CHRONOSEQUENCE CHANGES IN SOIL PROPERTIES OF TEAK (*TECTONA GRANDIS*) PLANTATIONS IN THE BAGO MOUNTAINS, MYANMAR

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SUZUKI, R., TAKEDA, S. & HLA MAUNG THEIN. 2007. Chronosequence changes in soil properties of teak (*Tectona grandis*) plantations in the Bago Mountains, Myanmar. Reforestation of teak (*Tectona grandis*) has been practised in Myanmar for more than a century. Since a large volume of biomass is removed when teak is harvested at the end of each rotation, the conservation of soil fertility during the growth period is crucial for sustainable production. To assess long-term changes in soil properties, soil samples were collected from teak plantations of different stand ages (0–96 years) in the Bago Mountains, Myanmar. Accretion of soil organic matter was not observed even 96 years after teak reforestation. A main factor interrupting the build-up of soil organic matter was the combustion of forest floor litter by forest fires. In contrast, an increase in exchangeable Ca was observed in surface soils with increasing age of teak plantations, despite an initial decrease in the first 20 years after reforestation. Teak generally requires a large amount of Ca and this explains the initial decrease in exchangeable Ca. However, Ca is returned to the soil surface in the form of Ca-rich teak litter. Even after combustion of litter, Ca can remain in ash and accumulate in surface soils over time because the volatilization temperature of Ca is generally higher than the temperature of forest fires. Soils in teak plantations should be managed considering these mechanisms and the conservation of litter appears to be important for sustainable soil management in teak plantations.

Keywords: Taungya, reforestation, second rotation, forest fire, calcicolous species, sustainable management

SUZUKI, R., TAKEDA, S. & HLA MAUNG THEIN. 2007. Perubahan kronologi ciri-ciri tanah ladang pokok jati (*Tectona grandis*) di Pergunungan Bago, Myanmar. Penghutanan semula pokok jati (*Tectona grandis*) diamalkan di Myanmar sejak lebih satu abad yang lalu. Memandangkan isi padu biojisim yang besar dikeluarkan apabila pokok jati ditebang pada hujung satu giliran, pemuliharaan kesuburan tanah semasa pertumbuhan penting bagi pengeluaran lestari. Untuk menilai perubahan jangka panjang ciri-ciri tanah, sampel tanah diambil daripada ladang jati yang berlainan umur (0–96 tahun) di Pergunungan Bago, Myanmar. Tokokan bahan organik tanah tidak dicerap walaupun 96 tahun selepas penghutanan semula. Faktor utama yang mengganggu penambahan bahan organik tanah ialah pembakaran sarap lantai hutan akibat kebakaran hutan. Sebaliknya, Ca boleh tukar dalam tanah permukaan didapati meningkat dengan umur walaupun terdapat pengurangan dalam 20 tahun pertama selepas penghutanan semula. Pokok jati pada umumnya memerlukan jumlah Ca yang tinggi dan ini menjelaskan penurunan Ca boleh tukar pada awalnya. Namun Ca dikembalikan kepada permukaan tanah dalam bentuk sarap jati yang kaya dengan Ca. Walaupun selepas pembakaran sarap, Ca boleh kekal dalam abu dan berkumpul dalam tanah permukaan selepas satu tempoh kerana suhu pemeruapan Ca pada umumnya lebih tinggi daripada suhu kebakaran hutan. Tanah di ladang jati perlu diurus dengan mempertimbangkan mekanisme tersebut. Pemuliharaan sarap nampaknya penting dalam pengurusan tanah lestari di ladang jati.

INTRODUCTION

The deforestation rate in Myanmar from 1990 till 2000 was estimated at 1.4%, the highest among South-East Asian countries (FAO 2001). Although 52% of the land area in Myanmar remains forested and Myanmar forests are considered to be well managed under the selection felling regime termed the Myanmar Selection System, the future sustainability of these forest resources should be carefully evaluated.

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Plantation forests can be used to compensate for depletion of forest resources. In Myanmar, reforestation of teak (*Tectona grandis*) using the taungya method has been practised for more than a century. A schematic of the taungya teak reforestation process is shown in Figure 1. The taungya system combines the planting of agricultural crops with forest trees and can be considered a transformation step from shifting cultivation to agroforestry (Preeyagrysorn 1992). Under this system, farmers who plant trees can cultivate intercrops for the first year after the establishment of a plantation.

As illustrated in Figure 1, a large volume of biomass is removed through the harvesting of teak at the end of each taungya teak reforestation cycle. Export of the biomass by timber harvesting disrupts the nutrient cycle and subsequently diminishes soil nutrient levels (Fölster & Khanna 1997, Aweto 2001). Given that such nutrient loss may far exceed rates of replenishment by the weathering of minerals or precipitation (Fölster & Khanna 1997), soil deterioration would occur with successive rotations. The associated potential decrease in productivity has been called the second rotation problem (Hase & Fölster 1983, Bruijnzeel 1992). While this problem is common to all wood production plantations, decreased productivity in taungya systems can be a potentially greater problem as it would harm not only tree growth but also the intercrop yields that give the incentive for farmers to participate in taungya reforestation.

To mitigate second rotation problems, the preservation of soil productivity during the growth period of teak is extremely important. However, many studies have found soil deterioration in teak plantations (Aborisade & Aweto 1990, Mongia & Bandyopadhyay 1992, Balagopalan 1995, Amponsah & Meyer 2000, Ye Myint & Saw Eh Dah 2001, Healey & Gara 2003), although the mechanism of soil deterioration has not been described in detail. Furthermore, soil properties in teak plantations have rarely been investigated using time series. Particularly in Myanmar, the availability of quantitative data is very limited despite the long existence of teak plantations. To examine future sustainability of taungya teak reforestation, long-term changes in the soil properties of teak plantations were assessed using a chronosequence approach. Long-term effects of litter dynamics on the soil properties of teak plantations were studied. Particular attention was given to the impact of forest fire on litter dynamics.

MATERIALS AND METHODS

Study area

The study area was located in Oktwin Township in Toungoo District, Bago Division, on the eastern slope of the Bago Mountains in Myanmar (Figure 2). The Bago Mountains form a watershed between the Ayeyarwady and Sittoung river catchments. With a maximum elevation of approximately 800 m above sea level, the Bago Mountains are composed of clastic, folded tertiary sediments (Bender 1983). The soils are generally light textured and classified as Ultisols. The clay content increases with soil depth and is highest in the B horizon (Bender 1983). The dominant forest type in the study area is moist teak forest (Kress *et al.* 2003), which is economically important because of the associated valuable tree species such as teak, pinkado (*Xylia xylocarpa*) and padauk (*Pterocarpus macrocarpus*).

Monthly precipitation and temperature (1988–2002) data from the Toungoo weather station (18° 55' N, 96° 28' E), located approximately 15 km east of the foothills of the Bago Mountains,

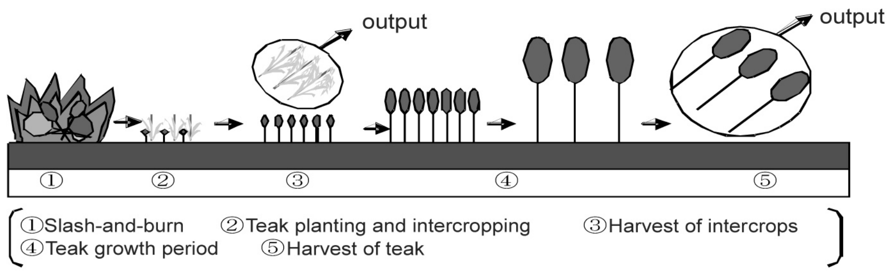

Figure 1 Schematic of the stages involved in the taungya teak reforestation process

are presented in Figure 3. The average annual rainfall during this period was 1969 mm. Distinct rainy and dry seasons occur, with the most rainfall falling from May till October, although several showers were observed in April and November. Mean annual temperature during this period was 26.9 °C.

Establishment of experimental plots

To evaluate long-term changes in the soil properties of teak plantations, 10 experimental plots were established in teak plantations of various stand ages (0–96 years) in the Kabaung and Bondaung reserved forests (18° 42'–18° 57' N, 95° 51'–96° 21' E) in Oktwin Township (Figure 2). Teak reforestation has been practised in these forests since 1884. General information on each experimental plot is presented in Table 1. TP2002 was established in the secondary forest where the taungya teak reforestation was newly started. The size of each experimental plot was 0.09 ha.

In Myanmar, teak plantations established in the early days did not have defined rotation period and they were treated as a natural teak-bearing forest after the final thinning at 40 years. Consequently, old teak plantations have only rarely been clear-felled and the second rotation of teak reforestation has seldom been undertaken. Although the second rotation would start in the near future, taungya teak reforestation in this

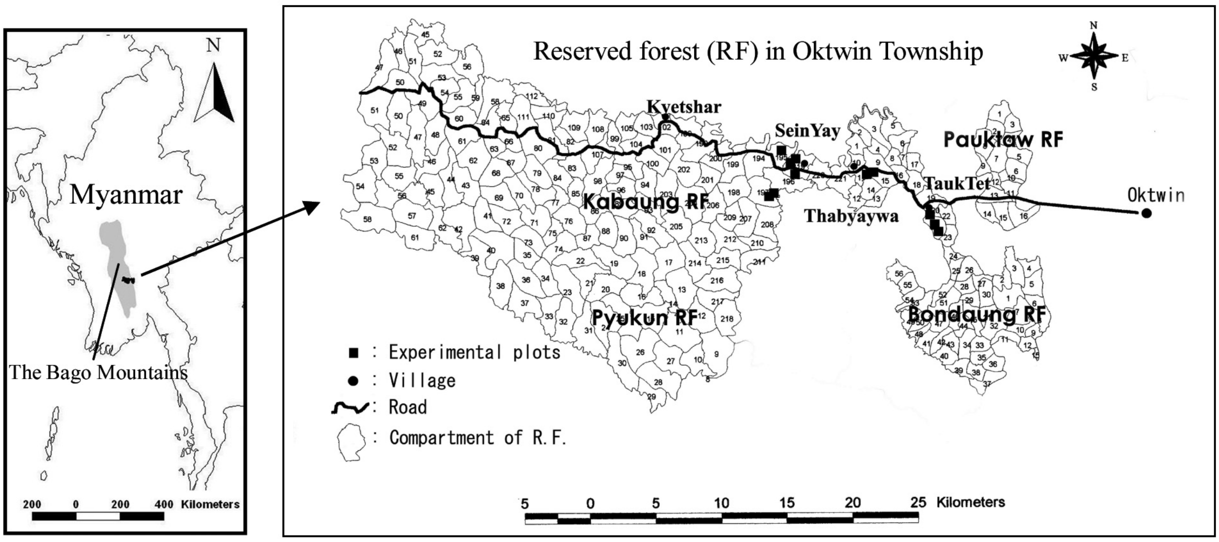

Figure 2 Location of the study area

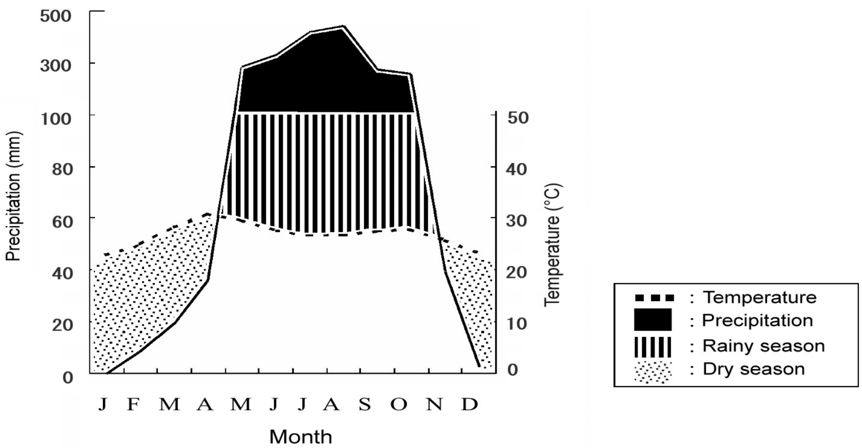

Figure 3 Mean monthly precipitation and temperature from the Toungoo weather station from 1988 till 2002

Table 1 General information on the experimental plots

Experimental plot no.	Stand age (years)	Year planted	Slope aspect (°)	Slope direction	Forest fire disturbance during dry season in 2002	Reserved Forest
TP2002	0	2002	11-34	N40°E	□	Kabaung
TP1998	4	1998	14-24	S44°W	□	Bondaung
TP1981a	21	1981	12-24	S14°W	●	Kabaung
TP1981b	21	1981	8-18	S14°E	●	Kabaung
TP1981c	21	1981	13-24	N54°E	○	Kabaung
TP1967	35	1967	20-34	S41°W	●	Bondaung
TP1966	36	1966	15-30	S24°E	●	Bondaung
TP1921	81	1921	8-24	S14°E	□	Kabaung
TP1906a	96	1906	14-32	S30°W	●	Kabaung
TP1906b	96	1906	10-26	S50°E	●	Kabaung

The numbers following TP indicate the year in which the plantation was established. All experimental plots except TP2002 belong to phase 4 in Figure 1, whereas TP2002 is before phase 1.
● = disturbed by forest fires, □ = artificially prevented from forest fires, ○ = not disturbed by forest fires under natural condition

region has been usually started after the felling of secondary forests. TP2002 was a bamboo-dominated secondary forest which can be considered as one of the typical initial condition of taungya teak reforestation in this region. In TP2002, all vegetation was felled in January 2002 and burned in April 2002 to start a new taungya teak reforestation.

The following experiments were conducted in these experimental plots.

Soil sampling and chemical analysis

To assess the general soil properties of teak plantations, surface soils, i.e. the upper 0–5 cm, were collected from all experimental plots except TP2002 in May 2002. Of the 12 surface soil samples that were collected from each experimental plot, four sets of samples were mixed together to create three composite samples. In TP2002, surface soil sampling was carried out in January 2002 to determine the soil condition before felling of bamboo-dominated secondary forest. All soil samples were air dried and filtered through a 2 mm sieve prior to soil analysis.

Soil pH was determined in a distilled water suspension with a soil to solution ratio of 1:5 using the glass electrode method (TOA pH meter, HM-TJ). The total carbon and nitrogen contents were determined using an NC analyser (Sumika Chemical Analysis Service, Sumigraph NC-800). The contents of exchangeable bases (Ca, Mg, K, Na) were determined by atomic absorption spectrophotometry (Shimadzu AA-670) after successive extraction using 1 M ammonium acetate at a pH of 7.0. The ammonium ion absorbed in the residue was replaced with 10% NaCl and measured using formol titration methods as cation exchange capacity (CEC). Available phosphorus was measured using the molybdophosphoric blue method after extraction with 0.03 N ammonium fluoride and 0.1 N hydrochloric acid. All soil samples were oven dried (105 °C, 24 hours) and weighed to determine water contents.

Litter dynamics

To measure the amount of litter production in mature teak plantations, 20 litter traps made of plastic screens (2 mm mesh) with individual surface areas of 0.5 m^2 were established in plot TP1921. Litter was collected from the traps one to two times a month from February 2002 till January 2003. The collected litter materials were divided into leaves (teak, other trees and bamboos), branches, bark, flowers and fruits. After measuring fresh weight, the litter materials were oven dried at 80 °C and reweighed to determine water contents.

The percent coverage of the forest floor by teak leaf litter in all experimental plots except TP2002 was determined in May 2002. This was achieved by dividing each experimental plot into nine subplots measuring 10 m^2 each and visually estimating the coverage of teak litter in each subplot. As frequent forest fires occur during the dry season in this region and they strongly affect the litter dynamics, situation of forest fire invasion in all experimental plots in the dry season of 2002 was also recorded (Table 1).

RESULTS

Soil pH

Figure 4 shows the soil pH (H_2O) of surface soil (0–5 cm) from different aged stands. The pH ranged from 5.6 to 6.5 and generally increased with stand age, although a slight decrease was observed during the initial stages. A logarithmic curve model shown in Figure 4 was well fitted to soil pH vs. stand ages (4–96 years).

Total carbon and nitrogen

Figure 5 shows the total carbon and nitrogen contents of surface soils (0–5 cm) from different aged stands. Total carbon in surface soil ranged from 1.0 to 2.5%. Carbon content decreased in the first 20 years of a stand and did not increase with increasing stand age. Total nitrogen in surface soil ranged from 0.08 to 0.16% and generally decreased with stand age. Logarithmic curve models shown in Figure 5 were well fitted to soil properties vs. stand ages.

Exchangeable bases (Ca, Mg, K) and available P

Figure 6 shows the levels of exchangeable bases (Ca, Mg, K) and available P in the surface soils (0–5 cm) from different aged stands. The exchangeable Ca contents ranged from 3.2 to 6.2 cmol(+) kg^{-1} and generally increased with stand age, although there was a decrease during the initial 20 years. A logarithmic curve model shown in Figure 6 was well fitted to the exchangeable Ca contents vs. stand age (21–96 years). The exchangeable Mg contents ranged from 2.8 to 5.5 cmol(+) kg^{-1} and had no clear relationship with stand age. The exchangeable K content in surface soils ranged from 0.2 to 0.6 cmol(+) kg^{-1}. While a general decrease in exchangeable K was observed in the first 20–40 years after reforestation, recovery of exchangeable K was observed in some teak plantations with a stand age of more than 80 years. The available P content ranged from 0.01 to 0.04 g kg^{-1}. An initial decrease in available P was observed in the first 20–40 years after reforestation. Recovery of available P was not clearly observed, although a relatively higher content of available P (≈ 0.03 g kg^{-1}) was observed in TP1906a. Any model was not fitted well to the contents of exchangeable Mg, K and available P vs. stand ages.

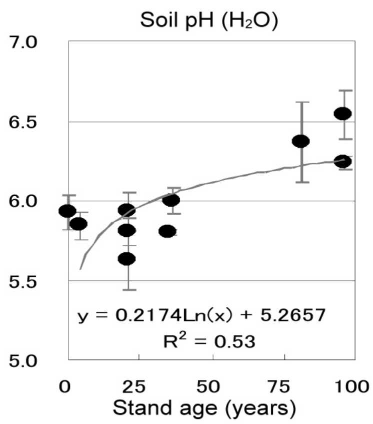

Figure 4 Soil pH(H_2O) of surface soil (0–5cm) from different aged stands in teak plantations

CEC and base saturation

Figure 7 shows the CEC and base saturation of surface soils (0–5 cm) from different aged stands. CEC ranged from 13.5 to 21.4 cmol(+) kg^{-1} and no clear relationship was observed between CEC and stand age. Any model was not fitted well to the CEC vs. stand ages. Base saturation ranged from 44.1 to 72.1% and generally increased with stand age after an initial decrease during the first 20 years of a stand.

Litter production in mature teak plantations

Monthly litter production for the 1-year period in TP1921 is shown in Figure 8. The annual litter production in TP1921 was 4.79 t ha^{-1} and leaf litter production accounted for 81.2%. The annual production of leaf and non-leaf (branch, bark, flower, fruit) litter was 3.89 t ha^{-1} and 0.90 t ha^{-1} respectively. Teak leaf litter production was 2.71 t ha^{-1} which accounted for 69.6% of the total annual leaf litter production. Leaf litter production, especially teak, exhibited an obvious seasonality. Most teak leaf litter was produced in the dry season and 80.6% of the annual teak leaf litter was produced from January till March.

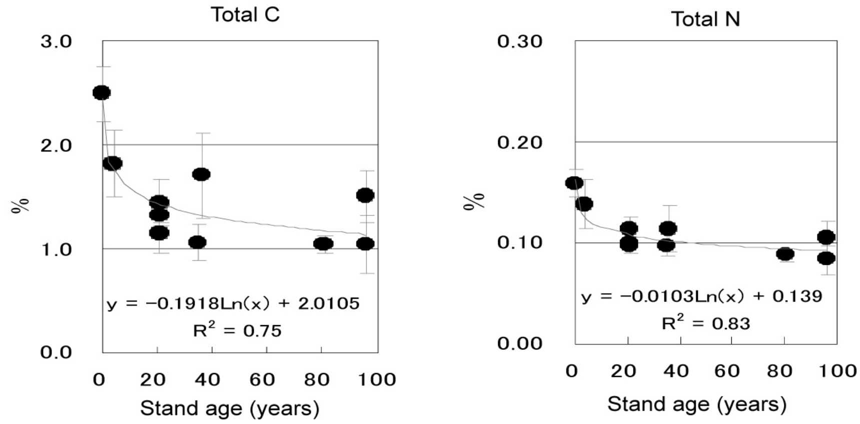

Figure 5 Total carbon and nitrogen contents of surface soils (0–5 cm) from different aged stands in teak plantations. To fit the logarithmic curve models, 0.1 was used for stand age TP2002. (Partly reproduced from Suzuki *et al.* 2004)

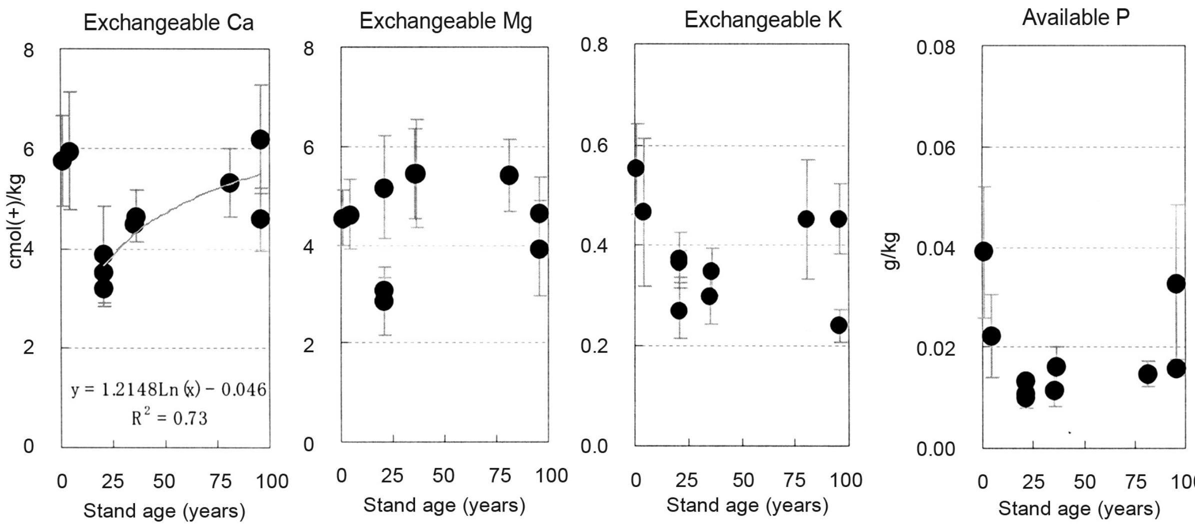

Figure 6 Exchangeable bases (Ca, K, Mg) and available P contents of surface soils (0–5 cm) from different aged stands in teak plantations

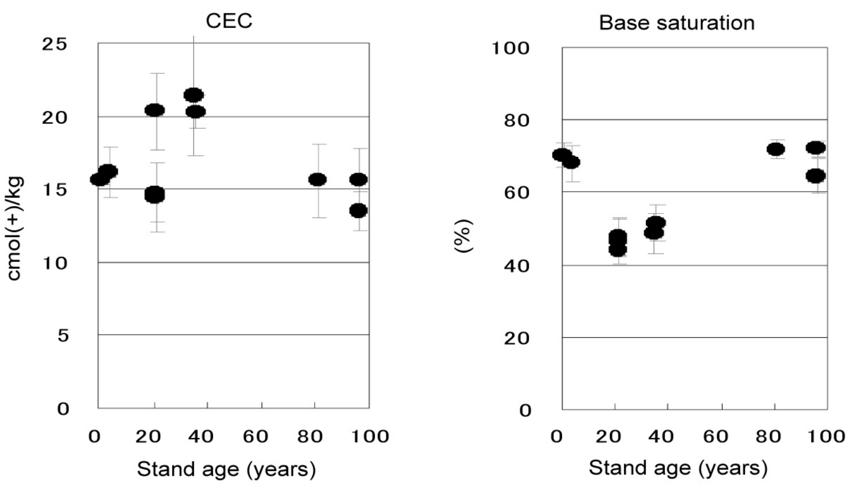

Figure 7 CEC and base saturation of surface soil (0–5cm) from different aged stands in teak plantations

Forest floor coverage by teak leaf litter

Figure 9 depicts forest floor coverage by teak leaf litter in May 2002 in all experimental plots except TP2002 as well as the occurrence of forest fire disturbance. No relationship was observed between teak leaf litter coverage and teak plantation stand age.

DISCUSSION

General trend of carbon and nutrient dynamics after reforestation

Although soil property dynamics after reforestation are site-specific and influenced by factors such as climate, tree species, topography, parent soil material, previous landuse, site management, among others, some general trends can be inferred. According to Paul *et al.* (2002) who reviewed 43 case studies concerning changes in soil carbon after reforestation, soil carbon levels in surface soils generally decreased relative to the initial carbon content during the first five years after reforestation, followed by a decrease in the rate of decline and an eventual recovery to original levels after approximately 30 years. Similar trends have been observed in soil mineral nutrient dynamics (Hase & Fölster 1983, Mendham *et al.* 2003). The decrease in soil carbon or nutrients observed during the

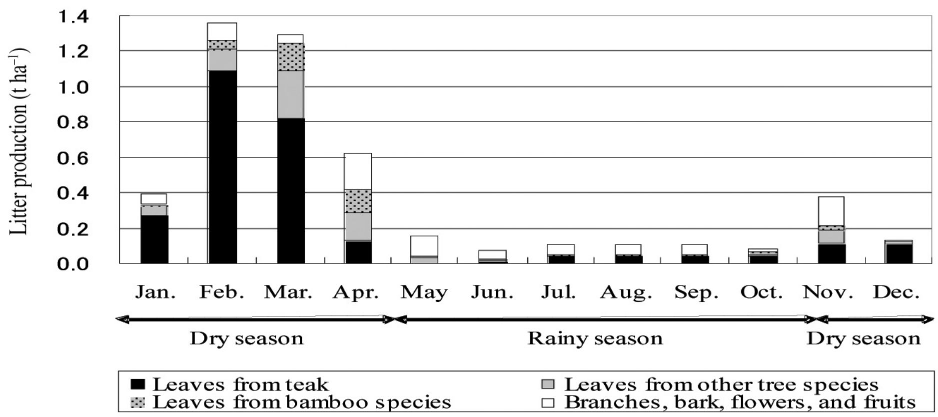

Figure 8 Monthly leaf litter production in plot TP1921 (Reproduced from Suzuki *et al.* 2004)

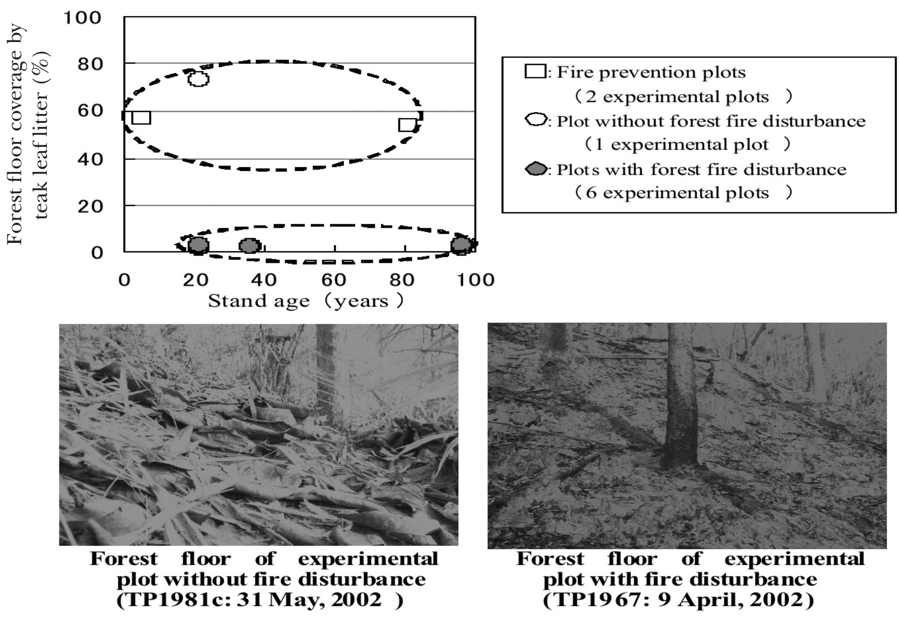

Figure 9 Forest floor coverage by teak litter in May 2002 in relation to stand age and fire disturbance history (Reproduced from Suzuki *et al.* 2004)

initial stage of reforestation is mainly a result of land preparation-related disturbance including leaching and erosion (Goncalves *et al.* 1997) or rapid nutrient absorption by fast-growing species (George & Buvaneswaran 2001). However, soil fertility would recover over time through litter accumulation on the soil surface or mineral weathering (Jordan 1985, Fölster & Khanna 1997).

In this study, an initial decrease in the levels of many soil properties was observed after teak reforestation and the levels of some nutrients, such as Ca or K, recovered as stands aged. However, contrary to published reports, soil carbon content in our experimental plots did not increase as stands aged, even after 96 years of reforestation. As shown in Table 2, many studies have reported that soil carbon levels in teak plantations are generally lower than those in adjacent natural forests. Thus, it is reasonable to infer that the decrease in soil carbon levels observed in this study is not uncommon among teak plantations. What is the main factor preventing the accumulation of soil carbon in teak plantations?

Carbon dynamics in teak plantations influenced by forest fires

In the tropics where many soils are poor in inorganic nutrients and rely on nutrient recycling from soil organic matter (SOM) to maintain fertility (Tiessen *et al.* 1994), the conservation of soil organic carbon is fundamental to sustainable forest soil management.

To understand the long-term dynamics of soil organic carbon in teak plantations, litter dynamics must be considered because soil organic carbon builds up as a result of plant litter production (Tiessen & Shang 1998) and the quantity of soil organic carbon in forest ecosystems is a result of the balance between the input of plant litter and carbon loss due to the decomposition of soil organic carbon over time (Jordan 1985, Turner & Lambert 2000, Liski *et al.* 2002). As shown in Figure 8, the annual teak leaf litter production in TP1921 was 2.71 t ha^{-1}. According to our research on the turnover of teak leaf litter in TP1921 (Suzuki *et al.* 2004), an estimated 0.14 t C ha^{-1} of humus-carbon could potentially be formed from this amount of leaf litter. Therefore, in theory, soil carbon levels in teak plantations could increase over time based on the litter supply. However, most litter that accumulated on the forest floor of many experimental plots was burned by forest fires, as shown in Figure 9. The coverage by teak leaf litter in the six experimental plots with forest fire disturbances was markedly lower than that in the plot without forest fire disturbance or fire prevention plots, suggesting that in many experimental plots the teak leaf litter was burned by forest fires and had almost completely disappeared by the end of May. Although forest fires in Myanmar are merely surface fires and not intense, they are of sufficient magnitude to completely burn forest floor litter. Furthermore, the overlap of the forest fire period and the teak defoliation period is a critical problem. The fire-hazard period in Myanmar normally lasts for about four months, from mid-January till mid-May (Myat Thinn 2000) with frequent fires at the end of the dry season. As shown in Figure 8, the main defoliation period for teak takes place from January till March and 80.6% of the annual teak litter was produced during these three months. It is therefore quite likely that the forest fires that occur during the teak defoliation period would easily consume a large proportion of the annual litter production and thus inhibit the accretion of soil carbon in the teak plantations.

Table 2 Soil carbon contents of surface soils in teak plantations and adjacent natural forests reported in other studies

Soil carbon content (%) of surface soil		Age of teak plantation (years)	Study area	Reference
Teak plantation	Natural forest			
1.5 ± 0.16	1.9 ± 0.10	15	Nigeria	Aborisade & Aweto (1990)
1.7	3.2	±20	India	Mongia & Bandyopadhyay (1992)
*11	*13	17–27	Ghana	Amponsah & Meyer (2000)
0.8	1.7	±40	India	Prasad *et al.* (1985)
1.92	2.39	Unknown	India	Balagopalan (1995)

* soil organic matter content (%)

Nutrient dynamics in teak plantations in relation to the chemical composition of teak leaf litter

The dynamics and properties of litter are important not only for investigations of carbon dynamics but also for those of mineral nutrient dynamics in forest ecosystems because the return of nutrients through litter is an important pathway for nutrient transfer between plants and soil (George & Buvaneswaran 2001). The nutrient contents in teak leaf litter have been examined in other studies, as outlined in Table 3. According to these studies, Ca levels are highest, followed by K content. The Mg and P contents are much lower. Based on these data shown in Table 3, the amounts of Ca, Mg, K and P supplied by annual teak leaf litter production in TP1921 (2.71 t ha^{-1}) were estimated to be 52.1, 6.6, 24.8 and 4.6 kg ha^{-1} $year^{-1}$ respectively. Many studies have reported that the annual return of nutrients through teak litter fall is highest for Ca (e.g. Tewari 1992). The long-term changes in soil nutrient levels observed in this study were likely influenced by the chemical composition of teak leaf litter.

Teak is a calcicolous species and requires a relatively large amount of soil Ca for its growth and development (White 1991, Tewari 1992). Of the various mineral elements needed in adequate quantities for the proper development of teak, Ca is regarded as the most important for regulating physiology (Bebarta 1999). In particular, the amount of nutrient uptake by young teak trees is much more than the amount of nutrients returned to the soil. According to George and Buvaneswaran (2001), about 75–85% of nutrients absorbed from soil were retained in two-year-old teak stands and only 15–25% of nutrients were returned to the soil. However, they also observed that about 66–77% of nutrients absorbed in 20-year-old teak plantations were returned to the soil.

The long-term changes in exchangeable Ca observed in this study (Figure 6) are likely related to these ecological properties of teak plantations. In young teak plantations, because the amount of Ca absorbed from the soil greatly exceeds the amount returned through the litter supply, an initial decrease in exchangeable soil Ca occurs, whereas in middle-aged to mature teak plantations, the amount of Ca returned to the soil is higher because of increased litter production. Consequently, large amounts of Ca absorbed from the soil (including the subsoil) would be returned to the soil surface through teak litter fall. Thus, the content of exchangeable Ca in surface soils would recover with increasing stand age. Even after the combustion of litter by forest fires, Ca, which has higher volatilization temperature than the temperature of forest fires, could remain in ash and percolate into the soil with the first rain.

The dynamics of K, the nutrient with the second highest concentration in teak leaf litter, followed a similar trend to that of Ca, although recovery of exchangeable K was not as clear as that of exchangeable Ca.

Because of the nutrient supply from teak litter, H and Al ions in soil exchangeable complexes were replaced by bases. Thus, an increase in soil pH with increased stand age was observed (Figure 4). An increase in the base saturation with increasing stand age also indicates the replacement of Al and H ions. According to Tewari (1992), teak which usually occurs on soils with a pH of 6.5 to 7.5, is practically absent at pH levels below 6.0, and its growth suffers at pH levels above 8.5. The soil pH range observed in this study, especially in the young to middle-aged teak

Table 3 Nutrient contents of teak leaf litter reported in other studies

Age of stand (year)	Nutrient contents (% on oven-dry basis)				Reference
	Ca	Mg	K	P	
20	1.10	0.17	0.83	0.11	Negi *et al.* (1990)
30	2.24	0.32	1.31	0.02	George & Buvaneswaran (2001)
33	2.34	0.29	0.76	0.27	Seth *et al.* (1963)
38	2.47	0.31	0.75	0.18	Kaul *et al.* (1979)
Unknown	1.17	0.28	1.51	0.25	Hase & Fölster (1983)
Unknown	2.21	0.10	0.34	0.19	Bebarta (1999)
Average	**1.92**	**0.25**	**0.92**	**0.17**	

plantations, was relatively lower than that normally found in soil under teak plantations. Therefore the increase in soil pH and base saturation may be considered as a self-reclamation process of soil condition by teak trees.

CONCLUSIONS

A main factor inhibiting the build-up of soil carbon may be the combustion of forest floor litter by fires. However, even after litter combustion, Ca, which is a dominant mineral nutrient in teak leaf litter, could remain in ash and accumulate in surface soils over time because the volatilization temperature of Ca is generally higher than the temperature of forest fires. Because of the nutrient supply from litter, H and Al ions in soil exchangeable complexes were replaced, increasing the soil pH to a level suitable for teak growth. These results indicate that forest fires, and the nutrient composition of teak leaf litter strongly influenced the long-term changes in soil properties of teak plantations. Litter conservation is important for sustainable soil management in teak plantations. Soils in teak plantations should be managed considering these mechanisms of nutrient recycling.

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