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NOTE AND COMMENT

Masamichi Takahashi · Hitomi Furusawa
Pitayakon Limtong · Vanlada Sunanthapongsuk
Dokrak Marod · Samruan Panuthai

Soil nutrient status after bamboo flowering and death in a seasonal tropical forest in western Thailand

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Abstract We have examined the surface (0–10 cm) soil characteristics of sites after bamboo (*Cephalostachyum pergracile*) mass flowering and death (DB sites) in comparison with sites with living bamboo (*Bambusa tulda*) (LB sites) in a seasonal tropical forest in Thailand. One year after bamboo flowering the DB sites were acidic with lower concentrations of exchangeable Ca and Mg and soil nitrogen than the LB sites. Therefore, although leaf and root litter of the dead bamboo was deposited in the DB sites after bamboo flowering, soil nutrient status decreased.

Keywords Bamboo death · Bamboo flowering · *Bambusa tulda* · *Cephalostachyum pergracile* · Soil nutrients

Introduction

Bamboo is a predominant under-story species in several Asian forest ecosystems. In lowland forests of Thailand, for example, many bamboo species are established in intermediate moisture sites where deciduous forests are usually distributed (Kutintara 1975; Gardner et al. 2000). Bamboo undergoes simultaneous mass flowering for long intervals of several decades (Wong 2004). Communities of bamboo species flower suddenly and simultaneously then all the flower clumps die, leading to drastic changes in forest dynamics and environmental conditions, for example, light intensity, seedling survival, organic matter decomposition, and nutrient cycling, although complete destruction of bamboo clumps requires another few years. As a result, the demography of tree seedling growth in western Thailand is strongly influenced by bamboo flowering (Marod et al. 2002).

Several nutrient cycling studies of bamboo communities have suggested that active nutrient cycling by vigorous bamboo growth and litter production improves soil fertility (Toky and Ramakrishnan 1983; Tripathi and Singh 1994; Christanty et al. 1997; Singh and Singh 1999). How soil fertility changes when a bamboo community flowers and dies has yet to be clarified, however. After mass flowering and death, nutrient uptake by the bamboo ceases and large amounts of dead organic matter are deposited. Consequently, the question which arises is whether soil fertility declines because of disruption of nutrient cycling or whether it is maintained because of release of nutrients from decomposing organic matter. This is important with regard to plant growth and vegetation succession. We therefore examined the surface soil-nutrient status of sites after bamboo flowering compared with those with living bamboo species in a seasonal tropical forest in western Thailand.

M. Takahashi (✉) · H. Furusawa
Department of Forest Site Environment, Forestry and Forest Products Research Institute, 1 Matsunosato, Tsukuba, Ibaraki 305-8687, Japan
E-mail: masamiti@affrc.go.jp
Tel.: +81-29-8733211
Fax: +81-29-8743720

P. Limtong · V. Sunanthapongsuk
Land Development Department, Paholyothin Rd., Chatuchak, Bangkok, 10900, Thailand

D. Marod
Department of Forest Biology, Faculty of Forestry, Kasetsart University, Bangkok, 10903, Thailand

S. Panuthai
Mae Klong Watershed Research Station, National Park, Wildlife and Plant Conservation Department, Bangkok, 10900, Thailand

Materials and methods

The study sites (14°35′N, 98°52′E) were located in the Mae-Klong Watershed Research Station, Kanchanaburi Province, western Thailand. This area has a tropical monsoon climate with rainy (May–September) and dry (November–March) seasons; April and October are the transitions between seasons. The mean annual temperature is 27.5°C and annual precipitation is approximately 1650 mm. The soil is loam to clay loam, well drained, and classified as Ultisol (Soil Survey Staff 2003).

The forest is a mixed deciduous forest (Kutintara 1975; Rundel and Boonpragob 1995) dominated in the study area by *Shorea siamensis*, *Vitex peduncularis*, *Dillenia parviflora* var. *Keruii*, and *Xylia xylocarpa* var. *Keruii*. Detailed descriptions of the vegetation are given elsewhere (Marod et al. 1999). Four bamboo species, *Gigantochloa albociliata*, *G. hasskarliana*, *B. tulda*, and *C. pergracile*, are predominant in the under-story vegetation (Marod et al. 1999). In the rainy season of 2001, *C. pergracile* in the watershed flowered and produced seeds. Throughout the dry season starting from September 2001, dead leaves and seeds of *C. pergracile* were deposited. After the rainy season of 2002 the seeds germinated in the open spaces left by the parent bamboo, an area of approximately 400–1,600 m^2.

In December 2002, approximately 1 year after flowering, two quadrates (20×20 m^2) were placed in each of two plots (plots 1 and 2) located on two mountain slopes approximately 1 km apart and 160–360 m a.s.l. One quadrate in each plot was placed in a site with dead bamboo (DB sites) and the other in a site with living bamboo (LB sites). Because flowering is simultaneous among all *C. pergracile* in these plots, it was difficult to make comparisons between living and dead individuals. Thus, as living bamboo we selected adjacent bamboo communities of *B. tulda* on the same slope, where soil and environmental conditions were thought to be the same. The distance between the DB and LB quadrates was within 60 m.

Five replicates of surface soil (0–10 cm), litter, and ground vegetation samples were collected from the corners and center of each quadrate. The litter layer and herbaceous ground vegetation in a 50×50 cm^2 frame were collected, dried at 70°C for 1 week in an oven, then used for biomass estimates. The moist surface soil samples were dried at 105°C in an oven for determination of soil moisture content.

Part of the moist soil samples were air-dried and sieved to obtain fine soil samples (< 2 mm). Soil pH was measured with soil water (1:5) slurry using a glass electrode. Exchangeable cations were extracted with 1 mol L^{-1} ammonium acetate and determined by atomic absorption spectrometry. Organic carbon was determined according to the Walkley and Black method, total nitrogen was determined using the Kjeldahl method, and available phosphate was extracted using the Bray method. All analyses were conducted as described previously (Jackson 1958). To determine potentially available nitrogen, mineralized soil nitrogen was evaluated by aerobic incubation; soil adjusted to 60% of its maximum water-holding capacity was incubated at 30°C for 28 days then mineralized. NH_4^+ and NO_3^- were determined using the steam distillation method. The extent of nitrification was expressed as the percentage of mineralized NO_3^- in total mineralized nitrogen.

To examine the effects of bamboo death and study plot on soil chemical properties, we used two-way analysis of variance (ANOVA). With the nitrification rates and soil moisture data, arc sine transformation was conducted before analysis. All statistics were conducted with Statistica (StatSoft, USA).

Results

Although all leaves became senescent, subsequently falling and accumulating on the ground after bamboo death, no significant difference between litter mass at the DB and LB sites was found 1 year after bamboo flowering (Fig. 1 and Table 1). Most of the litter had decomposed during the rainy season. Ground vegetation, mostly germinated bamboo seedlings, was greater at the DB sites than the LB sites, where little vegetation occurred under the shade of the growing bamboo canopy. Soil moisture also tended to be higher in the DB sites, although the difference was not significant.

In plot 1, but not plot 2, soil organic carbon content was lower in the DB site than the LB site (Fig. 2). Soil nitrogen content, on the other hand, was significantly

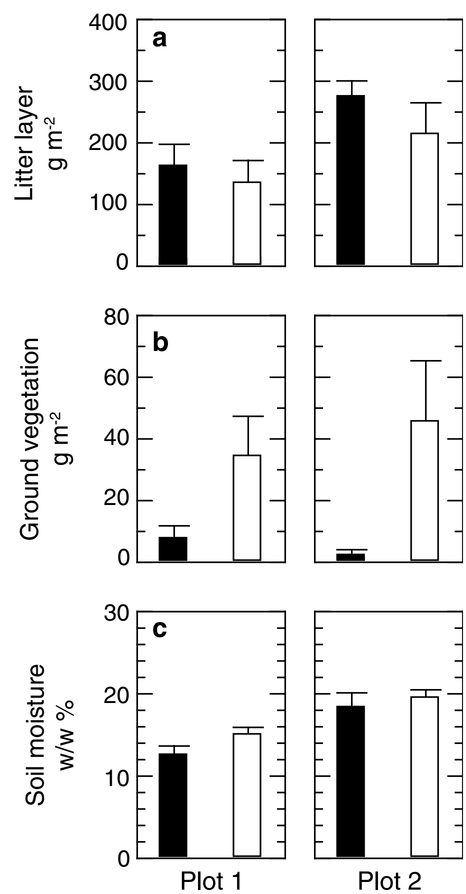

Fig. 1 Dry weights of the litter layer (**a**) and ground vegetation biomass (**b**), and soil moisture content (**c**), in the LB (*solid*) and DB (*open*) sites in plots 1 and 2 (mean + SE, $n = 5$)

Table 1 Results from two-way ANOVA of the effects of bamboo death and plot on litter layer mass, ground vegetation biomass, and soil characteristics

	df	MS	F	P	*df*	MS	F	P	*df*	MS	F	P	*df*	MS	F	P
	Litter				Vegetation				Soil moisture				Soil pH			
Bamboo	1	9717	1.436	0.248	1	6124	8.785	0.009	1	0.0017	2.535	0.131	1	0.221	2.309	0.148
Plot	1	46007	6.799	0.019	1	42	0.060	0.810	1	0.0136	20.506	0.000	1	0.084	0.885	0.361
Bamboo×Plot	1	1398	0.207	0.656	1	344	0.494	0.492	1	0.0002	0.330	0.573	1	0.013	0.131	0.722
Residual	16	6767			16	697			16	0.0007			16	0.096		
	Carbon				Nitrogen				Available N				Nitrification rate			
Bamboo	1	116.2	8.301	0.011	1	0.599	20.970	0.000	1	0.218	1.686	0.212	1	0.0345	2.453	0.137
Plot	1	12.6	0.900	0.357	1	0.002	0.085	0.775	1	0.121	0.932	0.349	1	0.0322	2.628	0.124
Bamboo×Plot	1	137.8	9.849	0.006	1	0.173	6.060	0.026	1	0.002	0.015	0.904	1	0.0008	0.064	0.804
Residual	16	14.0			16	0.029			16	0.129			16	0.0131		
	Exchangeable Ca				Exchangeable Mg				Exchangeable K				Exchangeable Na			
Bamboo	1	30.18	6.15	0.025	1	6.997	36.494	0.000	1	0.0051	0.392	0.540	1	0.066	3.852	0.067
Plot	1	70.20	14.30	0.002	1	0.310	1.617	0.222	1	0.0541	4.144	0.059	1	0.002	0.128	0.725
Bamboo×Plot	1	0.96	0.20	0.664	1	1.063	5.542	0.032	1	0.0016	0.124	0.729	1	0.024	1.387	0.256
Residual	16	4.91			16	0.192			16	0.0131			16	0.017		
	Available P															
Bamboo	1	1.8	0.727	0.406												
Plot	1	33.8	13.657	0.002												
Bamboo×Plot	1	5.0	2.020	0.174												
Residual	16	2.5														

lower in the DB site than the LB site in both plots. Available N was relatively low in the DB sites compared with the LB sites (Fig. 2), although the difference was not significant (Table 1). The extent of nitrification was approximately 50% in both sites, and bamboo flowering did not affect extractable P content. Soil pH in the DB sites tended to be acidic and there were fewer exchangeable cations (Fig. 3). The DB sites had significantly less exchangeable Ca and Mg than the LB sites, although there were no significant differences between exchangeable K and Na, which were present at very low concentrations.

Discussion

Our results indicate that total soil nitrogen, available nitrogen, and exchangeable Ca and Mg content were low in sites where bamboo had flowered and died. In general, the surface soil in the DB sites was relatively infertile compared with that in the LB sites, although a large amount of dead organic material, for example leaf litter, broken culms, and root litter were deposited after bamboo death. This suggests that nutrient conditions declined within a year after bamboo flowering and death. Thus, the nutrient status of the study forest is probably maintained by bamboo species through nutrient and carbon cycling, as has been found in other bamboo forests in the seasonally dry tropics (Tripathi and Singh 1994; Christanty et al. 1997; Arunachalam and Arunachalam 2002).

Because bamboo death creates an open canopy, soil temperature is likely to increase as a result of direct sunlight, and soil moisture is also likely to increase as a result of reduced evapotranspiration and interception by the bamboo. Such environmental changes will quicken the decomposition of fallen litter in DB sites during the rainy season, as seen in the sites in this work, where most of the litter decomposed within 1 year. This was confirmed by soil respiration monitoring near the study plots—soil respiration rates increased significantly for approximately 1 year after bamboo death before declining to the pre-flowering level (Panuthai, unpublished data). Tripathi and Singh (1994) have reported a significant reduction in total carbon and nitrogen in the surface soil (0–10 cm) of bamboo harvested sites in India; in our study, however, no clear decreases in soil carbon were detected. Variant results were obtained for plots 1 and 2 and a statistical interaction between bamboo and plot was observed (Table 1). We therefore suggest that the low soil carbon content observed in the DB site of plot 1 was within the range of variance of the soil characteristics rather than an effect of bamboo death during the short observation period. Trends were similar for total N and available P also (Fig. 2). Because N and P in the surface soil largely follow the dynamics of soil organic matter, the effects of bamboo death on N and P soil content should also be negligible in the short term.

In contrast, available N in the DB sites tended to be low, although the differences between sites were not significant in ANOVA, because of the large variation of available N at the LB site in plot 1 (Fig. 2 and Table 1). This might suggest that the labile N available for microbial activity is reduced after bamboo death. Singh and Singh (1999) reported that soil microbial biomass and available N increased with bamboo community development on a mine spoil soil. Bamboo death therefore seems to affect the labile fraction, which is related to the existence of the bamboo community, probably through leaf and root litter turnover.

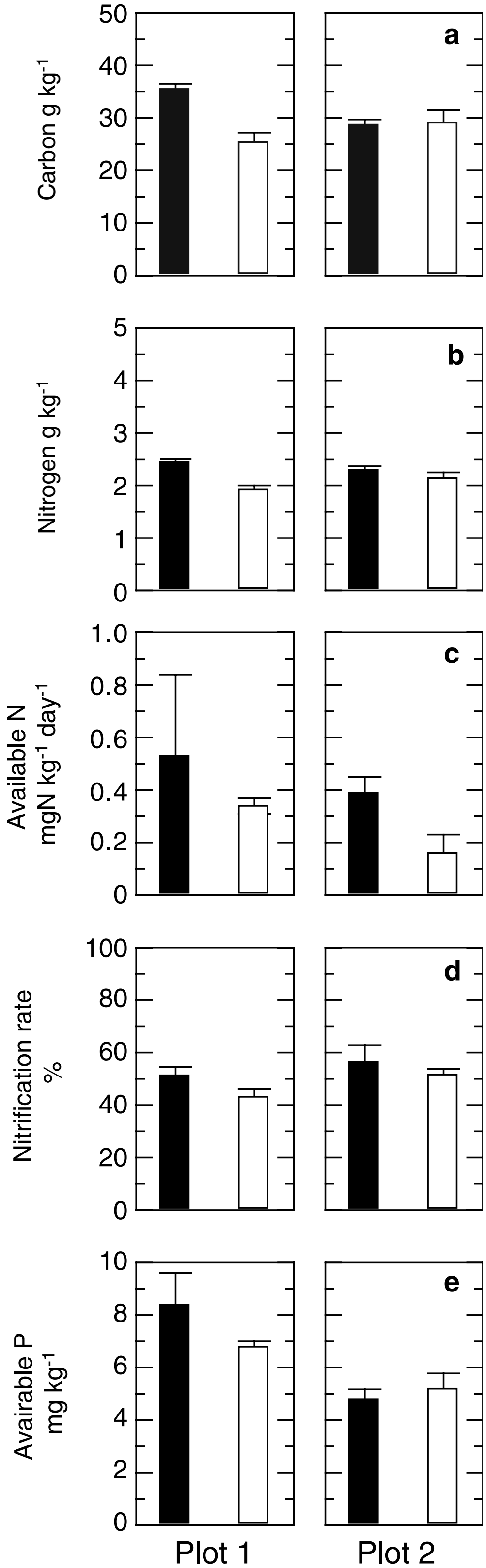

Fig. 2 Soil organic C content (**a**), total N content (**b**), available N content (**c**), nitrification rate (**d**), and available P content (**e**) at the LB (*solid*) and DB (*open*) sites in plots 1 and 2 (mean + SE, $n = 5$)

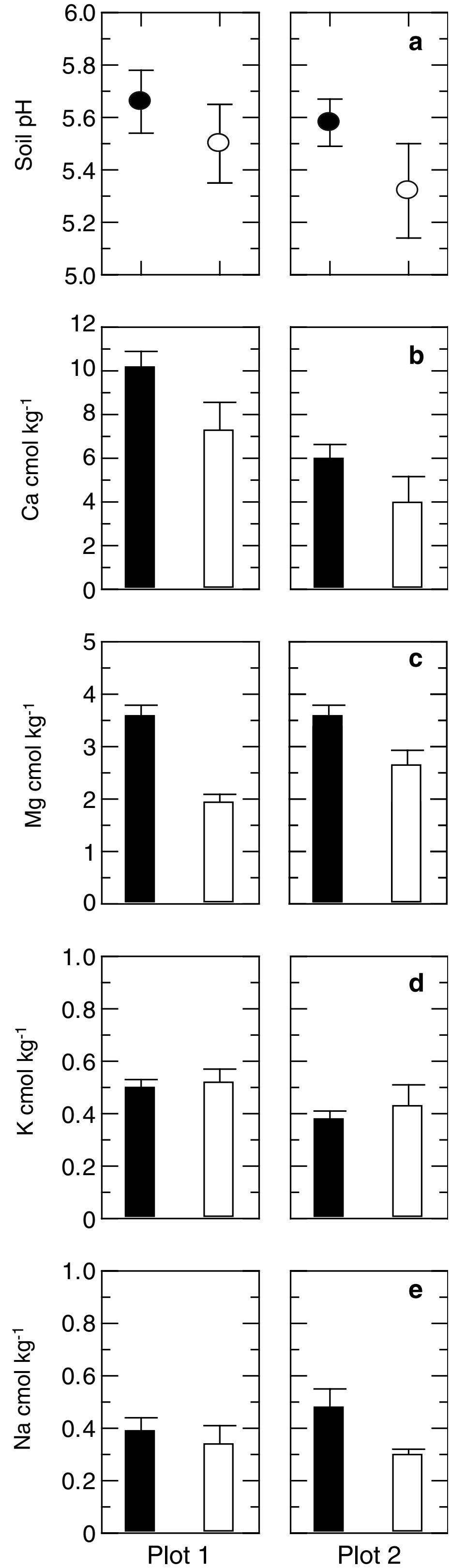

Fig. 3 Soil pH (**a**), and concentrations of exchangeable Ca (**b**), exchangeable Mg (**c**), exchangeable K (**d**), and exchangeable Na (**e**) at the LB (*solid*) and DB *open*) sites in plots 1 and 2 (mean ± SE, $n = 5$)

Although exchangeable Ca and Mg content at the LB sites were significantly higher than at the DB sites, no significant differences between exchangeable K and Na were found. After bamboo flowering and death, soil pH tended to decrease, which is in accordance with the lower concentrations of exchangeable Ca and Mg at the DB sites (Fig. 3). Details of the mechanisms behind the decreases in soil pH and exchangeable cations were not apparent from this study but higher soil moisture at the DB sites probably enhanced the leaching of cations from the surface soil especially in the rainy season. Cation leaching is also promoted by accumulation of mineralized nitrate, as is often found in soil after deforestation (Jordan 1985; Homann et al. 1994). No significant differences were found for K and Na, which were present in low concentrations. Because these ions are prone to leaching from the soil, the effect of bamboo flowering was likely to have been indistinct in the DB sites. Although K is quickly accumulated and stored in bamboo communities (Toky and Ramakrishnan 1983; Chandrashekara 1996), this bioaccumulated K is released soon after bamboo death, but then seems to be reacquired by bamboo seedlings and leached into the subsoil within a year after flowering.

Finally, inevitable differences are likely to be observed in comparisons between different bamboo species. These results might therefore have been affected by a species effect. Further study is needed to fully understand the consequences of bamboo death on soil characteristics and nutrient cycling in this mixed deciduous forest in Thailand.

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