Effects of Forest Fire on Leaf Litter Decomposition of Two Dominant Species (*Tristaniopsis obovata* and *Calophyllum pulcherrimum*) in a Heath Forest of South Kalimantan

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ABSTRACT In order to determine the effects of frequent forest fire on the decomposition process, two dominant species of heath forests were studied: *T. obovata* and *C. pulcherrimum*. During a period of two years, it was observed that *T. obovata* decomposed more rapidly with higher nutrient release than *C. pulcherrimum* in intact and post-fire stands. The decomposition rates of the two species were higher in the intact stand than in the post-fire stand. C/N ratio dynamics and nitrogen release were determined showing that *T. obovata* rapidly released nutrients and *C. pulcherrimum* retained nutrients. The results suggest that forest fire did not change the nutrient release pattern of these two dominant species, but did slow the decomposition rate and, consequently, affected the rate of nitrogen release.

Key words: decomposition rate, forest fire, intact heath forest, post-fire stand.

INTRODUCTION

At the end of the 1997 dry season, which was exceptionally dry due to ENSO, the biggest fires of the year broke out over almost all forest types in Kalimantan and Sumatra Island. The fires emitted smoke into the air blanketing the entire region in haze, reaching as far as Thailand, Philippines, Malaysia and Singapore. Forest fires have enormous impacts on tropical forest ecosystems and biodiversity (Barber & Schweithelm, 2000). The estimated area of damage by fires during 1997-1998 in Kalimantan was 75,000 ha of peat swamp forest, 2,375,000 ha of lowland forest, 2,829,000 ha of agricultural land, 116,000 ha of timber plantation, 55,000 ha of estate crops and 375,000 ha of dry scrub & grass land, with a total damage of 6,500,000 ha (RePPProT 1985). Frequent forest fires have occurred for the past twenty years and repeated burning cycles have completely transformed forests into grasslands or scrublands. As was reported by Abdulhadi *et al.* (1998), repeated burning has created large areas of unproductive grasslands in place of original dipterocarp forests. In a mixed dipterocarp forest in East Kalimantan after a forest fire about 90% of 240 trees in a 1.6-ha plot died (Whitmore, 1984). In a heath forest, floristic composition in burnt and un-burnt plots was quite similar, having 77% similarity about 1.5 years after the fire (Abdulhadi *et al.* 1998).

There is ample information on the effects of forest fire on vegetation dynamics, forest structure and species composition (Cochrane & Schulze 1999; Driscoll *et al.* 1999; Hjerpe *et al.* 2001). With regard to the effects of fire on nutrient dynamics in lowland tropical forests, the work of Kutiel & Inbar (1983),

Gillon & Rap (1989) and Driscoll *et al.* (1999) can be cited. However, little information is available on the impact of forest fire on the decomposition process in heath forests, the typical forest type in Kalimantan. This information is crucial, as the nutrient released from decomposing litter is the major nutrient source for plant growth (Lamber *et al.*, 1998), and furthermore, during forest fires the soil nutrient status changes, most notably, nitrogen loss increases (Aerts & Chapin 2000). The effects of fire on soil erosion, light intensity, pH, the quality of soil organic matter (Pietikäinen & Fritze 1996; Flannigan *et al.* 2000), surface runoff, soil moisture and temperature (Viro 1974; Cass *et al.* 1984) are subjects of much concern to studies on the effect of burning on the decomposition processes. The loss of organic matter from the soil surface after a forest fire also exposes the soil to direct sunlight, decreasing the activity of soil microorganisms, because of high temperatures (Viro 1974; Cass *et al.* 1984; Pietikäinen & Fritze 1996; Bazzaz 2000; Flannigan *et al.* 2000). The decomposition process is also dependent on such climatic factor as humidity and temperature (Köchy & Wilson 1997), as well as soil organisms (Gallardo & Merino 1993; Swift 1995). Therefore changes in these factors due to forest fire will affect the decomposition process. The objectives of this research were to examine 1) the decomposition rates of two dominant species in a heath forest in Central Kalimantan, and 2) the effects of forest fire on nitrogen release and C/N ratio dynamics during the decomposition process.

METHODS

Study site

The study site was in Lahei village, located 40 m above sea level, and 1° 55' S in latitude, 114° 10' E in longitude. Most of the area is covered with heath forest, with scattered patches of peat swamp forest. The annual precipitation at Palangkaraya is about 2800 mm (1993 to 1999 average), but is approximately 2970 mm when the data from the El Niño year (1997) are excluded. Monthly rainfall is over 100 mm in most months, and below 100 mm during the few months of the dry season. The annual mean temperature varies between 26–28°C. Heath forests in Borneo occur on poor sandy soils, strongly podzolized or even seasonally waterlogged soils, to form humus podzols, humus iron podzols, and ground water humus podzols (Specht 1979). Soil in heath forests is very acidic and poor in nitrogen content (Moran *et al.* 2000) and levels of all soil nutrients in the heath forest at the Lahei site were low to very low (in terms of FAO criteria) in the overall profile (Djuwansah 2000).

The heath forest is dominated by *Calophyllum pulcherrimum* Wall. ex Choisy, *Tristaniaopsis obovata* (Benn.) Wilson et Waterhouse, and *Palaquium leiocarpum* Boerl. The forest mainly consists of small trees (the maximum trunk diameter was 69.7 cm). The tallest tree is 37 m high and the number of species of trees with more than a 15 cm trunk girth is 122. The tree density of the heath forest is 1982 ha⁻¹ and basal area is 27.6 m² ha⁻¹ (Suzuki *et al.* 1998; Miyamoto *et al.*, 2002). Total above-ground biomass is 188.23 ± 3.9 t ha⁻¹ (Miyamoto 2002). The soil temperature of the heath forest was around 25 to 30°C throughout the study period. An intact forest stand and a post-fire stand (after the forest fire in 1997) of heath forest were selected as study sites. The distance between these two stands was about 2 km. The post-fire stand was dominated by *Imperata cylindrica*. Burnt stems and standing dead trees were scattered on the stand floor. The period of the study was February 1998–March 2000. In the dry season of 2002, the intact stand research site was destroyed by forest fire.

Field experiments

In the heath forest a 1-ha intact plot was established (Suzuki *et al.*, 1998; Miyamoto *et al.*, 2002). The trees of two dominant species (*T. obovata* and *C. pulcherrimum*) from outside the 1-ha plot were cut to collect their leaves and stems. Collected leaves were dried and 100 g leaves filled each litter bag. One set of three stem sizes for each dominant species (small = 2-3 cm, medium = 3-4 cm and large = 4-5 cm, stem diameter) was put in the litter bags. 428 litter bags (224 leaf and stem) were placed in the 1-ha intact stand and the post-fire stand systematically and samples were collected monthly. Nitrogen and carbon content was estimated by an automatic C-N analyzer (Vario EL, Elementar Analysensysteme GmbH, Hanau, Germany).

Statistical analysis

The decomposition constant k was estimated by fitting the exponential model $W(t) = W_0 e^{kt}$, where W_0 is initial mass, W represents the remaining mass of the litter, t is time, and k is the decomposition rate (Olson, 1963). ANOVA was used to examine the differences among species for mass and nutrient content in the intact and post-fire stands. A Scheffe test was used in an *a posteriori* comparison to examine significant differences among means ($p < 0.05$).

RESULTS

Decomposition rate of leaf and stem

Significantly different rates of decomposition were found between *T. obovata* and *C. pulcherrimum* ($p < 0.001$) and between the locations ($p < 0.05$) during the duration of the experiment. The rate of decomposition was higher in the intact stand than in the post-fire stand (Fig. 1). Leaf decomposition rate was higher for *T. obovata* ($k = 1.3 \text{ y}^{-1}$) than *C. pulcherrimum* ($k = 0.5 \text{ y}^{-1}$) in the intact stand, and also in the post-fire stand the rate was higher for *T. obovata* ($k = 0.8 \text{ y}^{-1}$) than *C. pulcherrimum* ($k = 0.2 \text{ y}^{-1}$). These results suggest that forest fires decrease the decomposition rate of these dominant species.

Fig. 1. Comparison of leaf decomposition rate of *T. obovata* and *C. pulcherrimum* in an intact and post-fire stand in a heath forest.

The rate of stem decomposition of the two species was not significantly different between the locations, species or diameter classes (Fig. 2). Although it was not statistically significant, the

decomposition rate of *T. obovata* was faster in the post-fire stand than the intact stand, while *C. pulcherrimum* showed no specific pattern.

Fig. 2. The decomposition rate of stems of the dominant species in intact and post-fire stands. S = small (2-3 cm), M = medium (3-4 cm) and L = large (4-5 cm), in stem diameter.

The decomposition of the remaining leaves in the post-fire stand fluctuated markedly during the study period. The decomposition of the remaining leaves was not constant during the first year, and thereafter during the second year, decomposed slowly. In the intact stand, the remaining leaves decomposed throughout the study period (Fig. 3). At the end of the experiment the lowest amount of remaining leaves was that of *T. obovata*, 12% and 15% of the initial mass of leaves in intact and post-fire stands, respectively. For *C. pulcherrimum* the remaining mass of leaves was 40% and 77% in the intact and post-fire stands, respectively.

Fig. 3. Remaining mass (%) of leaf litter *T. obovata* and *C. pulcherrimum* in intact and post-fire stands.

C, N and C/N ratio dynamics during the decomposition process

Decreasing carbon content was significantly different between the stands for both species ($p < 0.001$), and a decrease in carbon content was seen higher in the post-fire stand than in the intact stand (Fig. 4).

The nitrogen content of both species increased during the decomposition process in the intact stand and in the post-fire stand, but was lower in the post-fire stand than in the intact stand (Fig. 5). The nitrogen content of *T. obovata* was higher than that of *C. pulcherrimum* in the intact and post-fire stand, indicating that more nutrients from *T. obovata* were released, and a decrease in remaining leaf mass (Fig. 3) was followed by an increase in nitrogen content (Aber & Mellilo 1982; Anderson *et al.* 1983; McClaugherty *et al.*, 1985). The release of nitrogen of *T. obovata* was from 442.9 to 197.7 mg at the first year of decomposition process, and that was decreased to 37.6 mg at the end of study period (Fig. 5). The nitrogen release of *C. pulcherrimum* was from 338.6 to 164.8 mg, in the post-fire stand. Nitrogen was release in the intact stand from the two species, even though their C/N ratio was above 40, from 442.9 to 129.8 and 338.6 to 253.5 mg, for *T. obovata* and *C. pulcherrimum* respectively.

Fig. 4. Changes in carbon content and mass of decomposing litter during the decomposition period in intact and post-fire stands.

The C/N ratio of leaf litter from the two dominant species decreased in both study sites (Fig. 6). The C/N ratio of *T. obovata* decreased from 62 to 34 (in the intact stand) and to 31 (in the post-fire stand) during the first year and at the end of study decreased further to 31 (in the intact stand) and 27 (in the post-fire stand). The C/N ratio of *C. pulcherrimum* decreased from 77 to 45 in the intact stand and 46 in the post-fire stand, during the 2-yr period. Nitrogen mineralization in tropical forests occurs at a C/N ratio of approximately 30-40, thus nitrogen mobilization of *T. obovata* was correctly predicted during the second year, to have a C/N ratio lower than 34 followed by increased nitrogen content (Fig.

5). For *C. pulcherrimum* no net mineralization occurred until the end of the experiment in the intact and post-fire stands when the C/N ratio was higher than 40.

Fig. 5. Changes in nitrogen remaining and content of decomposing litter during the decomposition period in intact and post-fire stands.

Fig. 6. Changes in C/N ratio of leaf litter *T. obovata* and *C. pulcherrimum* during the decomposition period in intact and post-fire stands.

DISCUSSION

Decomposition rate

Leaf litter of *T. obovata* decomposed faster than that of *C. pulcherrimum*, due to the lower initial lignin content of *T. obovata* (28%) than *C. pulcherrimum* (49%) (Rahajoe & Kohyama submitted). Plant material with higher lignin content decomposes more slowly than those with lower initial lignin content (Berg & Staaf 1981; Berendse *et al.* 1987; 1989; Aerts 1997) or lower initial C/N ratio (Wieder & Lang 1982). Leaf litter of *T. obovata* was decomposed rapidly during the first rainy season. The loss of leaf mass is affected by leaching via tropical rainfall and is related to the leaching of soluble organic materials and inorganic compounds (Berg & Staaf 1980; Laskowski *et al.* 1995; Swift 1995). Resistant materials have a slower loss rate (Swift 1995).

The leaf decomposition rate of these two dominant species was significantly higher in the intact stand than in the post-fire stand, due to microclimatic changes on the forest floor caused by forest fire (Viro 1974; Cass *et al.* 1984; Flannigan *et al.* 2000). During a forest fire, the subsoil burns and only the A2 or A-E horizon remains (Djuwansah 1999). This horizon is white sand (quartz sand), which is nutrient poor, with a low water holding capacity (Viro 1974) and few soil materials (Cass *et al.* 1984; Dumontet *et al.* 1996). Forest fire exposes the soil surface to direct sunlight, accelerating soil desiccation (Pietikäinen & Fritze 1996; Zhang & Zak 1999; Bazzaz 2000). The combined factors of low soil moisture and high light intensity are unsuitable for the activity of primary decomposers (Zhank & Zak 1999), especially bacteria and fungi, and inhibition of microbial activity, resulting in slower decomposition rates in post-fire stands.

The change in carbon content with decomposition was significantly different between stands and a decrease in carbon content was seen only in the post-fire stand (Fig. 4). It is suggested that carbon-rich components of leaf litter, such as lignin, are selectively attacked by decomposers, thus indicating that forest fire changes soil microflora.

Nitrogen release and C/N ratio during the decomposition process

The increase in nitrogen content during decomposition found in this study is likely attributable to the immobilization of nutrients by bacteria and fungi colonized in the residual litter in intact and post-fire stands (Chale 1993; Odum *et al.* 1979). The rate of decomposition was lower in the post-fire stand than in the intact stand, and this low decomposition rate causes the lower nitrogen content in the post-fire stand than in the intact heath stand (Menaut *et al.* 1993). The opening up of areas by forest fire facilitates nitrogen loss by volatilization (Jordan 1985; Menaut *et al.* 1993; Aerts & Chapin 2000). Therefore the increase of nitrogen content of *C. pulcherrimum* and *T. obovata* was small and the nitrogen released from decomposing litter was easily leached by soil runoff via soil erosion (Cass *et al.* 1984; Jordan 1985; Menaut *et al.* 1993). This information suggests that nitrogen is less available in post-fire stands than in intact stands.

The dominant species in heath and peat swamp forests have their own patterns of releasing nitrogen to the forest floor (Rahajoe & Kohyama submitted). Torreta & Takeda (1999) classified the dominant species in Thailand as nutrient retention species (with a C/N ratio above 40) and rapid nutrient releasing species (with a C/N ratio about 30-40). In this study, *C. pulcherrimum* showed no net mineralization until the end of the experiment and nitrogen was immobilized in leaf litter. Species such

as *C. pulcherrimum* are important for the retention of nitrogen in the forest floor sub-systems, while *T. obovata* rapidly released nitrogen from decomposing litter. This study found that the two dominant species in the intact and the post-fire stands in central Kalimantan have different patterns, but similar responses to fire: *T. obovata* is characterized by rapid nutrient release and *C. pulcherrimum* by nutrient retention, suggesting that forest fire did not change the nutrient release pattern of these two dominant species, but did lower the decomposition rate and consequently affected the rate of nitrogen release for both species.

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