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Effect of Slash-and-burn on Nutrient Dynamics during the Intercropping Period of Taungya Teak Reforestation in the Bago Mountains, Myanmar

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Abstract In the Bago Mountains of Myanmar, teak (*Tectona grandis* Linn.) reforestation using the taungya system has been in continuous operation for more than a century. Under this system, farmers who plant teak trees can cultivate intercrops between the rows of teak. In this region, secondary forests, especially bamboo-dominated forests, are usually slashed and burned to start a new taungya reforestation. To investigate the effect of the burning of bamboo-dominated forests on nutrient dynamics, changes in the soil nutrient status during the slash-and-burn and subsequent intercropping periods of taungya reforestation were examined quantitatively with particular focus on the effect of ash incorporation. After burning, approximately 85.1% of the aboveground biomass was lost and 4.2 t/ha of ash was produced. Although the loss of aboveground biomass was enormous, a significant increase in the amount of exchangeable K in the surface soil was observed. The nutrient dynamics in the soil were heavily influenced by the properties of the K-rich ash, which reflected the chemical composition of the original vegetation. The available P in the surface soil also increased due to a combination of the soil-heating effect and ash incorporation. The burning of bamboo-dominated forests confers certain advantages, including an increase in the amount of readily available essential nutrients such as K and P because bamboo ash contains a large amount of water-soluble K, and sufficient burning enhances the mineralization of organic P by the soil-heating effect.
Key words: Ash incorporation, Ash solubility, Bamboo, Soil-heating effect, Soil properties, Volatilization loss

Introduction

In the Bago Mountains of Myanmar, teak (*Tectona grandis* Linn.) reforestation using the taungya system has been in continuous operation for more than a century. Taungya reforestation can be considered a step in the transformation from shifting cultivation to agroforestry (Preeyagrysorn, 1992). Under this system, teak is planted after the slashing and burning of forests, and farmers who plant teak trees can cultivate intercrops between the rows of teak for the first year after the establishment of a new plantation.

Several studies have reported that the slashing and burning of forests enriches soil nutrients due to the incorporation of ash from the burnt biomass (Stromgaard, 1984; Andriesse and Schelhaas, 1987; Lessa *et al.*, 1996; Tanaka *et al.*, 2005) or the effect of soil heating (Stromgaard, 1984; Kyuma *et al.*, 1985). However, enriched nutrients are more likely to be lost through leaching or erosion (Nye and Greenland, 1964; Tulaphitak *et al.*, 1985; Andriesse and Schelhaas, 1987; Kauffman *et al.*, 1993; Juo and Manu, 1996). Furthermore, the slash-and-burn method generally causes a substantial loss of nutrients through volatilization (Kauffman *et al.*, 1995; Mackensen *et al.*, 1996; Kato *et al.*, 1999). However, the reported magnitude of nutrient gain and loss varies widely among different studies, probably due to differences in factors such as the original vegetation, initial soil conditions, intensity of the burn, and climate.

In the Bago Mountains of Myanmar, bamboo-dominated secondary forests are among the most popular types of vegetation slashed and burned for taungya reforestation because forests with less valuable trees are usually selected by the forest department as reforestation sites. Bamboo-dominated forests are also favored by farmers who participate in taungya reforestation because bamboo plants can be felled easily and generally burn well. Many farmers recognize that sufficient burning of the bamboo has a positive effect on the intercrop yield. However, nutrient dynamics after the slashing and burning of bamboo-dominated forests have rarely been investigated; thus, limited quantitative data are available.

In this study, we traced the changes in soil nutrient status during the slashing and burning of a bamboo-dominated forest and subsequent intercropping periods of taungya teak reforestation by the repeated soil sam-

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pling method. Furthermore, although several studies have indicated the importance of ash incorporation in nutrient dynamics, few have examined the properties of the ash in detail. In the present study, nutrient composition and ash solubility were analyzed to investigate the effect of ash incorporation on nutrient dynamics.

Materials and Methods

Study area

The study area was located in the Oktwin Township (18°41'–18°57'N, 95°50'–96°40'E) on the eastern slope of the Bago Mountains in Myanmar (Fig. 1). The maximum altitude of the Bago Mountains is approximately 800 m above sea level. Elevation and slope degree around the study area were about 160 m and 11° to 34°, respectively. The Bago Mountains are composed of clastic folded tertiary sediments (Bender, 1983). Most of the soils in the study area were classified as Kandiustults based on the USDA classification system (Soil Survey Staff, 1999). The dominant forest type in the study area is moist teak forest, which is usually associated with the bamboo species *Bambusa polymorpha* and *Cephalostachyum pergracile* (Kress *et al*., 2003). The average annual precipitation between 1988 and 2002 was 1966 mm, with distinct rainy and dry seasons. Most rainfall took place between May and October, although several showers occurred in April and November. The average of mean annual minimum and maximum temperatures during 1988 to 2002 were 21.1 °C and 32.7 °C, respectively.

Experimental design

In Oktwin Township, taungya teak reforestation was carried out in compartments 197, 207, and 208 of the Kabaung Reserved Forest during 2002 (Fig. 1). In 2002, 202 ha of secondary forest, especially bamboo-dominated forest, were slashed and burned.

We selected an experimental plot (30 × 30 m²) in compartment 208 (18°49'N, 96°09'E) of the area where taungya teak reforestation had been initiated. All of the vegetation in the experimental plot was felled at the end of January and burned on 2 April 2002. The main intercrop cultivated in the plot was upland rice. Cash crops such as sesame and chili were also intercropped. The intercrops were harvested from October to December. The following experiments were performed in this plot.

Vegetation survey

Prior to the felling of the secondary forest, the diameter at breast height (DBH) and the heights of all the trees and bamboo plants (DBH≧1cm) were measured. Next, the trees and bamboo plants were identified by species. Several sizes of culms were cut from the two dominant bamboo species (*B. polymorpha* and *C. pergracile*) to determine the allometry between the DBH and dry weight of the culms.

Soil sampling and physicochemical analysis

Surface (0–5 cm) and subsurface (30–35 cm) soil samples were collected during four phases: I, before felling (20 January 2002); II, immediately after burning (4 April 2002); III, after sowing the intercrops (24 June 2002); and IV, after harvesting the intercrops (18 November 2002).

To investigate the heterogeneity of the burning conditions, the experimental plot was divided into nine subplots (10 × 10 m² each) prior to soil sampling. The

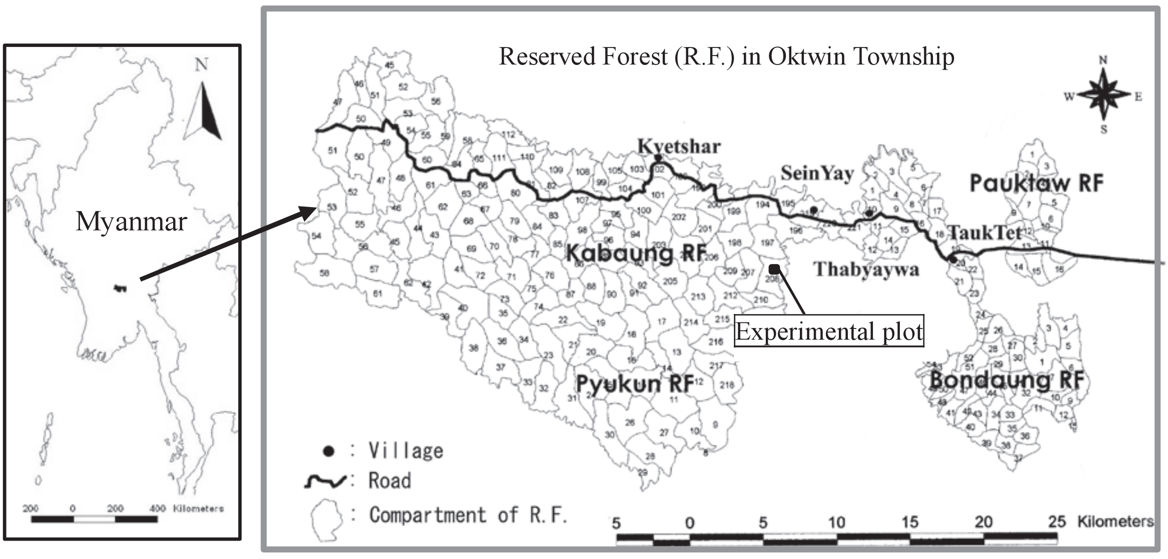


Fig. 1 Location of the study area.

pre-fell vegetation in the experimental plot was dense bamboo, and the aboveground biomass that was felled on the ground was nearly evenly distributed. Because bamboo burns easily compared to other tree species, the heterogeneity of the burning conditions in this plot appeared to be relatively low. According to our field observations, no marked differences were observed in terms of the burning conditions among the nine subplots.

At each sampling time, four surface soil samples and one subsurface soil sample were collected from each subplot (36 surface and 9 subsurface samples total). Surface soil samples collected from the same subplot were mixed together during each sampling to create composite samples. The soil samples collected during phase II were carefully segregated from the accumulated ash on the soil surface. All of the soil samples were air-dried and passed through a 2-mm sieve prior to analysis.

Soil pH was determined in a 1 M KCl suspension at a 1:5 soil to solution ratio using the glass electrode method (HM-7J; TOA Electronics). The total carbon and nitrogen contents were determined using an NC analyzer (Sumigraph NC-800; Sumika Chemical Analysis Service). To determine the exchangeable base content, the Ca, Mg, and K ions were analyzed by atomic absorption spectrophotometry (AA-670; Shimadzu Corporation) after successive extraction using 1 M ammonium acetate at pH 7.0. The amount of available P was measured using the molybdophosphoric blue method (UV mini-1240; Shimadzu Corporation) after extraction with 0.03 N ammonium fluoride and 0.1 N HCl (Bray No. 2 method). All soil samples were oven-dried (105 °C, 24 h) and weighed to determine the dry weight. Three core samples (100 mL) were collected from the surface (0–5 cm) and subsurface (30–35 cm) soil layers to determine the bulk density.

Ash sampling and chemical analysis

Prior to ash sampling, four quadrats (1 × 1 m^2 each) were set up in each subplot (36 total). The accumulated ash on the soil surface of each quadrat was carefully collected in plastic bags using a stainless steel spatula and immediately weighed. The ash samples were crushed into fine fragments using a mixer prior to analysis.

To extract the water-soluble fraction from the ash, the samples (1.0 g) were agitated with 25 mL of demineralized water for 8 h. To examine the total amount of bases (Ca, Mg, and K) and P in the ash, the samples (0.1 g) were digested with 10 mL of concentrated HCl then heated to 130 °C for 8 h. The base (Ca, Mg, and K) and P contents in each solution were determined by atomic absorption spectrophotometry (Shimadzu AA-670) and the molybdophosphoric blue method, respectively. All ash samples were oven-dried (105 °C, 24 h) and weighed to determine the dry weight.

Results

Pre-slash-and-burn vegetation

All tree and bamboo species (DBH≧1 cm) present in the experimental plot before the slash-and-burn are shown in Table 1. The dominant species were *B. polymorpha* and *C. pergracile*. The DBH of all tree species except *Stereospermum colais* was less than 20 cm.

The allometric models between the DBH of the culms and the dry weights of both bamboo species are shown in Table 2. Based on these models, the aboveground biomass of *B. polymorpha* and *C. pergracile* in the experimental plot was estimated to be 54.6 and 40.1 t/ha, respectively. The aboveground biomass of the tree species in the experimental plot was estimated to be 29.5 t/ha using the allometric model created by Ogawa *et al.* (1967) (Table 2). The total aboveground biomass of all of the vegetation in the experimental plot was estimated to be 124.2 t/ha.

Amount and properties of the ash

The amount of ash in the 36 quadrats ranged from 0.1 to 0.8 kg/m^2 and more than 80% of the quadrats had between 0.2 and 0.6 kg/m^2 of ash. The total amount of ash was estimated to be 4.2 t/ha and 199.5 $cmol_c$ of bases (Ca, Mg, K) were contained in 1 kg of ash.

Fig. 2 shows the amounts of total and water-soluble nutrients (Ca, Mg, K, and P) in the ash. The amounts of total and water-soluble K were markedly higher than those of the other nutrients. Particularly in the water-soluble fraction, 73.5 kg/ha of K, accounting for 92.1% of the gross amount of the four nutrients, was contained. In that fraction, 5.4 kg/ha of P was also contained. On the other hand, almost no water-soluble Ca and Mg were observed.

General soil properties

Table 3 shows the changes in chemical soil properties between phases I and IV. The soil pH (KCl) of the surface soil gradually increased from 4.64 in phase I to 4.85 in phase III before decreasing slightly between phases III and IV, although no statistically significant differences were observed throughout the observation period. The pH of the subsurface soil ranged from 4.14 to 4.18, and no significant change was observed.

The total carbon content of the surface soil de-

Table 1 Tree and bamboo species observed in the experimental plot

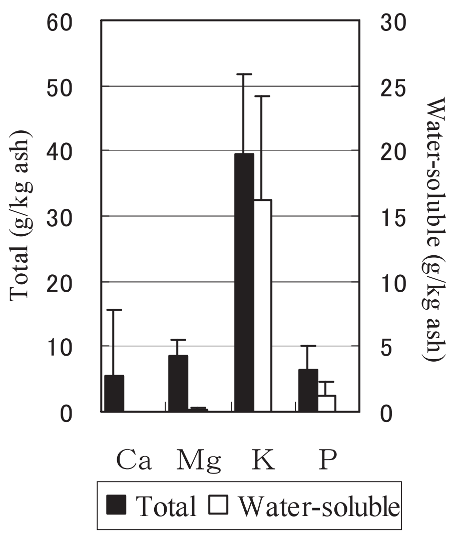
Species	Population density (number/ha)	DBH range (cm)	Basal area (m^2/ha)
*Bambusa polymorpha Munro**	367	2.9- 8.9 (6.5)	16.33
Cephalostachyum pergracile Munro*	456	1.6-11.2 (5.3)	11.31
Stereospermum colais (Buch.-Ham. ex Dillwyn) Mabb.	22	24.2-39.5 (31.9)	1.81
Ficus cunia Buch.-Ham.	56	5.1-18.2 (12.7)	0.81
Duabanga grandiflora (Roxb. ex DC.) Walp.	33	14.0-18.8 (16.6)	0.73
Tetrameles nudiflora R. Br.	11	13.4 (13.4)	0.16
Millettia brandisiana Kurz	44	3.2- 5.4 (4.2)	0.06
Croton oblongifolius Roxb.	11	7.0 (7.0)	0.04
Mitragyna rotundifolia (Roxb.) Kuntze	33	2.9- 3.8 (3.3)	0.03
Unidentified	11	4.8 (4.8)	0.02
Cordia grandis Roxb.	11	4.1 (4.1)	0.01
Xylia xylocarpa (Roxb.) Taub.	11	3.2 (3.2)	0.01
Alstonia scholaris (L.) R. Br.	11	2.2 (2.2)	0.00
Total	1078	—	31.40

*: Bamboo species The numbers in brackets are the mean DBH values (cm)

Table 2 Allometric models for the estimation of the aboveground biomass of tree and bamboo species in the experimental plot

Species	Allometric models	Reference
Bambusa polymorpha	$W = 0.105 D^{2.48}$ (r^2=0.986)	Present study
Cephalostachyum pergracile	$W = 0.148 D^{2.35}$ (r^2=0.994)	Present study
Tree species in dry monsoon forest in Thailand.	$W_S = 0.0396 (D^2H)^{0.9326}$ $W_B = 0.003487 (D^2H)^{1.027}$ $1/W_L = 31.3/(D^2H)^{0.7049} + 0.025$ $W = W_S + W_B + W_L$	Ogawa *et al.* (1967)

W : Aboveground biomass (kg), W_S: Biomass of stem (kg), W_B: Biomass of branches (kg)
W_L: Biomass of leaves (kg), D : DBH (cm), H : Tree height (m)



*Error bars indicate SD.

Fig. 2 The total and water-soluble nutrient levels (Ca, Mg, K, and P) in the ash.

creased slightly from 25.5 g/kg in phase II to 22.9 g/kg in phase IV; however, the decrease was not statistically significant. The total nitrogen content of the surface soil decreased from 1.6 g/kg in phase II to 1.4 g/kg in phase IV, and a significant difference ($P < 0.05$) was observed between phase IV and the other phases. The C/N ratio of the surface soil increased significantly ($P < 0.05$) from 15.0 in phase III to 16.7 in phase IV after a gradual decrease between phases II and III. The total amount of carbon and nitrogen in the subsurface soil decreased slightly during the observation period but was not statistically significant.

No significant change in the exchangeable base content was observed between phases I and II. However, between phases II and III, a significant increase ($P < 0.05$) in the amount of exchangeable K in the surface soil was observed, whereas no significant change was

Table 3 Changes in the chemical properties of the surface and subsurface soils

Surface soils(0-5cm)

Chemical properties	Phase I (Before felling)		Phase II (After burning)		Phase III (After sowing)		Phase IV (After harvesting)	
pH(KCl)	4.64[a]	(±0.17)	4.73[a]	(±0.17)	4.85[a]	(±0.15)	4.82[a]	(±0.20)
Total C(g/kg)	24.9[a]	(±2.7)	25.5[a]	(±3.2)	23.4[a]	(±1.9)	22.9[a]	(±1.9)
Total N(g/kg)	1.6[a]	(±0.1)	1.6[a]	(±0.1)	1.6[a]	(±0.1)	1.4[b]	(±0.1)
C/N ratio	15.7[a]	(±1.0)	16.0[a]	(±1.2)	15.0[a]	(±0.7)	16.7[b]	(±1.1)
Exchangeable bases								
Ca (cmol$_c$/kg)	5.76[a]	(±0.91)	5.86[a]	(±1.28)	5.73[a]	(±0.94)	5.48[a]	(±0.91)
Mg(cmol$_c$/kg)	4.54[a]	(±0.58)	4.49[a]	(±0.61)	4.59[a]	(±0.49)	4.30[a]	(±0.54)
K (cmol$_c$/kg)	0.55[a]	(±0.09)	0.60[a]	(±0.10)	1.00[b]	(±0.26)	0.86[b]	(±0.17)
Available P(g/kg)	0.04[a]	(±0.01)	0.06[ab]	(±0.02)	0.10[b]	(±0.05)	0.06[ab]	(±0.03)

Subsurface soils(30-35cm)

Chemical properties	Phase I (Before felling)		Phase II (After burning)		Phase III (After sowing)		Phase IV (After harvesting)	
pH(KCl)	4.14[a]	(±0.08)	4.12[a]	(±0.03)	4.18[a]	(±0.08)	4.12[a]	(±0.03)
Total C(g/kg)	9.3[a]	(±2.0)	9.2[a]	(±1.6)	8.2[a]	(±1.0)	8.5[a]	(±0.8)
Total N(g/kg)	1.0[a]	(±0.2)	0.9[a]	(±0.1)	0.9[a]	(±0.1)	0.9[a]	(±0.1)
C/N ratio	9.4[a]	(±0.8)	9.7[a]	(±1.0)	8.8[a]	(±0.3)	8.9[a]	(±0.2)
Exchangeable bases								
Ca (cmol$_c$/kg)	2.86[a]	(±0.51)	3.12[a]	(±1.26)	2.63[a]	(±0.65)	2.59[a]	(±0.34)
Mg(cmol$_c$/kg)	5.25[a]	(±0.21)	5.00[a]	(±0.51)	5.72[a]	(±0.83)	5.78[a]	(±0.91)
K (cmol$_c$/kg)	0.50[a]	(±0.12)	0.49[a]	(±0.02)	0.56[a]	(±0.18)	0.56[a]	(±0.11)
Available P(g/kg)	0.01[a]	(±0.00)	0.01[a]	(±0.00)	0.01[a]	(±0.00)	0.01[a]	(±0.00)

Mean (± S.D.).
Different letters in the same row indicate a significant difference (Tukey's HSD multiple comparison test, $P<0.05$)

found for the other bases. From phase III to IV, the level of all exchangeable bases in the surface soil decreased, although not significantly. The exchangeable base content of the subsurface soil showed no significant change throughout the observation period.

The available P content of the surface soil increased after burning, reaching its highest level in phase III before decreasing between phases III and IV. Although no significant differences were observed between phases I and II or phases II and III, the amount of available P in surface soil was continuously increased during phase I to phase III and the available P amount in phase III was significantly higher ($P < 0.05$) than that in phase I. The subsurface soil showed no significant change in available P throughout the observation period.

Discussion

Biomass loss and ash addition during the slash-and-burn period

Generally, the slash-and-burn method causes a substantial loss of nutrients through volatilization (Kauffman *et al*., 1995; Mackensen *et al*., 1996; Kato *et al*., 1999). In the experimental plot, almost all of the bamboo and small trees were incinerated, producing 4.2 t/ha of ash. However, the trunks of the larger trees, such as *S. colais* (DBH: 24.2–39.5 cm), did not burn and stayed on the ground. Assuming that the trunks of those trees with a DBH greater than 20 cm were left unburned, an estimated 14.3 t/ha of tree biomass remained. Consequently, the loss of biomass during the slash-and-burn period was estimated to be 105.7 t/ha, or 85.1% of the total aboveground biomass (124.2 t/ha).

Although the intensive combustion of biomass releases substantial amounts of C, N, and S into the atmosphere (Juo and Manu, 1996), the loss of nutrients with higher volatilization temperatures, such as bases (Ca, Mg, and K), is much smaller. As shown in Fig.2, the ash in our experimental plot was rich in K, and 173.1 kg/ha of K was added to the soil surface. The K in ash plays an important role in soil nutrient dynamics, as will be discussed later.

The chemical composition of plant ash depends upon the composition of the plants and the degree of their combustion (Khanna *et al.*, 1994). Several studies have reported that bamboo accumulates more K than other bases (Rao and Ramakrishnan, 1989; Shanmughavel and Francis, 1996a, 1996b; Mailly *et al.*, 1997), whereas tree dominated forests accumulated more Ca (Kyuma and Pairintra, 1983). Thus, the high K content of the ash reflected the characteristics of the bamboo plants that were initially present in the experimental plot.

Dynamics of soil organic matter

It has been recognized that the amount of soil organic matter (SOM) generally decreases with time during the slash-and-burn and subsequent cropping periods, mainly due to an increase in the decomposition rates of SOM (Nye and Greenland, 1964; Sanchez *et al.*, 1983; Lessa *et al.*, 1996; Roder *et al.*, 1997; Tanaka *et al.*, 2001; Wairiu and Lai, 2003; Funakawa *et al.*, 2005).

However, in the present study, the decrease in total soil carbon was not conspicuous throughout the observation period (Table 3). Similar results were obtained by Kendawang *et al.* (2005), who reported that the loss of SOM was compensated by the supply of dead plant roots or unburned organic matter associated with slashing and burning. A significant increase in the C/N ratio of the surface soil between phases III and IV was observed in the present study, suggesting that the addition of fresh organic matter with a higher C/N ratio, such as dead bamboo roots or residual of intercrops, to the soil surface mitigated the loss of SOM.

Dynamics of soil nutrients and the effect of ash incorporation

Typically, the slashing and burning of forests results in an increase in soil nutrient availability due to the effect of soil heating and the incorporation of ash from the burnt aboveground biomass (Giardina *et al.*, 2000). In this study, phase II (immediately after burning) soil samples were collected 2 days after burning. No rain was recorded during those 2 days, indicating that almost none of the ash was incorporated into the soil before sampling in phase II. Therefore, the main cause of the changes in soil nutrient status from phase I (before felling) to phase II was likely to have been soil heating, while the cause of the changes from phase II to phase III (after intercrop sowing) was probably ash incorporation.

Accordingly, the increase in amount of available P in the surface soil between phases I and II may have been due to the effect of soil heating. Several studies have reported an increase in available P after heating, caused by the mineralization of organic P in the soil (Andriesse and Koopmans, 1984; Kutiel and Shaviv, 1989; Saa *et al.*, 1993), possibly via the release of inorganic P from dead microorganisms (Marumoto *et al.*, 1982; Seeling and Zasoski, 1993; Serrasolsas and Khanna, 1995).

The significant increase ($P < 0.05$) in exchangeable K in the surface soil between phases II and III was probably due to ash incorporation. As ash components vary greatly in terms of solubility, and given that only a portion of the total element added is sufficiently soluble to react with the soil (Khanna *et al.*, 1994), the water-soluble nutrients in ash are a particularly important part of evaluating nutrient enrichment via ash incorporation. In the experimental plot, 73.5 kg/ha of water-soluble K, accounting for 92.1% of the gross amount of the four nutrients (Ca, Mg, K, and P) in the water-soluble fraction, was supplied via ash incorporation, and consequently, a significant increase in the amount of exchangeable K was observed. Because the taungya farmers in this region do not apply fertilizer to their intercrops, the water-soluble fraction of ash plays an important role in the supply of readily available nutrients for the intercrops.

The balance between the nutrient levels in the ash and those originally stored in the soil is also an important factor when considering the effect of ash incorporation on nutrient dynamics. Fig. 3 shows the amounts of the four nutrients in the surface soil and in the water-soluble and -insoluble fractions of the ash. The nutrient levels in the water-insoluble fraction were calculated by subtracting the water-soluble nutrients from the total ash nutrients. Because the amounts of Ca and Mg in the ash, particularly in the water-soluble fraction, were much less than those originally stored in the soil, the effect of ash incorporation on these two elements in the soil was not conspicuous. The amount of water-soluble P in the ash, however, was around 50% of the level of these nutrients in the surface soil in phase I. Thus, the effect of ash incorporation on the soil nutrient dynamics of P was not negligible, although the total amount of P in the ash was much less than that of K. Consequently, an increase in the amount of available P was observed after the incorporation of ash between phases II and III. Due to the combination of the soil-heating effect and ash incorporation, the amount of available P in the surface soil increased significantly ($P < 0.05$) from phase I to phase III.

From phase III to phase IV, a decrease in the amount of exchangeable K and available P in the surface soil was observed, although it was not statistically significant. This decrease indicates that some losses oc-

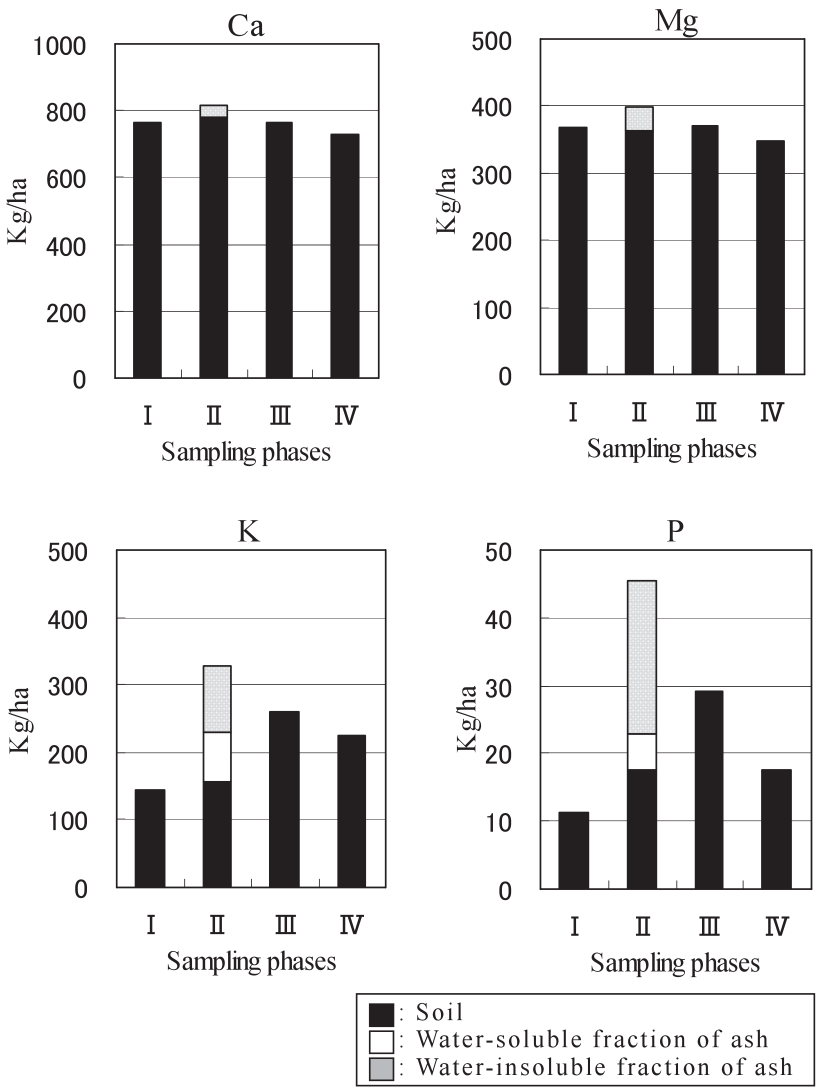


Fig. 3 The amounts of four nutrients (Ca, Mg, K, and P) in the surface soil and in the water-soluble and -insoluble fractions of the ash.

curred due to erosion, leaching, or plant uptake during the intercropping period (Sanchez *et al.*, 1983; Andriesse and Schelhaas, 1987; Roder *et al.*, 1997). However, none of the nutrients showed a significant decrease between phases I and IV, suggesting that 1 year of intercropping during taungya reforestation does not severely affect the soil nutrient status.

Conclusions

Although the loss of aboveground biomass due to slashing and burning was enormous, a significant increase in the amount of exchangeable K and available P in the surface soil was observed. These increases may play an important role in the growth of intercrops because the initial soil levels of these essential elements were relatively low and no fertilizer was applied in the study area. Thus, the advantage of burning bamboo-dominated forests is that it increases the supply of readily available nutrients in the ash, which contains large amounts of water-soluble K and sufficient burning enhances the mineralization of organic P by the soil-heating effect.

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