 0          | 0.4        | 1.4        | 0                         | 0   | 0          | 0          | 0.8        | 0          | 0.4        | 1.4        | S  |    |
|                                                                                        | 叶甲科 Chrysomelidae    | 0   | 0                        | 0          | 0.8        | 0          | 0.4        | 0.8        | 0                     | 0          | 1.6        | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | 0                         | 0   | 0          | 0          | 0          | 0          | 0          | 0          | PH |    |
| 弹尾目 Collembola                                                                         | 鳞跳科 Tomoceridae      | 1.6 | 0.8                      | 0          | 0          | 0          | 0          | 2.4        | 1.6                   | 0          | 0          | 0          | 0          | 0          | 1.6                   | 2.4        | 7.2        | 1.6        | 0          | 0.6        | 1.6                     | 0          | 0          | 0          | 0          | 0          | 1.6                       | 0   | 0          | 0          | 0          | 0          | 0          | 0          | F  |    |
|                                                                                        | 疣跳科 Neanuridae       | 2.4 | 3.2                      | 0          | 0          | 3          | 3.4        | 0          | 0                     | 0          | 2.4        | 0.6        | 1.2        | 0          | 0                     | 6.4        | 4          | 1.6        | 2.4        | 0          | 2.4                     | 1.6        | 0          | 1.2        | 0          | 0          | 2.4                       | 1.6 | 0          | 0          | 0          | 0          | 0          | 0          | F  |    |
|                                                                                        | 等节跳科 Isotomidae      | 3.2 | 6.4                      | 1.6        | 9.6        | 8.4        | 39.4       | 16.8       | 6.4                   | 1.6        | 3.2        | 3.2        | 16.2       | 4.8        | 23.2                  | 19.2       | 22.4       | 7          | 19.8       | 20.8       | 3.2                     | 3.2        | 2.4        | 1.6        | 2.4        | 0          | 2.4                       | 3.2 | 2.4        | 1.6        | 2.4        | 0          | 0          | F          |    |    |
|                                                                                        | 棘跳科 Onychiuridae     | 4.8 | 3.2                      | 1.6        | 14.4       | 8          | 10.6       | 11.2       | 4                     | 1.6        | 6.4        | 2.2        | 7.6        | 1.6        | 4                     | 24         | 18.4       | 4.8        | 11         | 6.4        | 16.8                    | 4.8        | 4          | 3.2        | 2.2        | 0          | 0                         | 0   | 0          | 0          | 0          | 0          | 0          | F          |    |    |
|                                                                                        | 短角跳科 Neelidae        | 2.4 | 0                        | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 2.4        | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | 0                         | 0   | 0          | 0          | 0          | 0          | 0          | F          |    |    |
|                                                                                        | 长角跳科 Entomobryidae   | 0   | 3.2                      | 0.8        | 4          | 0.4        | 1.8        | 1.6        | 0                     | 0          | 0          | 0          | 1.4        | 1.6        | 2.4                   | 0          | 0          | 0          | 1.6        | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | 0                         | 0   | 0          | 0          | 0          | 0          | 0          | 0          | F  |    |
|                                                                                        | 驼跳科 Cyphodidae       | 1.6 | 0                        | 0          | 6.4        | 1.6        | 2.6        | 4          | 0.8                   | 0          | 2.4        | 2.8        | 1.4        | 1.6        | 2.4                   | 15.2       | 8.8        | 2.4        | 4.6        | 1.6        | 2.4                     | 1.6        | 0.8        | 1.6        | 8.4        | 0          | 0                         | 0   | 0          | 0          | 0          | 0          | 0          | F          |    |    |
|                                                                                        | 爪跳科 Paronellidae     | 0   | 0                        | 0          | 2.4        | 0.6        | 0          | 0          | 0                     | 0          | 0.8        | 0.6        | 0          | 0.8        | 4                     | 10.4       | 7.2        | 1.2        | 0          | 0          | 0                       | 1.6        | 0          | 0          | 0          | 0          | 0                         | 1.6 | 0          | 0          | 0          | 0          | 0          | 0          | F  |    |
|                                                                                        | 球角跳科 Hypogastridae   | 1.6 | 2.4                      | 0          | 8          | 0.4        | 0          | 3.2        | 0.8                   | 0          | 0          | 0          | 1.8        | 0          | 0                     | 0          | 0          | 0          | 3          | 1.6        | 3.2                     | 0          | 0          | 0          | 0          | 1.8        | 0                         | 0   | 0          | 0          | 0          | 0          | 0          | 0          | PH |    |
|                                                                                        | 圆跳科 Sminthuridae     | 2.4 | 0.8                      | 0.8        | 11.2       | 1.2        | 0.2        | 4.8        | 0.8                   | 0          | 0          | 1.6        | 1.2        | 4.8        | 11.2                  | 11.2       | 8          | 4.6        | 3.8        | 12         | 2.4                     | 0          | 0          | 0          | 0          | 9.8        | 0                         | 0   | 0          | 0          | 0          | 0          | 0          | 0          | PH |    |
| 双翅目 Diptera                                                                            | 长角毛蚊科幼虫 Hesperinidae | 0   | 3.2                      | 0          | 0          | 0          | 3.2        | 0.8        | 1.6                   | 0          | 0          | 0.4        | 1.4        | 0          | 0                     | 0          | 0          | 0          | 1.2        | 1.8        | 0                       | 0          | 0          | 1.4        | 1.2        | 0          | 0                         | 0   | 0          | 0          | 0          | 0          | 0          | 0          | PH |    |
|                                                                                        | 尖眼蕈蚊科幼虫 Sciaridae    | 0   | 0                        | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0.6        | 0                       | 0          | 0          | 0          | 0          | 0          | 0                         | 0   | 0          | 0          | 0          | 0          | 0          | 0          | PH |    |
|                                                                                        | 蠅科幼虫 Geratopogonidae | 0   | 0                        | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | 0                         | 0   | 0          | 0          | 0          | 0          | 0          | 0          | PH |    |
|                                                                                        | 蝇科幼虫 Muscidae        | 0   | 2.4                      | 0          | 0          | 0          | 1.4        | 1.6        | 0                     | 0          | 0          | 0.6        | 0.6        | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | 0                         | 0   | 0          | 0          | 0          | 0          | 0          | 0          | S  |    |
|                                                                                        | 毛蚊科幼虫 Bionidae       | 0   | 0                        | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | 0                         | 0   | 0          | 0          | 0          | 0          | 0          | 0          | PH |    |
|                                                                                        | 冬大蚊科幼虫 Trichoceridae | 0   | 0                        | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | 0                         | 0   | 0          | 0          | 0          | 0          | 0          | 0          | PH |    |
|                                                                                        | 大蚊科 Tipulidae        | 0   | 0                        | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | 0                         | 0   | 0          | 0          | 0          | 0          | 0          | 0          | PH |    |
|                                                                                        | 摇蚊科 Chironomidae     | 0.8 | 6.4                      | 1.6        | 1.6        | 2          | 0.6        | 2.4        | 6.4                   | 1.6        | 3.2        | 1.6        | 0          | 0.8        | 0                     | 2.4        | 1.6        | 1.6        | 0          | 0          | 2.4                     | 0          | 1.6        | 2.6        | 0          | S          | 0                         | 2.4 | 0          | 1.6        | 2.6        | 0          | 0          | 0          | S  |    |
|                                                                                        | 长足虹科幼虫 Dolichopidae  | 0   | 0.8                      | 0          | 0          | 0          | 0          | 0          | 0.8                   | 0          | 0.8        | 0          | 0          | 0          | 0.8                   | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0.8        | 0          | 0          | 0                         | 0.8 | 0          | 0          | 0.8        | 0          | 0          | 0          | 0  | PR |
|                                                                                        | 水虻科 Stratiomyidae    | 0   | 0                        | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0.8        | 0          | 0.8        | 0          | 0.4                     | 0          | 0          | 0          | 0          | 0          | 0                         | 0   | 0          | 0          | 0          | 0          | 0          | 0          | 0  | F  |
| 甲螨亚目 Oribateida                                                                        | 粗脉毛蚊科 Pachyneuridae  | 0   | 0                        | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 2.4        | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | 0                         | 0   | 0          | 0          | 0          | 0          | 0          | 0          | PH |    |
|                                                                                        | 大翼甲螨科 Galumnidae     | 8.8 | 1.6                      | 1.6        | 0          | 0          | 0          | 1.6        | 2.4                   | 0          | 0          | 0          | 1.4        | 0          | 0                     | 2.4        | 1.6        | 0          | 0          | 0          | 0                       | 1.6        | 2.4        | 2.4        | 0.8        | 0          | 0                         | 1.6 | 2.4        | 2.4        | 0.8        | 0          | 0          | 0          | 0  | PR |
|                                                                                        | 若甲螨科 Oribatulidae    | 8   | 3.2                      | 0.8        | 2.4        | 1.6        | 1.8        | 3.2        | 4                     | 0.8        | 8.8        | 4          | 2.2        | 1.6        | 3.2                   | 3.2        | 2.4        | 5.6        | 4.2        | 2.4        | 4                       | 1.6        | 1.6        | 1.4        | 1.6        | 0          | 2.4                       | 4   | 1.6        | 1.6        | 1.4        | 1.6        | 0          | 0          | F  |    |
|                                                                                        | 隐囊螨科 Cryptognathidae | 0   | 0.8                      | 0          | 0          | 1.4        | 0          | 0          | 0                     | 0          | 1.6        | 8          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0.8        | 0          | F          | 0                         | 0   | 0          | 0          | 0          | 0.8        | 0          | 0          | 0  | F  |
|                                                                                        | 丽甲螨科 Liacidae        | 4   | 4.8                      | 0.8        | 4          | 1.8        | 0          | 4.8        | 8                     | 4.8        | 9.6        | 1.8        | 0          | 1.6        | 3.2                   | 5.6        | 2.4        | 0          | 0          | 0.8        | 2.4                     | 3.2        | 4          | 0          | 0          | 0          | 0                         | 2.4 | 0          | 0          | 0          | 0          | 0          | 0          | 0  | PH |
|                                                                                        | 土革螨科 Ologamasidae    | 4   | 4.8                      | 0.8        | 4          | 1.6        | 1.2        | 4          | 4                     | 1.6        | 11.2       | 2.4        | 0.8        | 2.4        | 1.6                   | 7.2        | 6.4        | 3.2        | 2.2        | 0.8        | 0                       | 2.4        | 0          | 5.2        | 2.2        | 0          | 0                         | 2.4 | 0          | 0          | 0          | 0          | 0          | 0          | 0  | PR |
|                                                                                        | 三甲螨科 Oribotritidae   | 0.8 | 1.6                      | 0          | 0          | 0          | 0          | 0          | 1.6                   | 0          | 4.8        | 1.6        | 0          | 0          | 0                     | 0          | 0          | 1.2        | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | 0                         | 0   | 0          | 0          | 0          | 0          | 0          | 0          | F  |    |
|                                                                                        | 无爪螨科 Alicorhagidae   | 0   | 0                        | 0          | 0.8        | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | 0                         | 0   | 0          | 0          | 0          | 0          | 0          | 0          | F  |    |
|                                                                                        | 绥螨科 Sejidae          | 0.8 | 1.6                      | 0          | 1.6        | 3.2        | 1.2        | 0          | 0.8                   | 2.4        | 0.8        | 2.6        | 3          | 0          | 0.8                   | 0          | 1.6        | 0.8        | 4.6        | 0.8        | 0                       | 4          | 1.6        | 0          | 3.6        | 0          | 0                         | 0   | 0          | 0          | 0          | 0          | 0          | 0          | 0  | PR |
|                                                                                        | 植绥螨科 Phytoseiidae    | 1.6 | 1.6                      | 0          | 1.6        | 0          | 0          | 1.6        | 1.6                   | 0          | 1.6        | 0          | 0          | 0          | 0.8                   | 0          | 1.6        | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | 0                         | 0   | 0          | 0          | 0          | 0          | 0          | 0          | 0  | PR |
| 厚厉螨科 Pachylaelapidae                                                                   | 1.6                  | 2.4 | 0.8                      | 3.2        | 1.6        | 0.8        | 0.8        | 3.2        | 0                     | 2.4        | 0.8        | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 1.4        | 0          | 0                         | 0   | 0          | 0          | 0          | 0          | 0          | 0          | PR |    |
| 奥甲螨 Oppidae                                                                            | 4                    | 1.6 | 0                        | 0          | 0          | 0          | 1.6        | 4          | 0                     | 3.2        | 1.2        | 0.8        | 0          | 0          | 0                     | 0          | 0          | 0          | 0.6        | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | 0                         | 0   | 0          | 0          | 0          | 0          | 0          | 0          | PR |    |
| 厉螨科 Laelapidae                                                                         | 1.6                  | 3.2 | 0                        | 1.6        | 1          | 1.8        | 1.6        | 1.6        | 1.6                   | 1.6        | 1.6        | 5.4        | 0.8        | 3.2        | 3.2                   | 4          | 1.6        | 6.6        | 0.8        | 1.6        | 1.6                     | 1.6        | 1.2        | 2.8        | 0          | 0          | 1.6                       | 1.6 | 1.6        | 1.6        | 1.2        | 1.6        | 1.2        | 2.8        | 0  | PR |
| 长须螨科 Stigmaeidae                                                                       | 0                    | 1.6 | 0                        | 2.4        | 0          | 0          | 1.6        | 2.4        | 0                     | 2.4        | 2.6        | 0.6        | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0.4        | 0          | 0          | 0                         | 0   | 0          | 0          | 0          | 0          | 0          | 0          | 0  | PR |

续表

| 土壤动物类群<br>Soil fauna groups | 马尾松 <i>P. massoniana</i> |            |            |            |            |            |            |            |            |            | 香樟 <i>C. camphora</i> |            |            |            |            |            |            |            |            |            | 柳杉 <i>C. fortunei</i> |            |            |            |            |            |            |            |            |            | 麻栎 <i>Q. acutissima</i> |            |            |            |            |            |    |    |  |  | 功能类群<br>Functional groups |            |  |  |  |  |            |  |  |  |  |
|-----------------------------|--------------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|-----------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|-----------------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|-------------------------|------------|------------|------------|------------|------------|----|----|--|--|---------------------------|------------|--|--|--|--|------------|--|--|--|--|
|                             | 2011-12-27               |            |            |            |            | 2012-03-07 |            |            |            |            | 2012-06-16            |            |            |            |            | 2012-08-25 |            |            |            |            | 2012-10-30            |            |            |            |            | 2011-12-27 |            |            |            |            | 2012-03-07              |            |            |            |            | 2012-06-16 |    |    |  |  |                           | 2012-08-25 |  |  |  |  | 2012-10-30 |  |  |  |  |
|                             | 2011-12-27               | 2012-03-07 | 2012-06-16 | 2012-08-25 | 2012-10-30 | 2011-12-27 | 2012-03-07 | 2012-06-16 | 2012-08-25 | 2012-10-30 | 2011-12-27            | 2012-03-07 | 2012-06-16 | 2012-08-25 | 2012-10-30 | 2011-12-27 | 2012-03-07 | 2012-06-16 | 2012-08-25 | 2012-10-30 | 2011-12-27            | 2012-03-07 | 2012-06-16 | 2012-08-25 | 2012-10-30 | 2011-12-27 | 2012-03-07 | 2012-06-16 | 2012-08-25 | 2012-10-30 | 2011-12-27              | 2012-03-07 | 2012-06-16 | 2012-08-25 | 2012-10-30 |            |    |    |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 橈甲螨科 Nothridae              | 6.4                      | 9.6        | 1.6        | 3.2        | 2.8        | 8.6        | 7.2        | 11.2       | 6.4        | 12.8       | 3.2                   | 7.8        | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 1.4                   | 0          | 0          | 1.6        | 2.4        | 0          | 1.4        | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | 0  | PR |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 赤螨科 Erythraeidae            | 0                        | 0          | 0          | 2.4        | 2.6        | 1.2        | 0          | 0          | 0          | 1.6        | 4.8                   | 2.6        | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 1.6        | 1.6        | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | 0  | PR |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 罗甲螨科 Lohmannidae            | 0                        | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | F  |    |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 珠甲螨科 Damaeidae              | 0                        | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 1.6        | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | F  |    |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 联甲螨科 Synchotritidae         | 0                        | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | F  |    |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 缝甲螨科 Hypochthonidae         | 2.4                      | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | PR |    |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 直卷甲螨科<br>Archoplophoridae   | 3.2                      | 2.4        | 0          | 0          | 0          | 0.4        | 0.8        | 1.6        | 0          | 0          | 0                     | 1.8        | 0.8        | 1.6        | 6.4        | 0          | 0          | 1.6        | 6.4        | 0          | 0                     | 10.6       | 0.8        | 1.6        | 1.6        | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | F  |    |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 四奥甲螨科 Quadropiidae          | 0                        | 0          | 0          | 1.6        | 0.8        | 0          | 0          | 1.6        | 0          | 0.8        | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | PR |    |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 吸螨科 Bdellidae               | 0                        | 0.8        | 0          | 1.6        | 0          | 0          | 0.8        | 0          | 1.6        | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | F  |    |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 原蛱甲科 Progapygidae           | 0.8                      | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0.6                   | 0          | 0          | 0          | 0          | 0          | 0.4        | 0          | 0          | 0          | 0                       | 0          | 0          | 0.4        | 0          | 0          | PH |    |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 石蜈蚣目<br>Lithobionomorpha    | 0                        | 0          | 0          | 0.8        | 0.2        | 0.4        | 0          | 0.8        | 0.8        | 0.8        | 0.6                   | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 1.4                   | 1          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | PR |    |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 蜘蛛目 Araneae                 | 0.8                      | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0.8        | 0                     | 0          | 0          | 0.8        | 0          | 0          | 0.8        | 0          | 0          | 0          | 0                     | 0          | 0.8        | 0.8        | 0.4        | 0.6        | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | 0  | PR |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 跳蛛科 Salticidae              | 0.8                      | 1.6        | 0.8        | 0.8        | 0.4        | 0.4        | 0          | 0.8        | 0          | 0.8        | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | PR |    |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 皿蛛科 Linyphiidae             | 0                        | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | PR |    |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 狼蛛科 Lycosidae               | 0                        | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0.8        | 0.8        | 0                     | 0.6        | 0.8        | 0          | 0.4        | 0          | 0          | 0          | 0          | 0.4        | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | 0  | PR |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 蟹蛛科 Thomisidae              | 0                        | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | PR |    |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 园蛛科 Araneidae               | 0.8                      | 0          | 0          | 0.8        | 0          | 0          | 0.8        | 0          | 0          | 0.8        | 0                     | 0          | 0.8        | 0          | 0.4        | 0          | 0          | 0          | 0          | 0.4        | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | 0  | PR |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 漏斗蛛科 Agelenidae             | 0                        | 0          | 0          | 0          | 0          | 0          | 0.8        | 0.8        | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | 0  | PR |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 叶蟱科 Jassidae                | 0                        | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | PH |    |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 同翅目 Homoptera               | 3.2                      | 1.6        | 0          | 0          | 0          | 0          | 2.4        | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0.8        | 0          | 2.2                   | 0          | 0.8        | 0          | 0.8        | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | S  |    |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 啮虫目 Psocoptera              | 2.4                      | 0          | 0          | 0.8        | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | PH |    |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 综合纲 Symphyla                | 0                        | 0.8        | 0          | 0.8        | 0          | 0          | 0          | 0          | 0          | 1.6        | 1.2                   | 0          | 0.8        | 0          | 0.6        | 0          | 0          | 0.8        | 0          | 0.6        | 0                     | 0          | 0          | 0.8        | 0.8        | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | 0  | PH |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 缨翅目 Thysanoptera            | 0                        | 0.8        | 0          | 0.8        | 0          | 0          | 0          | 0          | 0.8        | 1.6        | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | S  |    |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 蜚蠊目 Blattoptera             | 1.6                      | 1.6        | 1.6        | 1.6        | 1          | 0.8        | 0.8        | 0.8        | 3.2        | 3.2        | 2.8                   | 1.2        | 0.8        | 0.8        | 1.6        | 1.6        | 1.6        | 1.6        | 5          | 5.4        | 0.8                   | 0.8        | 4.8        | 28.8       | 2.6        | 24.8       | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | 0  | PH |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 膜翅目 Hymenoptera             | 0                        | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0.2                   | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | PH |    |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 切叶蚁亚科 Myrmicinae            | 0                        | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | PH |    |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 毒蜂科 Lymantridae             | 0                        | 0          | 0          | 0          | 0          | 0.6        | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0.8        | 0.4        | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | PH |    |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 尺蛾科 Geometridae             | 0                        | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0.2        | 0          | 0.8        | 0          | 0.8        | 0          | 0.2                   | 0          | 0.8        | 0          | 0.8        | 0.4        | 0          | 0          | 0          | 0          | 0                       | 0          | 0.8        | 0.4        | 0.4        | 0          | S  |    |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 土蜂科 Cydnidae                | 0                        | 0.8        | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | PH |    |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 海蟑螂科 Ligidae                | 0                        | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0.2        | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | PH |    |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 直翅目<br>Orthoptera           | 0                        | 0          | 0.8        | 0.8        | 0          | 0          | 0          | 0          | 0          | 0.8        | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | PH |    |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 伪蝎目<br>Pseudoscorpiones     | 0                        | 0          | 0          | 0.8        | 0.6        | 0.6        | 0.8        | 0.8        | 0          | 0          | 0.8                   | 0.8        | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 1.6        | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | 0  | PR |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 盲蛛目 Opiliones               | 0                        | 0          | 0          | 0.8        | 0          | 0          | 0          | 0.8        | 0          | 1.6        | 1.4                   | 0          | 0          | 0.8        | 0          | 0          | 0.8        | 0          | 0.8        | 0          | 0                     | 0          | 0          | 0.8        | 0          | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0.8        | 0          | 0          | 1.2        | 0  | PR |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 离爪目 Apocheila               | 0                        | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 1.6        | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                     | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0          | 0                       | 0          | 0          | 0          | 0          | 0          | 0  | PH |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 合计 Total                    | 78.4                     | 83.2       | 16         | 100        | 47         | 84.6       | 87.2       | 78.4       | 28         | 107        | 56.4                  | 63.8       | 30.4       | 69.6       | 130        | 101        | 46.2       | 90.8       | 54.4       | 50.4       | 46.4                  | 59.2       | 29.2       | 71.4       |            |            |            |            |            |            |                         |            |            |            |            |            |    |    |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| 类群数                         | 29                       | 34         | 14         | 35         | 25         | 25         | 29         | 32         | 13         | 38         | 29                    | 24         | 20         | 21         | 19         | 22         | 22         | 22         | 24         | 17         | 18                    | 23         | 18         | 20         | 23         |            |            |            |            |            |                         |            |            |            |            |            |    |    |  |  |                           |            |  |  |  |  |            |  |  |  |  |
| Number of groups            |                          |            |            |            |            |            |            |            |            |            |                       |            |            |            |            |            |            |            |            |            |                       |            |            |            |            |            |            |            |            |            |                         |            |            |            |            |            |    |    |  |  |                           |            |  |  |  |  |            |  |  |  |  |

PH: 植食性 Phytophaga; PR: 捕食性 Predators; F: 菌食性 Fungivore; S: 腐食性 Saprozoic

PH: 植食性 Phytophagous; PR: 捕食性 Predators; F: 菌食性 Fungivore; S: 腐食性 Saprophagous

附表 2 土壤动物优势类群  
Appendix 2 Dominant groups of soil fauna community

|            | 马尾松 <i>P. massoniana</i>                                                                                       |                     |                                                       | 樟 C. camphora       |                                                                           |                     | 柳杉 <i>C. fortunei</i>                                 |                     |                                                         | 麻栎 <i>Q. acutissima</i> |                                                         |                     |
|------------|----------------------------------------------------------------------------------------------------------------|---------------------|-------------------------------------------------------|---------------------|---------------------------------------------------------------------------|---------------------|-------------------------------------------------------|---------------------|---------------------------------------------------------|-------------------------|---------------------------------------------------------|---------------------|
|            | 优势类群<br>Dominant species                                                                                       | 百分比/%<br>Percentage | 优势类群<br>Dominant species                              | 百分比/%<br>Percentage | 优势类群<br>Dominant species                                                  | 百分比/%<br>Percentage | 优势类群<br>Dominant species                              | 百分比/%<br>Percentage | 优势类群<br>Dominant species                                | 百分比/%<br>Percentage     | 优势类群<br>Dominant species                                | 百分比/%<br>Percentage |
| 2011-12-27 | 大翼甲螨科 Galumnidae<br>若甲螨科 Galumnidae                                                                            | 21.43               | 等节跳科 Isotomidae<br>棘跳科 Onychiuridae                   | 32.11               | 等节跳科 Isotomidae<br>圆跳科 Sminthuridae                                       | 31.58               | 等节跳科 Isotomidae<br>圆跳科 Sminthuridae                   | 72.06               | 等节跳科 Isotomidae<br>圆跳科 Sminthuridae<br>棘跳科 Onychiuridae | 72.06                   | 等节跳科 Isotomidae<br>圆跳科 Sminthuridae<br>棘跳科 Onychiuridae | 72.06               |
| 2012-03-07 | 懒甲螨科 Nothridae                                                                                                 | 11.54               | 懒甲螨科 Nothridae<br>丽甲螨科 Liacaridae                     | 24.49               | 等节跳科 Isotomidae<br>圆跳科 Sminthuridae                                       | 49.43               | 棘跳科 Onychiuridae                                      | 33.33               | 棘跳科 Onychiuridae                                        | 33.33                   | 棘跳科 Onychiuridae                                        | 33.33               |
| 2012-04-27 | 懒甲螨科 Nothridae<br>等节跳科 Isotomidae<br>摇蚊科 Chironomidae<br>棘跳科 Onychiuridae<br>大翼甲螨科 Galumnidae<br>蚊科 Formicidae | 60.00               | 懒甲螨科 Nothridae<br>丽甲螨科 Liacaridae<br>蚊科 Formicidae    | 51.43               | 棘跳科 Onychiuridae<br>等节跳科 Isotomidae<br>圆跳科 Cyphodoridae                   | 44.92               | 棘跳科 Onychiuridae<br>蚊科 Formicidae                     | 20.69               | 棘跳科 Onychiuridae<br>蚊科 Formicidae                       | 20.69                   | 棘跳科 Onychiuridae<br>蚊科 Formicidae                       | 20.69               |
| 2012-06-16 | 棘跳科 Onychiuridae<br>圆跳科 Sminthuridae                                                                           | 25.60               | 懒甲螨科 Nothridae<br>土草螨科 Ologamasidae                   | 22.43               | 等节跳科 Isotomidae<br>棘跳科 Onychiuridae                                       | 40.40               | 蚊科 Formicidae                                         | 48.65               | 蚊科 Formicidae                                           | 48.65                   | 蚊科 Formicidae                                           | 48.65               |
| 2012-08-25 | 等节跳科 Isotomidae<br>棘跳科 Onychiuridae                                                                            | 34.89               | 0.00                                                  | 0.00                | 等节跳科 Isotomidae<br>若甲螨科 Oribatulidae<br>蚊科 Formicidae<br>棘跳科 Onychiuridae | 48.48               | 土草螨科 Ologamasidae<br>棘跳科 Onychiuridae                 | 28.77               | 土草螨科 Ologamasidae<br>棘跳科 Onychiuridae                   | 28.77                   | 土草螨科 Ologamasidae<br>棘跳科 Onychiuridae                   | 28.77               |
| 2012-10-30 | 等节跳科 Isotomidae<br>棘跳科 Onychiuridae<br>懒甲螨科 Nothridae                                                          | 69.27               | 等节跳科 Isotomidae<br>懒甲螨科 Nothridae<br>棘跳科 Onychiuridae | 49.53               | 等节跳科 Isotomidae<br>棘跳科 Onychiuridae<br>直卷甲螨科 Archoplophoridae             | 45.59               | 蚊科 Formicidae<br>圆跳科 Sminthuridae<br>驼跳科 Cyphodoridae | 60.22               | 蚊科 Formicidae<br>圆跳科 Sminthuridae<br>驼跳科 Cyphodoridae   | 60.22                   | 蚊科 Formicidae<br>圆跳科 Sminthuridae<br>驼跳科 Cyphodoridae   | 60.22               |

附表 3 凋落物分解过程中的凋落物质量  
Appendix 3 The litter quality in the process of litter decomposition

|                             |                           | 2011-12-27   | 2012-03-07   | 2012-04-27   | 2012-06-16   | 2012-08-25   | 2012-10-30   |
|-----------------------------|---------------------------|--------------|--------------|--------------|--------------|--------------|--------------|
| 马尾松<br><i>P. massoniana</i> | 碳 Carbon (g/kg)           | 479.37±17.57 | 479.20±17.42 | 490.32±14.87 | 457.40±27.71 | 470.04±24.72 | 424.23±13.63 |
|                             | 氮 Nitrogen / (g/kg)       | 11.47±0.55   | 14.90±0.21   | 13.46±0.73   | 17.65±0.30   | 13.58±0.33   | 16.52±0.58   |
|                             | 磷 Phosphorus / (g/kg)     | 0.86±0.03    | 1.02±0.05    | 0.89±0.06    | 1.28±0.04    | 1.26±0.04    | 0.78±0.03    |
|                             | 木质素 Lignin / %            | 29.31±1.02   | 33.32±0.70   | 34.84±1.02   | 38.62±1.07   | 43.66±1.34   | 42.06±0.95   |
|                             | 纤维素 Cellulose / %         | 13.89±0.56   | 12.88±0.53   | 12.76±0.38   | 11.24±0.41   | 9.27±0.57    | 11.69±0.38   |
|                             | 碳/氮 Carbon/Nitrogen       | 41.83±1.13   | 32.14±0.80   | 36.47±1.19   | 25.90±1.26   | 34.62±1.31   | 25.69±0.20   |
|                             | 碳/磷 Carbon/Phosphorus     | 560.55±6.18  | 472.20±9.23  | 551.53±24.33 | 355.88±11.82 | 372.57±9.98  | 540.86±5.20  |
|                             | 氮/磷 Nitrogen/Phosphorus   | 13.41±0.27   | 14.70±0.57   | 15.13±0.83   | 13.75±0.26   | 10.77±0.17   | 21.06±0.29   |
|                             | 木质素/氮 Lignin/ Nitrogen    | 25.48±0.82   | 22.30±0.07   | 26.02±1.16   | 21.87±0.15   | 32.09±0.52   | 25.42±0.71   |
|                             | 木质素/纤维素 Lignin/ Cellulose | 2.10±0.02    | 2.57±0.01    | 2.74±0.01    | 3.42±0.04    | 4.67±0.07    | 3.58±0.01    |
| 香樟 <i>C. camphora</i>       | 碳 Carbon / (g/kg)         | 439.69±39.62 | 445.63±18.86 | 451.85±13.81 | 457.35±32.53 | 449.45±33.59 | 392.70±4.01  |
|                             | 氮 Nitrogen / (g/kg)       | 9.63±0.30    | 11.05±0.94   | 11.86±0.91   | 16.51±0.18   | 13.27±0.70   | 14.62±0.36   |
|                             | 磷 Phosphorus / (g/kg)     | 0.57±0.02    | 0.61±0.01    | 0.69±0.03    | 1.16±0.03    | 0.68±0.06    | 0.70±0.03    |
|                             | 木质素 Lignin / %            | 28.30±0.86   | 30.10±1.36   | 31.55±1.03   | 34.19±1.22   | 38.24±0.91   | 42.46±0.91   |
|                             | 纤维素 Cellulose / %         | 13.64±0.49   | 12.62±0.16   | 11.89±0.36   | 11.20±0.12   | 10.27±0.45   | 7.92±0.58    |
|                             | 碳/氮 Carbon/Nitrogen       | 45.62±2.89   | 40.46±2.09   | 38.23±2.49   | 27.69±1.67   | 33.87±1.71   | 26.87±0.48   |
|                             | 碳/磷 Carbon/Phosphorus     | 767.13±44.46 | 736.02±15.18 | 651.83±9.58  | 394.14±18.34 | 663.54±7.51  | 559.61±19.13 |
|                             | 氮/磷 Nitrogen/Phosphorus   | 16.82±0.17   | 18.24±1.21   | 17.10±1.03   | 14.24±0.21   | 19.63±1.14   | 20.83±0.63   |
|                             | 木质素/氮 Lignin/ Nitrogen    | 29.38±0.61   | 27.14±2.03   | 26.72±1.74   | 20.71±0.30   | 28.92±1.28   | 29.01±0.28   |
|                             | 木质素/纤维素 Lignin/ Cellulose | 2.08±0.01    | 2.36±0.02    | 2.66±0.02    | 3.05±0.05    | 3.74±0.03    | 5.37±0.11    |
| 柳杉 <i>C. fortunei</i>       | 碳 Carbon / (g/kg)         | 484.43±13.49 | 481.51±18.41 | 452.76±25.09 | 453.51±22.91 | 448.47±27.03 | 426.28±36.91 |
|                             | 氮 Nitrogen / (g/kg)       | 12.74±0.34   | 17.56±0.95   | 16.76±1.03   | 9.88±0.30    | 17.18±0.86   | 18.81±0.80   |
|                             | 磷 Phosphorus / (g/kg)     | 1.01±0.01    | 1.06±0.02    | 1.13±0.02    | 0.97±0.06    | 1.52±0.10    | 1.13±0.10    |
|                             | 木质素 Lignin / %            | 28.50±0.82   | 34.91±0.45   | 38.21±0.76   | 40.61±0.18   | 42.50±1.38   | 36.51±1.02   |
|                             | 纤维素 Cellulose / %         | 14.32±0.88   | 10.80±0.48   | 8.85±0.56    | 7.36±0.35    | 8.51±0.38    | 6.81±0.47    |
|                             | 碳/氮 Carbon/Nitrogen       | 38.04±0.12   | 27.44±0.66   | 27.03±0.27   | 45.89±1.08   | 26.09±0.34   | 22.64±1.08   |
|                             | 碳/磷 Carbon/Phosphorus     | 479.17±6.75  | 452.12±10.39 | 400.56±15.43 | 468.19±7.44  | 294.78±8.30  | 376.14±13.74 |
|                             | 氮/磷 Nitrogen/Phosphorus   | 12.60±0.16   | 16.48±0.67   | 14.82±0.66   | 10.21±0.40   | 11.30±0.40   | 16.64±0.87   |
|                             | 木质素/氮 Lignin/ Nitrogen    | 22.36±0.22   | 19.95±0.96   | 22.81±1.25   | 41.17±1.21   | 24.73±0.71   | 19.32±0.66   |
|                             | 木质素/纤维素 Lignin/ Cellulose | 2.01±0.02    | 3.24±0.08    | 4.28±0.10    | 5.55±0.12    | 5.00±0.03    | 5.26±0.03    |
| 麻栎 <i>Q. acutissima</i>     | 碳 Carbon / (g/kg)         | 490.11±15.99 | 444.93±12.80 | 484.82±11.32 | 436.94±20.03 | 437.06±18.71 | 420.53±32.50 |
|                             | 氮 Nitrogen / (g/kg)       | 9.82±0.31    | 15.00±0.28   | 15.47±0.79   | 11.72±0.48   | 16.07±1.25   | 20.96±0.49   |
|                             | 磷 Phosphorus / (g/kg)     | 0.88±0.02    | 1.02±0.06    | 0.98±0.03    | 0.71±0.06    | 1.54±0.30    | 1.15±0.17    |
|                             | 木质素 Lignin / %            | 28.16±0.58   | 29.56±0.77   | 33.87±0.53   | 36.10±1.20   | 41.96±0.79   | 43.58±1.50   |
|                             | 纤维素 Cellulose / %         | 13.80±0.30   | 12.41±0.45   | 10.89±0.45   | 10.88±0.35   | 8.87±0.69    | 10.02±0.37   |
|                             | 碳/氮 Carbon/Nitrogen       | 49.90±0.21   | 29.66±0.48   | 31.39±1.09   | 37.28±0.61   | 27.27±1.40   | 20.05±1.12   |
|                             | 碳/磷 Carbon/Phosphorus     | 555.91±9.94  | 436.48±14.87 | 496.28±5.65  | 617.73±27.27 | 289.23±37.60 | 370.02±31.78 |
|                             | 氮/磷 Nitrogen/Phosphorus   | 11.14±0.21   | 14.72±0.70   | 15.83±0.57   | 16.58±0.92   | 10.61±1.29   | 18.53±2.16   |
|                             | 木质素/氮 Lignin/ Nitrogen    | 28.77±0.78   | 19.81±0.30   | 21.96±0.92   | 30.79±0.80   | 26.23±1.81   | 20.78±0.27   |
|                             | 木质素/纤维素 Lignin/ Cellulose | 2.05±0.01    | 2.40±0.03    | 3.10±0.03    | 3.30±0.01    | 4.74±0.18    | 4.37±0.05    |

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