人为干扰对鼎湖山马尾松林土壤细根和有机质的影响

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摘要:通过处理(根据当地习惯收割凋落物和林下层)和保护(无任何人为干扰)样地的比较试验,1990～1995 年期间研究了人为干扰对鼎湖山生物圈保护区马尾松 (*Pinus massoniana*) 林土壤细根和有机质的影响。在此 5a 的研究期间,由于人为干扰活动而直接从处理样地取走的林下层和凋落物总量为 21.7 t/hm²。在保护样地,林下层生物量从 2.2 t/hm² 增加至 11.10 t/hm²,地表凋落物(包括枯死的林下层)量则从 3.0 t/hm² 增加至 13.3 t/hm²。收割林下层和凋落物这种人为干扰活动对林地土壤细根生物量的影响不明显,但却显著降低土壤轻腐殖质(Soil light organic matter)量。在细根分解过程中,其分解速率在处理样地(试验结束时细根残存量占起始量的 40.8%)显著高于在保护样地(试验结束时细根残存量占起始量的 44.3%);与 Ca、Mg 和 K 元素不同,N 和 P 两种元素的释放速率在处理样地显著高于保护样地,表明这种人为干扰活动不仅直接取走所收割的林下层和凋落物中的养分,而且还可能增加林地有效养分的流失潜力。

关键词:人为干扰;土壤有机质;细根;分解;马尾松;南亚热带

Effects of human impacts on fine roots and soil organic matter of a pine forest in subtropical China

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Abstract: Effects of human impacts on fine roots and soil organic matter of a pine forest in subtropical China were studied by comparing treatment (harvesting understory and litter according to practice of local people) and control (no harvest) plots in a pine forest from 1990 to 1995. During this studied period, the total amount of material harvested by this practice in treatment plots was 21.7 t/hm². In control plots, the standing stocks of understory increased from 2.2 to 11.1 t/hm² at a significantly linear pattern, while the standing stocks of litter (including dead understory) increased from 3.0 to 13.3 t/hm². Harvesting practice had no significant effect on the standing fine root biomass, but significantly reduced soil light organic matter in pine forest. Mass loss in decomposing fine roots was linear in both control and treatment plots. Fine roots decomposed significantly faster in treatment (40.8 percent of initial mass remaining at the end of the 448 day experiment) than in control plots (44.3%). Nutrient losses from decomposing fine roots were significantly faster in treatment plots than in control plots for N and P, but there were no significant difference for other elements. These trends indicated that there could be a higher potential for nutrient loss by harvesting understory and litter (more nutrients available for understory uptake and litter mobilizing N during early stage of decomposition) and by leaching in treatment plots.

Key words: human-impact; soil organic matter; fine roots; decomposition; *Pinus massoniana*; subtropical China

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1 Introduction

Conversion to non-forest use is considered to be one of the largest threats to tropical forests worldwide. Currently, tropical deforestation is estimated to be on the order of 10 million hm^2 per year during the 1990s[1]. However, of equal concern, but yet poorly known, is degradation of tropical forests, including reductions in biomass, fragmentation, and loss in biodiversity[2]. Degradation is generally the cause when a forest has a significantly lower biomass than would be expected given the climate conditions and the soil type[3]. Factors behind degradation included: intensive harvesting of biomass for timber and fuelwood, unsustainable agriculture, fires, and overgrazing by domestic animals. Removal of biomass causes nutrient losses and changes in soil physical and chemical characteristics[4~7]. The amount of nutrient loss depends on the intensity of the activities, environmental factors, and type and successional state of the forest. If nutrient losses cannot be recovered during regrowth, forests often become degraded through time[8, 9]. Thus, it is important that the effects of human-impacts on the forest ecosystem structure, function and dynamics be well understood to develop sustainable forest management plans. However, disturbed ecosystems are among the least studied in the tropics[10].

Most of the land originally covered with primary forests in southern China has been degraded by human activities during the past several hundred years[11]. In extreme cases, the land became completely non-vegetated[12]. Attempts to reverse this process of land degradation have been initiated in the southern region of China. Over the last few decades, large areas have been reforested with a native pine species, *Pinus massoniana*. Forests planted with this species currently are the largest planted forest area in southern China and the largest area of pine forests in China[13, 14]. Cutting of trees is prohibited, but harvesting of understory and litter is allowed to satisfy human fuel needs. Compared with whole-tree harvest, this practice removes less biomass from the forests.

Previous research on the organic matter and nutrient cycling dynamics in these disturbed pine forests in southern China demonstrated that harvesting understory and litter removed substantial quantities of nutrients, and appeared to exceed most nutrient inputs from atmospheric deposition[15, 16]. This harvesting has also other indirect effects: it increased the potential for leaching losses of nitrogen[7]. Compared with remnant mature forests of the region, rehabilitated forests (reforested but no understory and litter harvesting), and other tropical pine forests, the disturbed forest appears to have lower productivity and lower nutrient levels[7, 14~17]. The current low site productivity appears to be mainly caused by the practice of biomass removal on this initially degraded site[7, 14~16].

In response to nutrient poor sites, forest often develop a dense fine root system to capture or extract nutrients to maintain a tight nutrient cycle[18, 19]. Because *Pinus massoniana* can tolerate nutrient-poor soils and low soil moisture, it is often found on barren hills and serves as a primary species in forest succession[14]. Fine roots may be especially important in this degraded human-impacted pine forests, but there is no information available on fine roots in any of these pine forests to ascertain their importance.

The goals of the present study were to: (1) determine the role of fine roots on nutrient cycling in the disturbed pine forest; (2) effects of harvesting understory and litter on soil light organic matter; (3) effects of harvesting understory and litter on fine root decomposition and its nutrient dynamic. Results from such studies will provide insight into the mechanisms underlying the low productivity, low biomass, and low nutrient availability observed previously in the degraded site[14~16]. This has important application to the field of ecosystem rehabilitation and restoration[20].

2 Methods

2.1 Description of study site

This study was conducted in a pine forest in the UNESCO/MAB Dinghushan Biosphere Reserve (DHSBR) in southern China. In 1956, the area became the first nature reserve in China and was affiliated with the Chinese Academy of Sciences. In 1978, a National Forest Ecosystem Experimental Station was established in the reserve. One year later, the reserve was placed in the UNESCO/MAB network of reserves for the humid tropics. The biosphere reserve lies in the middle part of Guangdong Province (112°10′ E longitude and 23°10′ N latitude).

The DHSBR occupies an area of approximately 1200 hm^2. There are mainly three forest types in this reserve: pine (disturbed), pine-broadleaf mixed (rehabilitated), and monsoon evergreen broadleaf forests (MEBF-mature). The monsoon evergreen broadleaf forest, at about 250～300 m above sea level (asl) occupies 20% of the reserve area, the mixed pine and broadleaf forest, at about 200 m asl occupies 50%, and the pine forest, at about 50～200 m asl occupies 20%[21]. The pine forest was planted in about 1930. It has been under constant human pressures most of the time since it was planted (generally the harvesting of understory and litter)[11].

The reserve has a monsoon climate and is located in a subtropical moist forest life zone[11]. The mean annual rainfall of 1927 mm has a distinct seasonal pattern, with 75 percent of it falling from March to August and only 6 percent from December to February[22]. Annual average relative humidity is 80 percent. Mean annual temperature is 21.0℃, with an average temperature of the coldest (January) and hottest (July) month of 12.6℃ and 28.0℃, respectively[22].

The pine forest (disturbed) is dominated by *Pinus massoniana*. Pine trees range from 100 to 1 000 trees per hm^2, with diameters of 4 to 32 cm and heights of 3 to 11 m[15]. Age of pine trees range from 12 to 69 a, with a mean value of 30 a. In addition to pine trees, there were a few eucalyptus trees (*Eucalyptus robusta*). Understory species included grasses, ferns, vines and shrubs for a total of 43 species[15]. The soil in the pine forest is lateritic red earth formed from sandstone, the soil depth is generally less than 30 cm to bedrock[15].

To investigate the impact of harvesting understory and litter in the pine forest (disturbed) on soil organic matter and fine roots, we used a paired-plot design, with 20 replicates[15]. Each pair consisted of a treatment (continued harvest) and control (no harvest) plot, 10 m × 10 m in size, and surrounded by a 10 m wide buffer strip. In the treatment plots, local people continued to harvest litter and understory according to their practice (about 2 to 3 times a year) from the beginning of the experiment in May 1990. Control plots were protected from any harvesting. Each plot of a pair was similar in soil, slope, aspect, and elevation to its matched plot[15].

2.2 Field sampling

The amount of litter and understory removed by harvesting was estimated by inviting four women from the local village onto the treatment plots to harvest at their usual time and in their usual manner. Once to twice per year, litter only was raked from the plots. All the material in the treatment plots was raked from the plots and the fresh weight determined in the field. In addition, generally once a year in the fall, the treatment plots were subject to a full harvest. In this case, all understory plants were cut to the ground surface, weighed, and removed. Then the ground surface was raked and the material separated into pine needles and dead understory; fresh weights were measured for each component. Subsamples of all material from each plot were returned to the laboratory for wet-to-dry weight ratios[15].

In November 1990, all biomass (excluding trees) in three 1 m^2 randomly located quadrants in each of the 20 control plots in pine forest was harvested. Material was separated into live understory, dead understory, and pine litter. These components were weighted in the field and subsampled for wet-to-dry weight ratios. This sampling was repeated in Oct. 1991, Oct. 1992, Oct. 1993 and Oct. 1995. We used this data to determine the pattern of standing stocks of understory biomass and of litter (including dead understory and pine litter) in control plots of pine forest.

Soil organic matter can be divided into several fractions depending upon its role in soil nutrient dynamics[23]. The more labile fraction (active fraction)[23], comprised mainly of plant residues in various stages of decomposition, is most likely the fraction that would be most responsive to the removal of litter and understory and the fraction that would respond the fastest after the practice was stopped. This fraction is also referred to as the light organic matter fraction (LOM)[24]. Light organic matter is operationally defined as the fraction that passes a 2 mm sieve but not a 0.25 mm sieve after the soil is floated in water[24]. The heavy organic matter is the remnant of the total soil organic matter (SOM) after removing the LOM[24].

On Sept. 11, 1990, we collected from each plot in pine forest one composite soil sample to 10 cm depth using a standard soil probe (1.9 cm inside diameter) taken at seven random location throughout the plot in pine forest[24]. We used these cores to measure the light organic matter fraction (LOM) in the soil and the fine root biomass (≤ 5 mm diameter) in pine forest. Simultaneously, we collected an additional composite sample of three cores from approximately the plot center for determining soil bulk density. Samples were returned to the lab for separation and analysis[15,16]. Sampling was repeated on May 15, 1995.

Ingrowth cylinders were used in two randomly selected pairs of plots in pine forest to determine fine root growth rate (≤ 5 mm but mostly ≤ 2 mm diameter; dead roots were not separated). At the beginning of the study, soil from 0～10 cm depth was collected, air-dried, and roots removed by sieving. This material was then packed into 72 cylinders (10 cm tall, 7 cm diameter and 8 mm mesh)[25] at approximately the original bulk density. One Feb. 21, 1991, the cylinders were randomly placed in holes to 10 cm deep. Three replicate cylinders (12 at each collection) from each plot were collected at 2 months intervals from April 1991 to Feb. 1992. The cylinders were returned to the lab for separation and analysis.

Fine root decomposition in pine forest (≤ 2 mm diameter) and changes in nutrient concentration were determined by using closed, mesh litter bags. A total of 40 bags were prepared from 0.5 mm mesh polyvinyl screen of approximately 25 cm × 25 cm in dimension. Each bag was filled with about 10 g, water-cleaned and air-dried mixed fine root mass. On Jan. 28, 1995, the mixed fine root bags were evenly distributed in the soil (0～10 cm depth) among two randomly selected pairs of plots. Two replicate bags (8 at each collection) were collected from each plot at about 4, 8, 16, 32, 48 weeks after the start of the study. The bags were returned to the lab for separation and analysis.

2.3 Laboratory procedures and data analyses

For extracting LOM, the unground soil samples were placed in a 500 ml beaker, water was added, and the contents stirred several times[24]. The contents were sieved through a 2 mm and 0.25 mm sieve; this procedure was repeated until no more material was trapped on the sieves. The organic matter collected in the 0.25 mm sieve (LOM) was dried to a constant weight at 105℃. Subsamples were ashed at 550℃ and reweighed to provide the ash content. Results are reported on an ash-free basis.

The material collected on the 2 mm sieve was mostly fine roots (≤ 5 mm diameter); any coarse woody roots and non-root material was removed from the samples by hand. We used the water method to clean the soil off material from the ingrowth cylinders.

All root material from each experiment was dried to a constant weight at 40℃ immediately after finishing the process above. Root samples were ground to pass a 0.15 mm mesh sieve. Subsamples of roots were dried at 105℃, and all results are reported on 105℃ basis[15,16,24]. Fine root production rates were estimated with the methods described by Cuevas and Medina: fine root production was calculated as the mass of roots in the cylinder, expressed on an area basis, divided by the number of days of exposure[18].

All N concentrations of root material were determined with semimicro-Kjeldahl digestion[26] followed by detection of ammonium with a Wescan ammonia analyzer[27]. Concentrations for other elements (P, K, Ca, and Mg) were determined with the methods given in Anderson and Ingram: total phosphorus was determined by the colormetric method and the available cations were determined by the atomic absorption method. Nutrient content of a component was determined as the product of nutrient concentration and the mass of the component[24].

A paired t-test was used to test the differences in fine roots, light organic matter, fine root decomposition and its nutrients between treatment and control plots. Least square regression analysis was used to determine the relationship between fine root biomass and LOM. Differences for all tests were considered to be significant at the 0.05 level.

3 Results

3.1 Quantity of understory and litter

The total amount of material harvested in treatment plots each year during the period of 1990 to 1995 varied from 3.0 to 6.1 t/(hm^2 · a), with an average of 3.5 t/(hm^2 · a) (Fig. 1). The larger amount of material harvested in 1995 was most likely caused by no harvesting in 1994. Understory accounted for 53 to 80 percent of the total harvested material. The total amount of material harvested in treatment plots for the five years was 21.7 t/hm^2.

In control plots, however, after stopping harvesting practice the standing stocks of understory increased from 2.2 to 11.1 t/hm^2 at a significantly linear pattern ($R^2=0.974$, $p=0.002$, $n=5$, curve not showed in the Figures) with year during the studied period of 1990 to 1995 (Fig. 2). Similarly, the standing stocks of litter (including dead understory) in control plots increased from 3.0 to 13.3 t/hm^2 during the period of study.

3.2 Fine root biomass and light organic matter

The standing fine root biomass tended to be positively correlated with light organic matter in September 1990 for both control and treatment plots (p values for control and treatment plots was 0.026 and 0.086, respectively, Fig. 3). After five years in May 1995, a stronger correlation between standing fine root biomass and light organic matter was found in treatment

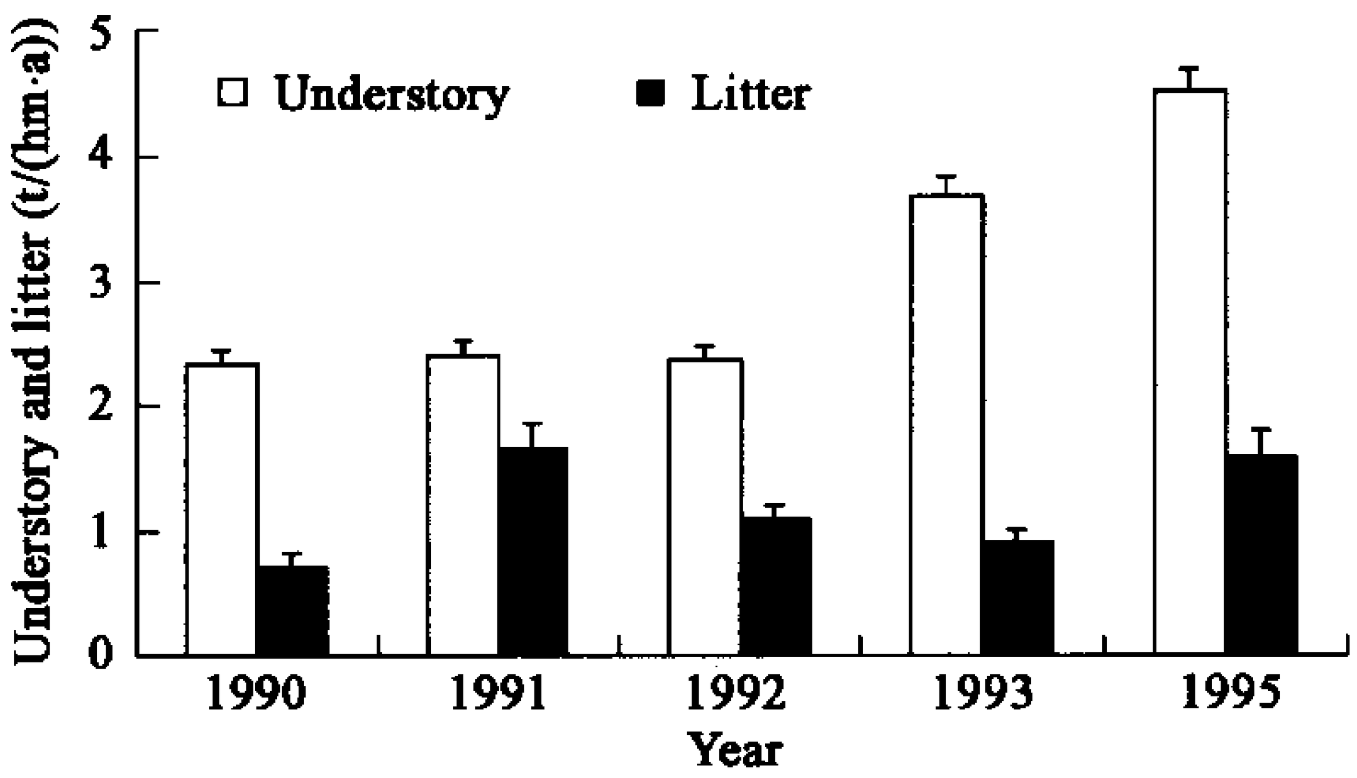

Fig. 1　Dyanamic of understory and litter harvested in the treatment plots of pine forest in Dinghushan biospherer reserve, southern China during 1990～1995

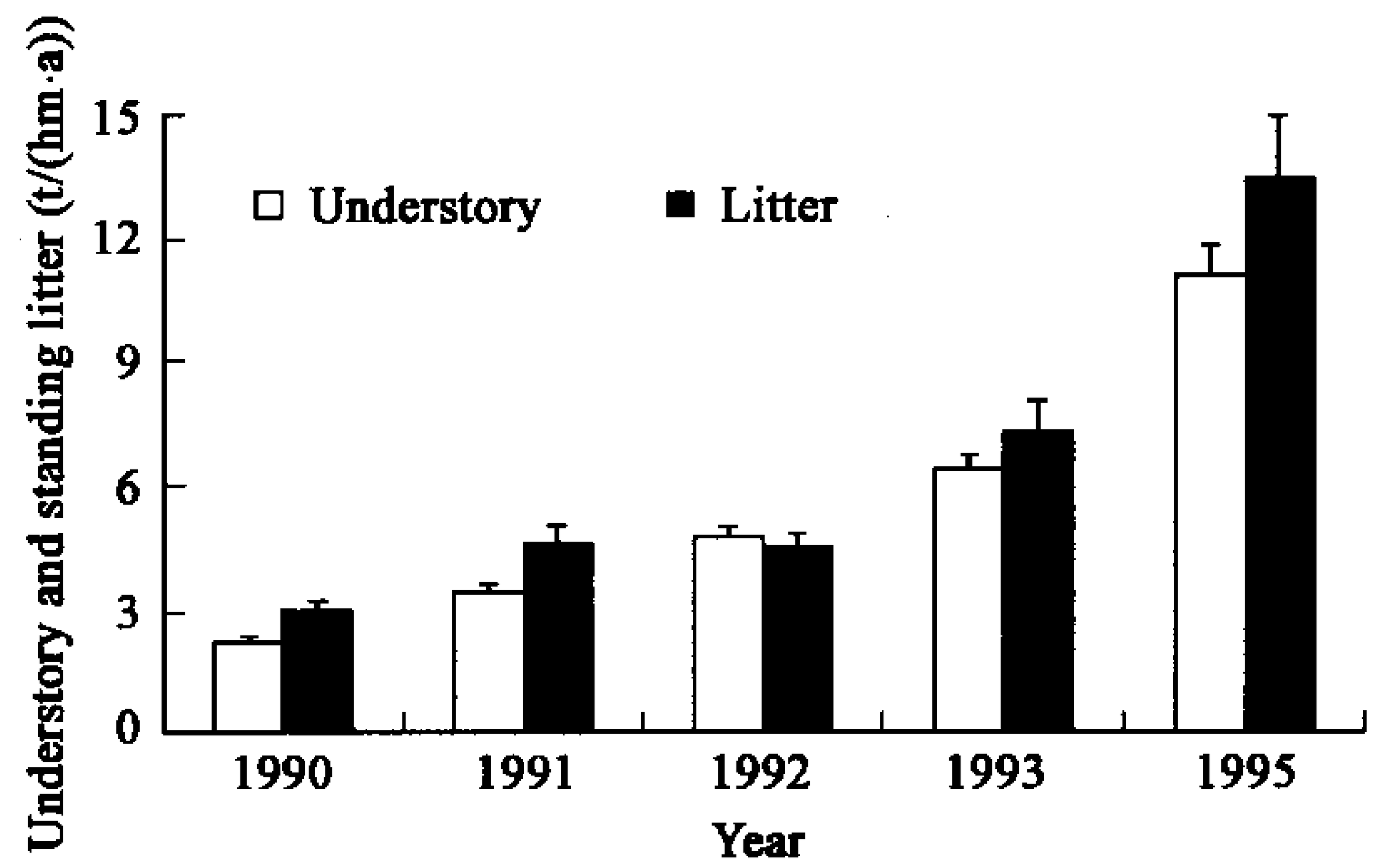

Fig. 2　Dyanamic standing stocks of unerstory and litter harvested in the control plots in pine forest in Dinghushan biosphere reserve, southern China during 1990～1995

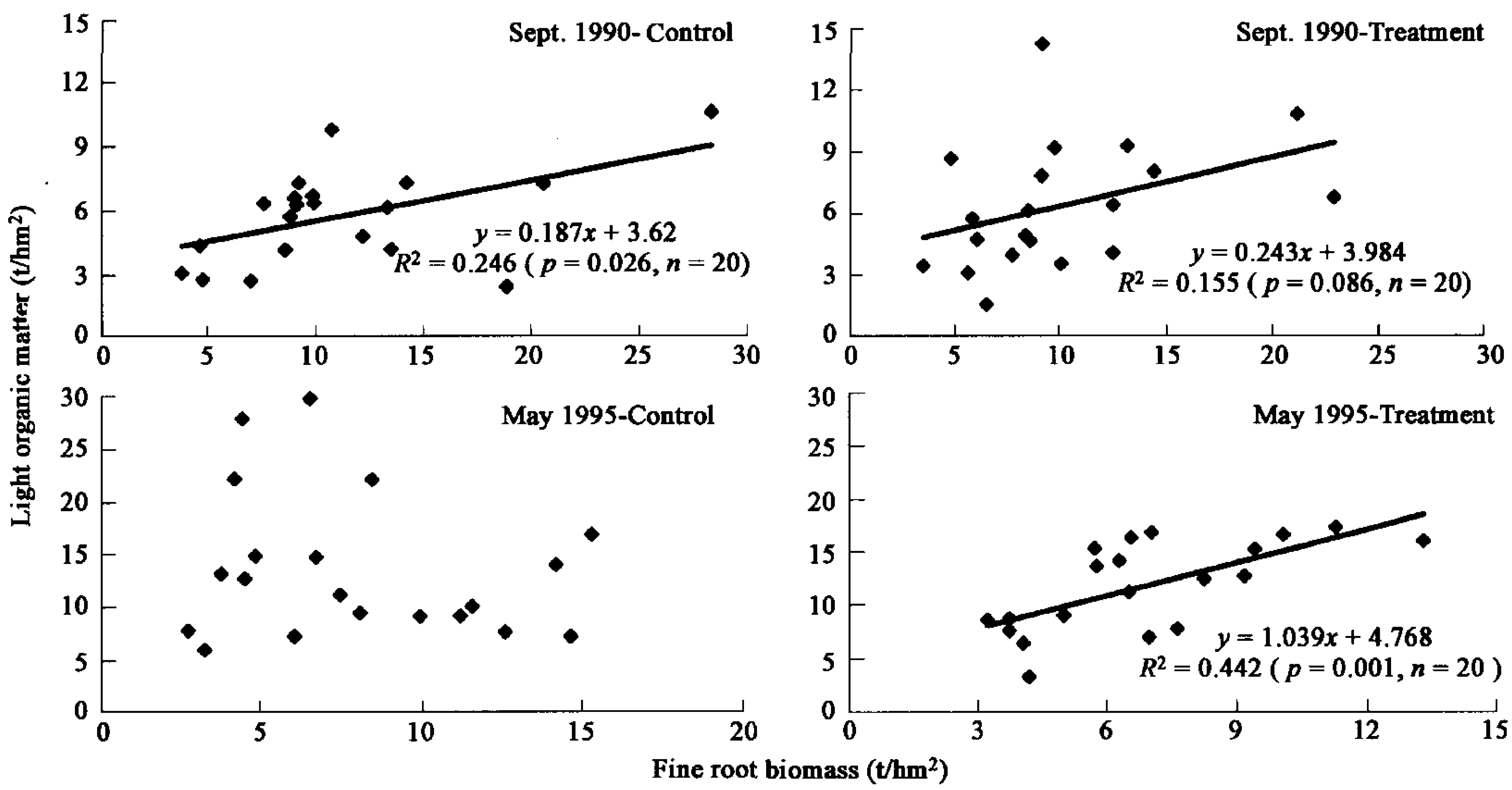

Fig. 3　Relationship of fine root biomass and soil light organic matter in Sept. 1990 and May 1995 in a pine forest of Dinghushan biosphere reserve, southern China

plots ($p<0.001$), but not significant in control plots (Fig. 3). This suggests that soil light organic matter depended more on fine roots in treatment plots than in control plots.

There was no significant difference in the standing fine root biomass between control and treatment plots in September 1990 ($p=0.254$) and in May 1995 ($p=0.244$, Fig. 4). The mean fine root production in 1991 tended to be higher in control plots (3.0 t/(hm^2 · a)) than in treatment plots (2.4 t/(hm^2 · a)), but not significantly ($p=0.077$). Neither was there a difference in light organic matter between control and treatment plots in September 1990 ($p=0.648$), but the light organic matter in control plots was significantly higher than that in treatment plots in May 1995 ($p<0.01$, Fig. 4). The differences of the standing fine root biomass and soil light organic matter in the same plots between September 1990 and May 1995 were partially caused by the seasonal variation. The results indicated that during the study period harvesting practice had no significant effect on the standing fine root biomass, but

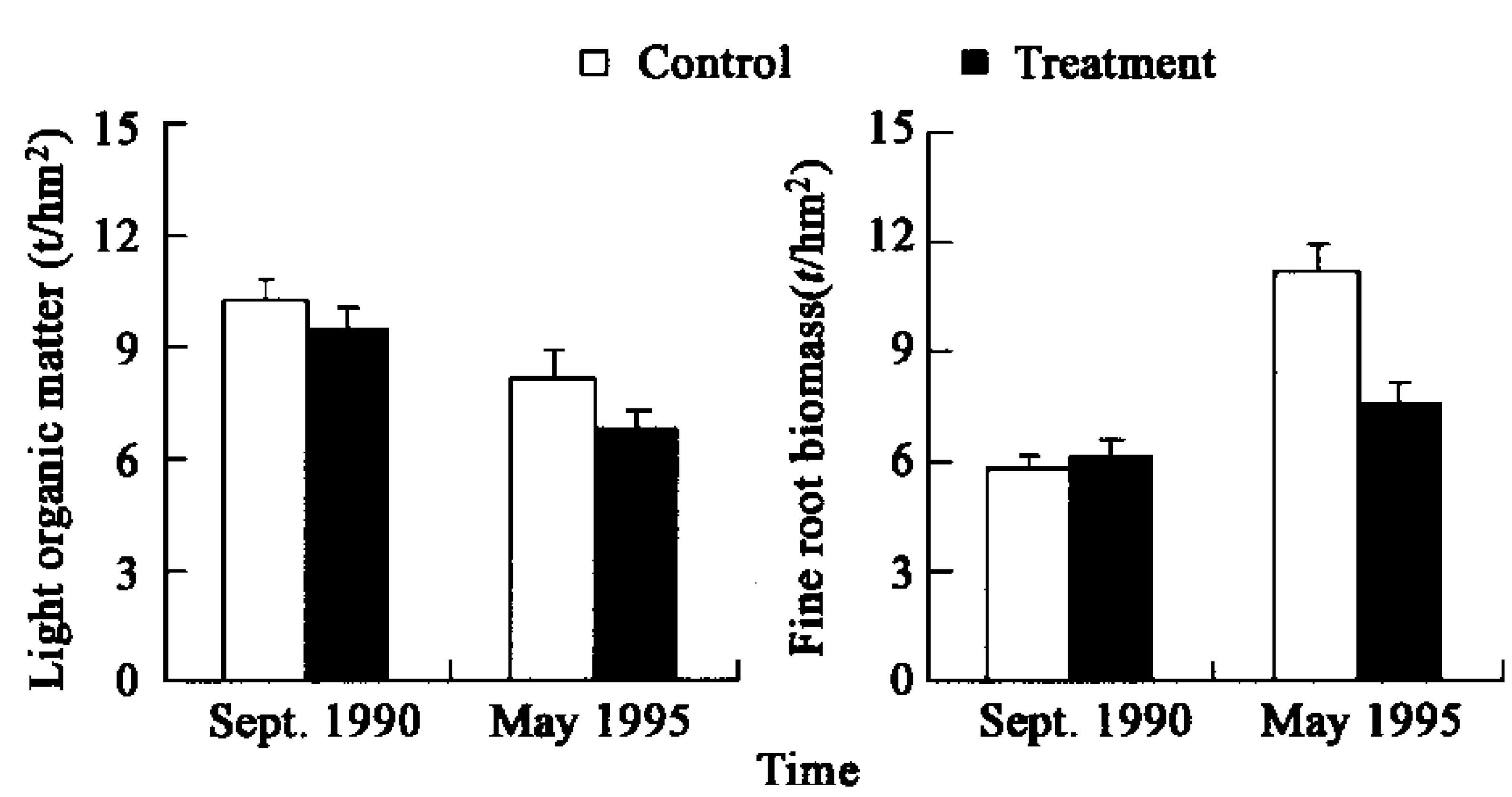

Fig. 4　A comparison of fine root biomass and soil light organic matter between control and treatment plots in a pine forest of Dinghushan biosphere reserve, southern China

* Significant at $p<0.01$

significantly reduced soil light organic matter in pine forest.

3.3 Fine root decomposition and its nutrient dynamic

The patterns of fine root decomposition in treatment and control plots were similar to each other, and they both did not follow the typical exponential model (Fig. 5). Instead, the pattern of decomposition was linear. The decomposition coefficients (k) were 0.47 and 0.44 (obtained from the linear regression equation for mass loss; Fig. 5) for treatment and control plots, respectively. During the first five sampling dates, no significant differences were found between treatment and control plots in decomposition rates, although the differences between them grew with time. However, comparisons of final mass remaining between treatment and control plots indicated that fine roots decomposed significantly faster in treatment plots (40.8 percent of initial mass remaining at the end of the experiment) than in control plots (44.3%; $p<0.05$; Fig. 5).

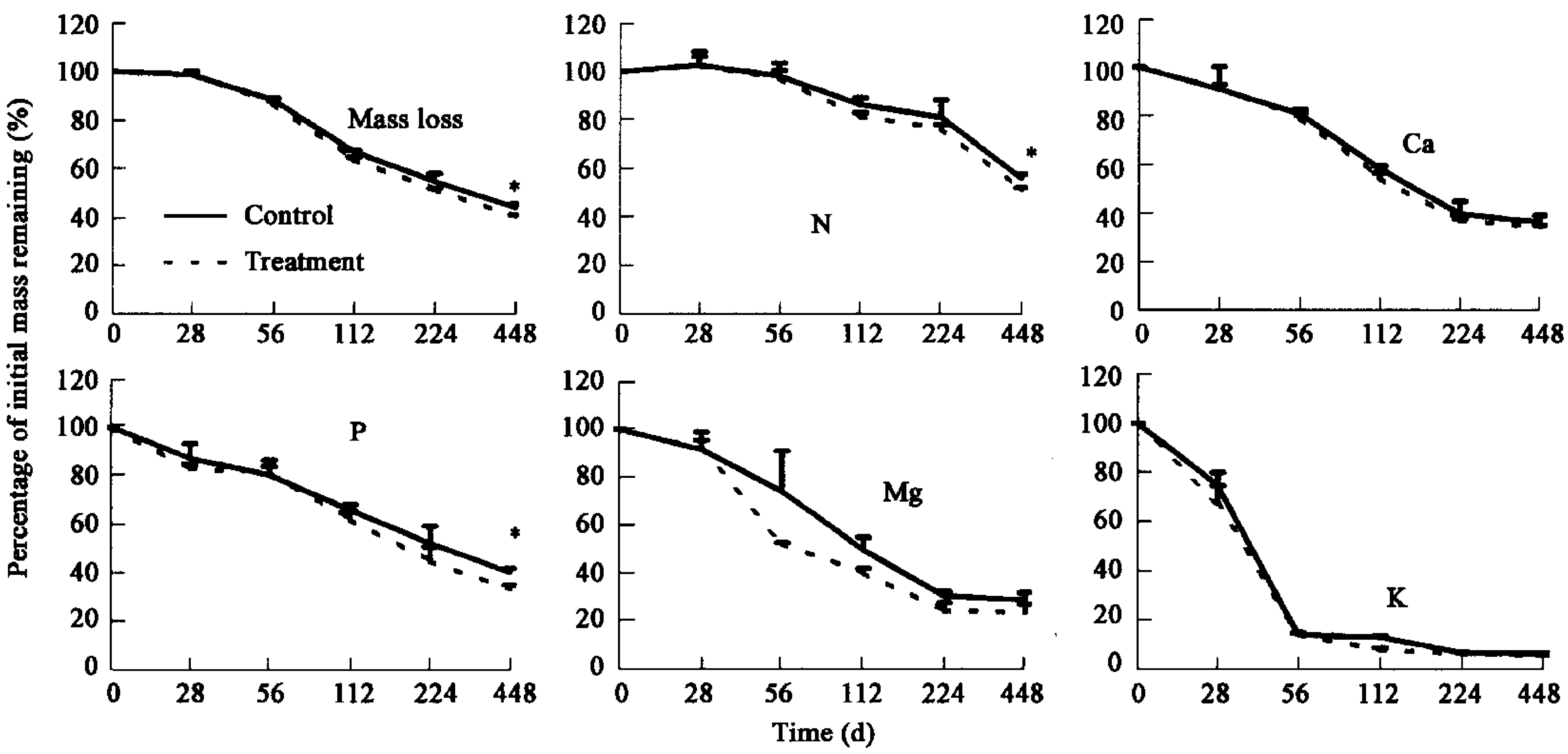

Fig. 5 Patterns of changes in mass and nutrient contents in decomposing fine roots in control and treatment plots of a pine forest in Dinghushan bioshere reserve, southern China

* Singnificant at $p<0.01$ level

The changes in nutrient concentrations in decomposing fine roots varied by element but not by site (Fig. 6). Nitrogen increased throughout the total period of the study. No changes occurred in Ca and P concentrations. Mg and K decreased for the whole period, but K decreased much faster (Fig. 6). No significant differences were found in nutrient concentrations between treatment and control plots.

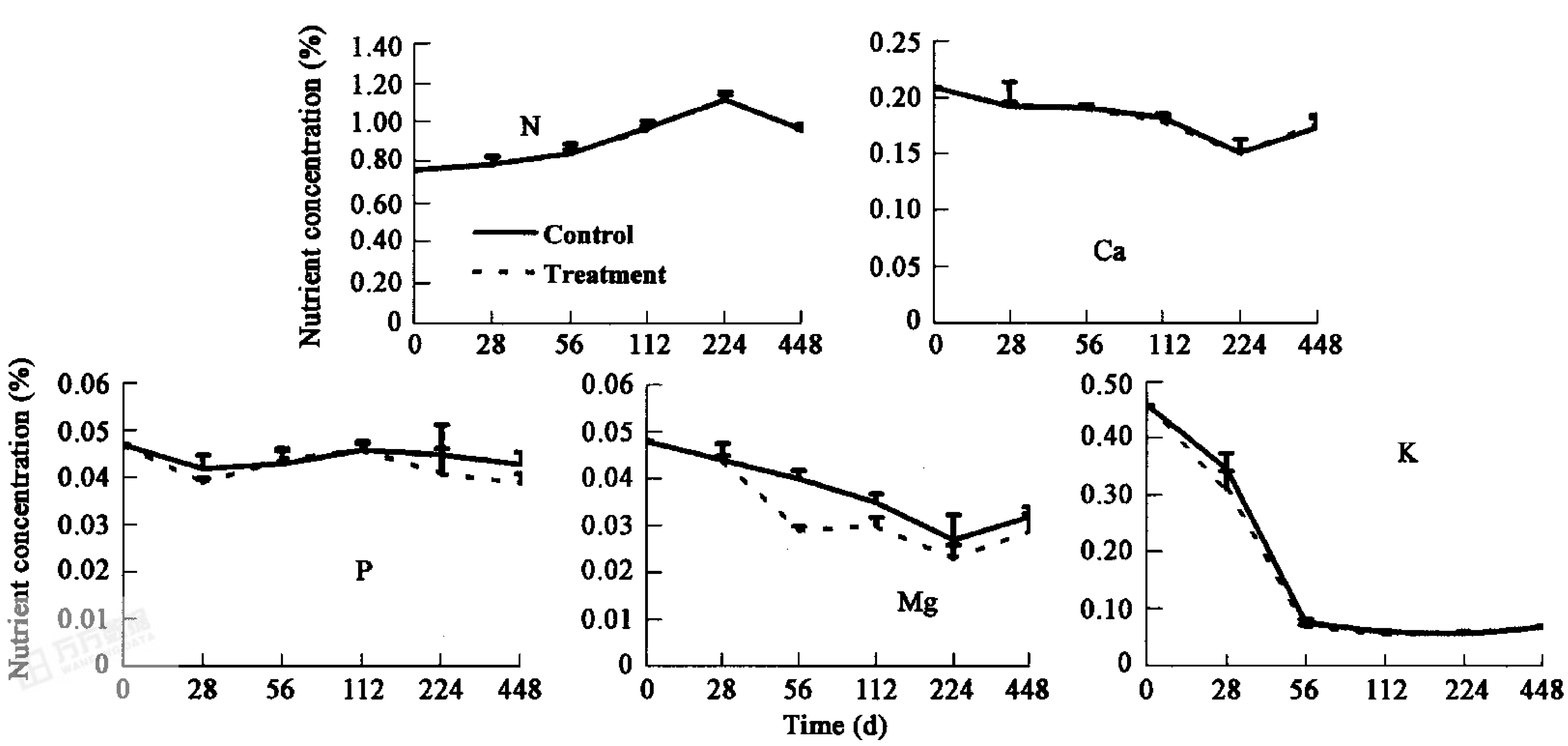

Fig. 6 Patterns of nutrient concentrations in decomposing fine roots in control and treatment plots of a pine forest in Dinghushan biosphere reseve, southern China

Combining the changes in rates of mass loss with nutrient concentrations resulted in the patterns of nutrient content change shown in Fig. 5 (N, Ca, P, Mg and K). Nitrogen was the only element that exhibited patterns of immobilization followed by mineralization (Fig. 5). The N content in decomposing fine roots increased during the first 50 days, followed by a slight decline over the next 350 days period to 51.7% ~ 56.2%, for treatment and control plots respectively, with no further changes. Ca, P and Mg all decreased slowly in a generally linear manner during the whole course of the experiment and follow the linear rate of the mass loss. The highly mobile element K showed the greatest change with an approximate 85 percent loss over the first 56 days, followed by an additional 8 percent over the next 390 days (Fig. 5). Generally, losses in the contents of all nutrients from the decomposing fine roots were in the order K>Mg>P>Ca>N. Comparisons of final nutrient contents indicated that nutrient losses from decomposing fine roots were significantly faster in treatment plots than in control plots for N and P ($p<0.05$), but with no significant difference for the other elements (Fig. 5).

4 Discussion

4.1 The role of fine roots on carbon and nutrient cycling in the pine forest

Mean fine root biomass of the pine forest to 10 cm depth for Sept. 1990 and May 1995 was 9.1 t/hm^2 in control plots and 8.1 t/hm^2 in treatment plots (Fig. 4). These estimates account for about 10 percent of the total biomass in control plots in 1990 (81.1 t/hm^2), and about three to four times the understory biomass (2.2 t/hm^2)[15]. Annual fine root biomass production was 3.0 t/(hm^2 · a) in control plots and 2.4 t/(hm^2 · a) in treatment plots, accounting for about 39 to 48 percent of the total biomass production in control plots during the study period (6.2 t/(hm^2 · a)), and about 1.2 times litterfall (2.3 t/(hm^2 · a))[15]. These values above were also high in comparisons with those of monsoon evergreen broadleaf forest. Although mean fine root biomass of the pine forest (8.1~ 9.1 t/hm^2, Fig. 4) was similar to the value of monsoon evergreen broadleaf forest in the Dinghushan Biosphere Reserve (11.4 t/hm^2, ≤ 5 mm diameter)[28], the percentage of fine root biomass to the total biomass of the pine forest (10%) was two times higher than that of monsoon evergreen broadleaf forest (4%)[28]. Annual fine root biomass production (3.0 t/(hm^2 · a) in control plots and 2.4 t/(hm^2 · a) in treatment plots) was also similar to the values of monsoon evergreen broadleaf forest (2.6 t/(hm^2 · a))[28], but the percentage of annual fine root biomass production to the total biomass production (39%~48%) in control plots was almost two times higher than that of monsoon evergreen broadleaf forest (17%)[28]. Furthermore, fine root decomposition rates (0.47 and 0.44 for treatment and control plots respectively, Fig. 5) were similar to rates of litter or fine root decomposition for other forests (0.44 and 0.37 for pine needles and mixed litter, and 0.40~0.49 for fine roots of the monsoon evergreen broadleaf forest, respectively)[15, 28]. Thus, fine roots play an important role in returning carbon and nutrients to the soil in the disturbed pine forest. This suggestion is also partially supported by result of the present study that soil light organic matter depended more on fine roots in treatment plots than in control plots (Fig. 3).

4.2 Impacts of harvesting on soil organic matter, fine root decomposition and its nutrient dynamics

As mentioned above, previous research demonstrated that the disturbed pine forest had lower productivity and lower nutrient levels[15, 16]. Then, the question is whether the low site productivity is mainly caused by the practice of biomass removal on this initially degraded site and what are the mechanisms underlying the low site productivity? In order to answer these questions, we compared the soil light organic matter data and the fine root decomposition for control and treatment plots.

First, compared to completely harvesting a forest, harvesting of litter and understory removes less organic matter and nutrients from the forest sites. However, results from this study indicated that harvesting understory and litter removed substantial organic matter (3.5 t/(hm^2 · a), Fig. 1) from treatment plots. As a result, the soil light organic matter depended more on fine roots in treatment plots than in control plots because of the continuous removal of organic matter from the treatment plots during the study period and the last several decades, and that the control plots having had more opportunity to accumulate organic matter from litterfall because of stopping harvesting from the beginning of the study (Fig. 2, Fig. 3). After stopping harvesting for 5 years, soil light organic matter in control plots was significantly higher than that in treatment plots ($p<0.01$, Fig. 4), suggesting that harvesting practice significantly reduced soil organic matter. Thus, it can be inferred that the soil organic matter of the disturbed site has had little opportunity to recover from the original degraded site because of the continuous removal of organic matter during the last several decades. We believe that this is one of the reasons that the current site productivity in the disturbed forest is low.

Second, we have demonstrated that fine roots decomposed significantly faster in treatment plots than in control plots (Fig. 5) and that nutrient losses from decomposing fine roots were significantly faster in treatment plots than in control plots for N and P (Fig. 5). There are two possible explanations for these findings:

(1) Changes in soil physical characteristics likely occurred due to the understory and litter harvesting, particularly the cycles of soil drying and wetting. Removal of understory and litter increased the exposure of the soil surface to sunlight and rainfall. As a result, there would be a higher fluctuation of soil temperature and moisture, or more stress for microorganism in treatment plots, leading to differences in species composition and quantities of microorganism between control and treatment plots[29]. Cycles of wetting and drying greatly affect decomposition of organic matter and the turnover of biomass[30].

(2) Changes in soil chemical characteristics also likely occurred due to the understory and litter harvesting. Fine root decomposition may be limited by soil nitrogen availability. This pine forest (both control and treatment plots) was severely degraded as humans disturbed the forest for a long time. This is also reflected in the low soil nitrogen availability compared with other adjacent forests[7, 16]. Nitrogen concentrations and contents increased during early litter decomposition[16]. This is consistent with the results found in our fine root decomposition results (Fig. 5 and Fig. 6). These findings suggested that fine roots or litter contain insufficient nitrogen to meet the growth and maintenance requirements of decomposers[31]. Thus nitrogen maybe a limiting factor for plant growth, microorganism activities, and decomposition. Furthermore, litter decomposition rates have been shown to accelerate with N addition in this disturbed pine forest[32] and other forests[31, 33~36]. As mentioned above, previous research has demonstrated that fewer understory plants and low microbial activity leads to low uptake and low immobilization of N, resulting in higher mineral N contents in treatment plots than in control plots[7].

In sum, the higher decomposition rates and N and P losses from decomposing fine roots in the treatment plots suggest that in the short term these would increase the nutrient availability in the site, but in a long term it would deplete the soil nutrient pool faster through direct removal from harvesting understory and litter (more nutrients available for understory uptake and for litter mobilizing N during early stage of decomposition as mentioned above) and indirect loss from higher potential of nutrient leaching. This is probably one of the reasons that soil nutrient availability is low in this pine forest.

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