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博 士 学 位 论 文

皆伐火烧对杉木林和栲树林碳、氮动态的影响

Effects of Clear-cutting and Slash Burning on Dynamics of Carbon and Nitrogen in Chinese Fir and *Castanopsis fargesii* Forests

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摘　要

作为重要商品林基地的我国亚热带地区，把大面积常绿阔叶林皆伐后进行全面火烧，是我国南方集体林区经营杉木人工林的主要营林技术环节之一，但大面积火烧将造成迹地养分损失、水土流失、土壤物理性质退化等。营林用火已在温带森林的规定火烧、热带地区的刀耕火种中得到大量研究。早期有关研究主要集中在火烧对 N、P 等森林生长限制元素的损失及其对森林长期生产力、水文状况、径流化学的影响上；随着人们对全球环境变化的关注，皆伐火烧对生态系统 C、N 循环的影响研究在近十几年逐渐受到重视，但目前有关皆伐火烧后我国亚热带地区常绿阔叶林 C、N 动态的研究未见报道。作为森林生态系统主要 CO_2 源的土壤呼吸（约 68±4 Pg C·a^{-1}），它的微小变化不但会引起大气中 CO_2 浓度的明显改变，更会影响森林贮存 C 能力。皆伐火烧后土壤生境条件发生显著变化，土壤呼吸将作出怎样的响应已引起人们的极大关注。目前国外对温带林土壤呼吸的特征、影响因素及其对气候变化的响应等研究较多，如何对土壤各组分呼吸（土壤自养呼吸和异养呼吸）进行有效分离则研究较少。我国对森林土壤呼吸研究则与国外有相当差距，皆伐火烧下土壤呼吸及各组分呼吸动态更未有涉及。本文以福建沙县异州杉木林和栲树林为研究对象，通过野外定位观测和室内分析，在研究皆伐火烧影响林分 C、N 库和土壤肥力的基础上，着重探讨土壤呼吸及各组分呼吸对皆伐火烧的响应及机制，这对进一步拓展我国森林土壤研究，深入分析森林 C 汇能力有所裨益，为正确评价森林用火提供重要基础资料，并对我国亚热带山区森林管理者科学用火具有一定指导意义。本文主要得出以下结论：

1. 皆伐前杉木林 C、N 库总量分别为 238 t·hm^{-2} 和 8405 kg·hm^{-2}，栲树林的分别为 338 t·hm^{-2} 和 10223 kg·hm^{-2}。两林分乔木层为主要的 C 贮库，而林分主要 N 库存在于土壤层。杉木林和栲树林乔木层 C 库分别占林分 C 库总量的 53%和 62%，矿质土壤层 N 库则分别占林分 N 库总量的 92%和 84%。灌木草本层和枯枝落叶层 C、N 总贮量分别约占林分 C、N 总贮量的 2%。皆伐后杉木林树干（包括树皮）和粗枝中 104 t·hm^{-2} C 和 287 kg·hm^{-2} N 移出林地，分别占其林分 C 和 N 总贮量的 44%和 3%；栲树林通过树干（包括树皮）和粗枝迁移的 C、N 量分别为 156 t·hm^{-2} 和 738 kg·hm^{-2}，分别占其林分 C、N 贮量的 46%和 7%。两林分皆伐后，土壤 C 和 N 贮量发生损失。皆伐后 3 个月，杉木林和栲树林土壤有机 C 贮量分别损失 26%和 32%；土壤全 N 分别损失 12%和 11%。可见

皆伐使林分 C、N 总贮量明显减少，需进一步研究 C 和 N 贮量的变化。

2．采伐迹地火烧后杉木林和栲树林采伐剩余物养分（N、P、K）损失总量分别为 302.5 kg·hm^{-2} 和 644.8 kg·hm^{-2}，损失率分别为 56.5%和 55.1%。表土灼烧使两林分表土 N、P 损失分别达~20%和~10%，但土壤 K 总量增加。火烧后 1 年杉木林表土侵蚀损失的 N、P 和 K 总量为 365.5 kg·hm^{-2}，栲树林的为 465.3 kg·hm^{-2}，而且栲树林表土侵蚀损失的养分量占火烧前表土养分量的比例（约 3%）也略大于杉木林（约 2%）。火烧后 5 天土壤结构得到改善、养分矿化增强、土壤微生物数量、酶活性及呼吸强度均增加。但火烧后 1 年两种林分土壤有机质和有效养分含量及其他大部分土壤性质下降。表明火烧短时期内促进了立地生产力的提高，但由于我国南方山地地形破碎，坡度较大，雨量充沛，雨强较大，雨量集中，火烧后裸露幼林地水土肥流失较为严重。因此必须根据具体情况采用不同的措施清理采伐剩余物。

3．杉木林和栲树林火烧后土壤有机 C 和全 N 贮量发生了明显的变化。火烧后 5 天、1 年和 5 年表层土壤有机 C 和全 N 贮量均显著低于火烧前水平（$P < 0.05$）。火烧后 5 年杉木林土壤有机 C 和全 N 贮量分别占火烧前的 85%和 77%，栲树林相应的土壤有机 C 和全 N 贮量分别占火烧前的 72%和 73%。可见火烧后土壤有机 C 和全 N 的损失明显，要做到生态恢复是一个长期的森林发展过程。

4．从 2001 年 10 月至 2003 年 12 月首次对杉木林和栲树林皆伐、火烧后土壤呼吸动态进行对比研究，并探讨皆伐火烧的影响机制。两种林分土壤呼吸速率季节变化均呈单峰曲线，最大峰值出现在 2002 年和 2003 年的 5 月至 7 月。与不采伐的杉木林和栲树林土壤呼吸速率（即对照）相比，2001 年 10-12 月两林分皆伐地和火烧地的土壤呼吸速率都增加，但到 2002 年和 2003 年时反而低于对照地。两林分皆伐地和火烧地土壤温度与对照地的均无显著差异，但皆伐地和火烧地土壤含水量低于对照地。两林分土壤呼吸与土壤温、湿度的关系采用双因素模型（$R = ae^{bT}W^{c}$）拟合结果优于仅考虑土壤温度或土壤湿度的单因素模型。与对照地相比，皆伐地和火烧地土壤呼吸速率与土壤温度和土壤湿度的相关性较弱。两林分皆伐地和火烧地土壤呼吸的 Q_{10} 值低于对照地的。可见，林地干扰后土壤呼吸除受土壤温、湿度影响外，还与凋落物数量和质量、根系呼吸、土壤有机质数量和质量的变化有关。在 2001 年 10-12 月、2002 年和 2003 年栲树林对照地、皆伐地和火烧地的土壤呼吸通量均显著高于杉木林（$P < 0.05$），但其是否不利于大气

CO_2吸存，还有待于对栲树林和杉木林生态系统的 C 平衡分析。

5．将传统的挖壕沟法运用到皆伐火烧后土壤各组分呼吸（根系呼吸、枯枝落叶层呼吸、矿质土壤呼吸）的分离研究这一全新领域，探讨土壤各组分呼吸对皆伐火烧的响应模式和机制。除杉木林和栲树林皆伐地和火烧地根系呼吸外，两林分皆伐地和对照地枯枝落叶层呼吸速率以及皆伐地、火烧地和对照地的矿质土壤呼吸速率的季节变化模式与土壤总呼吸的类似，均呈单峰曲线，最大值出现在春末或夏初。两林分皆伐、火烧处理后的前 3 个月（2001 年 10 月至 12 月），根系呼吸高于对照，但随后迅速降低甚至消失。类似地，杉木林和栲树林皆伐地枯枝落叶层（含采伐剩余物）呼吸速率分别在伐后的前 18 个月（2001 年 10 月至 2003 年 3 月）和前 14 个月（2001 年 10 月至 2002 年 11 月）高于对照地；矿质土壤呼吸速率分别在杉木林火烧后的前 8 个月（2001 年 10 月至 2002 年 5 月）和栲树林火烧后的前 11 个月（2001 年 10 月至 2002 年 8 月）高于对照地和皆伐地，而两林分皆伐地矿质土壤呼吸速率在伐后的前 5-6 个月（2001 年 10 月至 2002 年 2-3 月）高于对照地。从 2003 年 4 月至 12 月，两林分皆伐地枯枝落叶层呼吸速率和矿质土壤呼吸速率及火烧地矿质土壤呼吸速率均低于对照地。栲树林对照地根系呼吸、枯枝落叶层呼吸和矿质土壤呼吸的年通量均高于杉木林对照地。2002-2003 年杉木林和栲树林对照地根系呼吸平均年通量分别占其土壤呼吸年通量的 35%和 46%，而两林分皆伐地和火烧地的土壤呼吸以矿质土壤呼吸为主，比例超过 60%。两林分对照地土壤各组分呼吸与土壤温度的相关性高于皆伐地和火烧地。皆伐地和火烧地土壤各组分呼吸与土壤湿度的相关性高于与土壤温度的，但对照地却相反。双因素关系模型（$R = ae^{bT}W^{c}$）拟合结果优于仅考虑土壤温度或土壤湿度的单因素关系模型，土壤温度和土壤湿度共同解释不同年份对照地各组分呼吸速率季节变化的 83%以上。皆伐火烧后土壤各组分呼吸与土壤温、湿度的相关性减弱。需进行更长时间的定位观测，以更好地评价森林经营活动对土壤 C 吸存的影响。

关键词：皆伐火烧；有机碳；全氮；杉木林；栲树林

Effects of Clear-cutting and Slash Burning on Dynamics of Carbon and Nitrogen in Chinese Fir and *Castanopsis fargesii* Forests

Abstract

Chinese fir (*Cunninghamia lanceolata*) is one of the most important plantation tree species in China in terms of planting area, yield and timber usage. The history of managing this plantation exceeds 1000 years in China. In recent decades, many pure Chinese fir stands were established in the southern part of China for an expected highly economic return, leading to a sharp decline in the area of natural forest of broadleaf trees. It is a traditional silvicultural practice in South China to extablish a plantation of Chinese fir by clear-cutting natural forests, slash burning and site preparation. However, timber harvest and slash burning can cause a substantial loss and redistribution of organic matter and nitrogen. Further, yield decline and land degradation in such disturbed ecosystem have become serious problems, possibly due to high precipitations, steep slopes and fragile soils in this region. How the soil fertility can be maintained in the successively planted Chinese fir stands has received considerable concern. In view of increasing awareness about anthropogenic emissions of carbon as a contributor to global warming and the role of forests as C sinks, information about C and N pools and changes associated with disturbances, including forest management, is needed. Especially, a good understanding on how soil CO_2 efflux having been impacted by forest management practices is necessary for predicting carbon sequestration. Many attempts have been made, mainly in temperate and tropical forests, to estimate the changes of C and N stored in world forests associated with clear-cutting and slash burning. Littal has been carried out in forests of southern China, a most important area of subtropical forests in the world. Furthermore, few studies have monitored the components of soil respiration before and after disturbance. The aim of this study is to investiagte in detail the effects of clear-cutting and slash burning on the storages of C and N, soil fertility, soil respiration and its components in a Chinese fir plantation and *Castanopsis fargesii* forest, located in the Yizhou State Forestry Centre in

Fujian Province, China. This study will enhance our understanding on forest carbon and nitrogen cycles and help to set up a guideline for forest fire management.

Major conclusions were summarized as follows:

1. Carbon and nitrogen pools in both Chinese fir and *Castanopsis fargesii* forests before clear-cutting were examined by comparing C and N contents in above- and below-ground biomass of tree, understorey plants and forest floor + mineral soil (0-100 cm). The taotal C and N in Chinese fir plantation before clear-cutting were 238 t·hm^{-2} and 8405 kg·hm^{-2}, respectively. The corresponding values for *Castanopsis fargesii* forest were 338 t C·hm^{-2} C and 10223 kg N·hm^{-2}. For both forests, most of the C was in trees, whereas most of the N was in the soil. C and N pools in understorey plants and forest floor were small in the two forests (about 2% of the total of the ecosystem, respectively). During the process of clear-cutting, 104 t C·hm^{-2} and 287 kg N·hm^{-2} in stemwood with bark and coarse branches (>2 cm) were removed from the Chinese fir forest, compared to 156 t C·hm^{-2} and 738 kg N·hm^{-2} from the *Castanopsis fargesii* forest. After clear-cutting, substantial losses of soil C and N were found in both forests. The loss of soil organic C three months after clear-cutting was 26% in Chinese fir site and 32% in *Castanopsis fargesii* site. The corresponding losses of soil total N in Chinese fir and *Castanopsis fargesii* forests were 12% and 11%, respectively. Our results indicated that clear-cutting had caused ramarkable short-term changes in ecosystem C and N in both sites. However, further study is warranted to investigate how long these changes will last.

2. The nutrient (the sum of N, P and K) removed by burning residues was estimated at 302.5 kg·hm^{-2} (56.5% of the total in residues) in Chinese fir and 644.8 kg·hm^{-2} (55.1% of the total) in *Castanopsis fargesii* site. Firing had reduced the total N and P in topsoil by ~20% and ~10%, respectively in both forests, while the total K had been increased. The total loss of nutrient (N, P and K) one year after burning through surface erosion was 365.5 kg·hm^{-2} in Chinese fir and 465.3 kg·hm^{-2} in *Castanopsis fargesii*. The proportion of lost nutrient through surface erosion in Chinese fir was greater than that in *Castanopsis fargesii*t. Improvement of soil structure and increase in mineralization of nutrients, associated with increased number of

microbes, enzymatic activities and elevated soil respiration rate occurred on day 5 after fire. However, organic matter, available nutrient contents and most of other soil parameters in topsoils had declined one year after fire in both Chinese fir and *Castanopsis fargesii* sites. These results suggested that the short-term productivity can be stimulated shortly after firing but reduced thereafter due to soil and water losses in South China, where highly intensive precipitation, steep slopes and fragile soil factors can be expected. Therefore, silvicultural measurements should be developed in plantation management to provent nutrient loss.

3. Slash burning caused remarkable changes in surface soil C and N in the two sites. In post-burn samples (taken on day 5, at the end of year 1, and year 5 at the depth of 0-10 cm) from both sites, the organic C and the total N were significantly lower than that in pre-burn samples ($P < 0.05$). Compared to the pre-burn levels, the organic C storage in surface soil 5 years after burning was only 85% in Chinese fir and 72% in *Castanopsis fargesii*, while the total N storages were 77% and 73%, correspondingly. Results suggested that the recovery of soil organic C and total N after fire was a long-term process.

4. Effects of clear-cutting and slash burning on soil respiration were investigated in Chinese fir and *Castanopsis fargesii* sites from late October 2001 to December 2003 . Soil respiration was measured as CO_2 evolved in situ using a method of soda lime absorption. Respiration levels varied seasonally with maximum rates observed in May to July. Clear-cut and burned plots showed increases in CO_2 evolution rates and the total soil respiration in October-December 2001 compared with that of controls in both sites. In 2002 and 2003, respiration rates as well as accumulated CO_2 efflux were significantly lower in both treatments than that of controls. Soil temperature and moisture content at 10 cm depth were monitored in treatments and controls. There were no significant difference in soil temperature among treatments in each site, while clear-cut and slash burned treatments resulted in reduced soil moisture contents. Relationships between soil respiration and soil environmental variables were examined via a regression analysis. A combination of soil temperature and soil moisture content proved to be a reliable predictor of CO_2 evolution in control plots, but not in clear-cut and burned plots. The Q_{10} values in clear-cut and burned plots were lower than that