Effect of *Acacia* plantations on net photosynthesis, tree species composition, soil enzyme activities, and microclimate on Mt. Makiling

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Abstract

To determine the effectiveness of rehabilitation on improving ecosystem functions, we examined net photosynthetic rate (P_N), tree species composition, soil enzyme activities, and the microclimate (air and soil temperature, relative humidity) of an area on Mt. Makiling that has been rehabilitated and protected from fire for over 12 years. After it was last burned extensively in 1991, restoration was initiated by planting *Acacia mangium* and *Acacia auriculiformis.* We selected three areas to study in 2003. Two areas were rehabilitated with *A. mangium* and *A. auriculiformis*, and one was still dominated by *Imperata cylindrica* and *Saccharum spontaneum*. P_N of *A. mangium* and *A. auriculiformis* showed significantly lower values than those of *I. cylindrica* and *S. spontaneum*. The *Acacia* plantations had more naturally regenerated tree species than the grassland. Additionally, more tree species appeared in the *A. mangium* plantation than in the *A. auriculiformis* plantation. *Ficus spetica* was present in all of the study sites. Dehydrogenase and phosphatase activities were significantly higher in soil under the *Acacia* plantations than under grassland. Grassland showed higher air temperature, relative humidity, and soil temperature as well as a larger variation per hour in these parameters compared to the *Acacia* plantations. The highest air temperature, relative humidity, and soil temperature were measured in April during the dry season. From the regression analysis, soil temperature was significantly correlated with air temperature. Hence plantations, as a rehabilitation activity for grassland, promote natural regeneration and stabilize the microclimate. This stabilization of the microclimate affects establishment and growth of naturally occurring tree species.

Additional key words: *Acacia mangium; Acacia auriculiformis;* dehydrogenase; grassland; *Imperata cylindrica;* phosphatase; *Saccharum spontaneum*; triphenyl formazan; 2.3.5-triphenyltetrazolium chloride.

Introduction

Tropical forests comprise nearly 50 % of the world's forest, but during recent years they are disappearing at a rate of 1 300 000 hectares per year (FAO 2001). The significance of this statistic is that large-scale deforestation occurs in most developing countries, particularly in tropical Asia and Central America, which show the highest loss at an annual rate of more than 1 %. The main factors contributing to the degradation of the forest ecosystem are shifting cultivation, forest fire, illegal logging, and over-logging. In addition, the widespread extent of *Imperata cylindrica*, makes it difficult for degraded ecosystems to be restored to their original state. To rehabilitate degraded forest ecosystems successfully, tree species that can overcome *I. cylindrica* have to be introduced. Nitrogen fixing tree species as pioneer species are recommended in grasslands, because they are fast growing and are more effective in competing with *I. cylindrica* (Banerjee 1995). Thus, *Acacia* species are planted for rehabilitation of barren land such as mining areas, *etc*. (Jim 2001).

The Philippines has a total land area of 30 million hectares (ha). Fifty-three percent of the land area, equivalent to 15.88 million ha, are considered forest lands. However, as of 1996, only 5.49 million ha of forest lands

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Abbreviations: DBH – diameter at breast height; MUB – modified universal buffer; P_N – net photosynthetic rate; PPFD – photosynthetic photon flux density; RBA – relative basal area; RD – relative density; RH – relative humidity; TTC – 2,3,5- triphenyltetrazolium chloride; TPF – triphenyl formazan.
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are actually covered with forest. In 1999, only 800 000 ha were primary forests (dipterocarp forests), about 2/3 of which was degraded. Most grassland ecosystems in the Philippines were formerly forested areas that have been initially converted to upland agriculture and progressively degraded by such unsustainable land use systems as shifting cultivation.

The pace of natural regeneration differs by time and degraded area. Artificial regeneration has to be applied to areas that are difficult to regenerate naturally or to accelerate speed of restoration. Vegetation type, structure, and canopy closure influence the microclimate (Raich and Tufekcioglu 2000, Martius *et al*. 2004). The microclimate is the result of the interactions among various biological, biophysical, hydrological, and topographical factors in an ecosystem. The microclimate could be considered the 'pulse' of an ecosystem because of its direct and indirect effects on most ecosystem processes and *vice versa* (Xu *et al*. 2004). Plant cover changes soil temperature and moisture, and these effects often differ among vegetation types (Gates 1980); therefore, vegetation plays a critical role in shaping the microclimate through the change of energy and water balance across the landscape (Xu *et al*. 2002).

Tree stands modify the microclimate in terms of reduced air and surface soil temperature, increased relative humidity, and reduced irradiance compared to grasslands (Dela Cruz and Luna 1994). The microclimate is a factor that determines the environmental conditions for forage productivity (Feldhake 2001), crops, and soil organisms (Martius *et al*. 2004). Knowledge of the physical and chemical properties of soil has enabled foresters to assess the capacity of sites to support productive forests. The concept of soil quality includes assessment of soil properties and processes as they relate to the ability of soil to function effectively as a component of a healthy ecosystem (Schoenholtz *et al*. 2000).

Dehydrogenase enzymes are involved in oxidative and reductive reactions within the Krebs tricarboxylic acid cycle. Greater activity of the soil microbial population is reflected through an increase in dehydrogenase activity when the oxidation of carbon compounds is used as an index of respiration in the soil (Smith and Pugh 1979, Lee *et al*. 1998, Park *et al*. 1998). Phosphatases, which may be of plant or microbial origin, are involved in the transformation of organic and inorganic phosphorus compounds in soil. Phosphatase activity is influenced by various soil properties, soil biocoenoses, vegetation cover, and the presence of inhibitors and activators (Hysek and Sarapatka 1998). Phosphatases may play a significant role in P availability to plants from native soil organic P compounds (Rastin *et al*. 1988, Firsching and Claassen 1996, Lee *et al*. 1998, Park *et al*. 1998), and phosphatase activity is also strongly correlated with the rate of release of inorganic N to the soil solution (Boerner and Brinkman 2003).

Acacia mangium and *Acacia auriculiformis* are major fast-growing plantation species used not only for pulp and timber production but for multi-purposes in the tropical Asia region. Their importance as plantation species can be attributed to rapid growth, rather good wood quality, and tolerance to a range of soil types and pH values (Yamamoto *et al*. 2003).

We investigated the tree species composition, soil, and microclimate in *Acacia* species plantations to identify the effects of tree planting on these parameters in a former grassland area on Mt. Makiling, Philippines, from August 2003 to June 2004. The objective of this study was to examine the effects, after ten years, of planting *A. auriculiformis* and *A. mangium* in grassland areas in terms of changes in species composition and microclimate (air and soil temperature, relative humidity).

Materials and methods

Study sites: Mt. Makiling Forest Reserve is located in South Central Luzon, Philippines (121°14'E, 14°08'N) and covers an area of 4 244 ha. Mt. Makiling is an isolated volcanic cone, but no eruption has been recorded in human history. The climate is tropical monsoon in character, with two pronounced seasons: wet from May to December and dry from January to April. The average annual precipitation is 2 397 mm, and the annual temperature ranges 25.5–27.5 °C. The dominant soil type of the area is clay loam which is derived from volcanic tuff with andesite and a basalt base (Luna *et al*. 1999).

The original vegetation surrounding the mountain base has been cleared, and the land has been cultivated. However, remnant individuals in the ravines indicate that a dipterocarp forest zone was once present in the lowlands. The dominant dipterocarp species still in the area are *Parashorea malaanonan*, *Shorea guiso*, and *Shorea contorta*. However, the lesser presence of dipterocarp species indicated that the species has suffered heavy utilization in the past with the result that numerous non-dipterocarp tree species have now formed a species-rich secondary tropical rain forest (Luna *et al*. 1999).

The study sites are located in So Kay Inglesia on the southwest slope of Mt. Makiling at 500 m a.s.l. This area has been previously cultivated and perennially burned prior to the 1990s. The last time it was burned extensively was in April 1991. To restore this fire-degraded area, *A. mangium* and *A. auriculiformis* were planted between 1993 and 1997 accompanied by intensive protection from fire.

Tree species composition and growth: In 2003, three sampling sites were established in grassland, a 10-year-old *A. auriculiformis* plantation and a 10-year-old *A. mangium* plantation. A total of nine sample plots (plot size: grassland 10×10 m, *Acacia* plantations: 20×20 m) were established whose elevation ranged 520–535 m a.s.l. All of the tree species with a diameter at breast height (DBH) above 5 cm were identified, and their DBH was measured along with height and crown diameter. Tree height was measured using a clinometer and a pole of fixed length using the formula below. All trees were marked using numbered plastic labels and were plotted on a coordinate axis. Two regeneration quadrants (2×2 m) were established in each plot, and all seedlings in the quadrant were identified and measured for root collar diameter and height.

$$H_t = h_0 \frac{(P_t - P_1)}{(P_2 - P_1)}$$

where, H_t: height at the top of tree [m], h_0: length of fixed-length pole [m], P_t: angle measurement to the top of tree [%], P_1: angle measurement to the base of the tree [%], and P_2: angle measurement to the top of the pole [%].

Net photosynthetic rate (P_N) of *A. mangium*, *A. auriculiformis, I. cylindrica*, and *Saccharum spontaneum* were measured on fully expanded, mature leaf number 4 counted from each shoot apex on every individual in the three different sites. P_N was measured with a broad-leaf cuvette of the *Licor-6400* Portable Photosynthesis System (*LI-COR*, Lincoln, NE, USA). The leaf was sealed, and the CO_2 concentration was allowed to be maintained at ambient levels. Air flow through the analyzer was adjusted to maintain leaf cuvette relative humidity near ambient levels (60–70 %) during measurement. The average cuvette temperature was maintained at 25 °C.

Soil enzyme activity: Soil samples were collected from two different depths at 0–15 cm, and the samples were sieved with a 2-mm sized mesh, air-dried, and kept in a dry place. Dehydrogenase activity was determined by the 2.3.5-triphenyltetrazolium chloride (TTC) method. Six grams of soil sample including 1 % of $CaCO_3$ were treated with 3 % TTC and 2.5 cm^3 distilled water and then incubated for 24 h at 37 ºC. The sample was then extracted with 10 cm^3 methanol prior to filtration using ash-less filter paper (*Whatman* No. *42*). TPF was used as the standard solution, and the absorbance of the filtered samples was read at 485 nm with a UV-spectrophotometer (Gong 1997, Park *et al*. 1998).

One gram of soil with 4 cm^3 MUB (Modified Universal Buffer, pH 6.5), 0.2 cm^3 toluene, and 1 cm^3 *p*-nitrophenyl phosphate solution was incubated at 37 ºC. After 1 h, 1 cm^3 of 0.5 M calcium chloride and 4 cm^3 of 0.5 M sodium hydroxide were added, and the sample was swirled for a few seconds and filtered through *Whatman* No. *2* filter paper. The filtered solution's absorbance was read at 400 nm with a UV-spectrophotometer (Tabatabai and Bremner 1969, Park *et al*. 1998).

Microclimate measurements: Monthly rainfall data (September 2002–March 2003) were collected from two nearby rain gauge stations which have different altitudes of 100 and 300 m a.s.l. Three *HOBO* Pro Series Data Loggers (*On-set Computer Corporation*, Porasset, MA, USA) for monitoring air temperature and relative humidity and three soil temperature loggers (*On-set Computer Corporation*, Porasset, MA, USA) were established in the grassland, *A. auriculiformis*, and *A. mangium* sites. We recorded soil temperature at a depth of 5 cm. The data loggers for air temperature and relative humidity were established at an above-ground height of 2 m. Data were recorded at 1-h intervals for air temperature and relative humidity and at 2-h intervals for soil temperature. We computed the mean, standard deviation, minimum and maximum of *HOBO* data by month. To identify variations of the microclimate among sites, we calculated the mean of the absolute value of change per hour.

Results

P_N (Fig. 1) expressed on a leaf area basis of both *Acacia* species was significantly lower than those of *I. cylindrica* and *S. spontaneum*. In contrast, there was no significant difference between *A. mangium* and *A. auriculiformis*.

Tree species composition: The relative basal area (RBA) of both *Acacia* plantation areas was about 80 %. However, relative density (RD) of the *A. auriculiformis* plantation was 70 %, and this was higher than that of the *A. mangium* plantation. *Ficus septica,* as a naturally regenerated species, showed the highest values of RBA and RD in both *Acacia* plantation areas. Particularly, the RBA and RD values of *F. septica* were greater in the *A. mangium* plantation than in the *A. auriculiformis* plantation. The total number of occurring species was six in the *A. mangium* plantation and three in the *A. auriculiformis* plantation. In the *A. auriculiformis* and *A. mangium* plantations, mean DBH and height were 10 cm and 8 m, and 9 cm and 5.7 m, respectively. Six tree species appeared in the grassland, but all of these had a DBH below 5 cm excluding one, *F. septica* (Table 1). Fig. 2 shows the distribution of tree species in both *Acacia* plantations, and the size of the circle represents the crown diameter of the trees. *Calliandra calothyrsus* appeared in both *Acacia* plantations with more *C. calothyrsus* seedlings in the *A. auriculiformis* plantation than in the *A. mangium* plantation.

Seedlings of *Diplodiscus paniculatus* showed the highest value of emergence in terms of naturally regenerated species followed by *Ervatamia pandacaqui, Ficus congesta*, and *F. septica* in descending order (Fig. 3).

Table 1. Relative density (RD) and relative basal areas (RBA) of tree species in *Acacia auriculiformis* and *Acacia mangium* plantations. Tree species were measured and recorded when the DBH was above 5 cm only. Most occurring tree species (*Alstonia macrophylla, Cratoxylum sumatranum, Ficus septica, Macaranga tanarius, Neonauclea bartlingii, Wendlandia uvariifolia*) had a DBH below 5 cm.

Species	*A. auriculiformis* RD [%]	RBA [%]	*A. mangium* RD [%]	RBA [%]	Remarks
Acacia auriculiformis	69.6	82.7	-	-	Planted in 1993
Acacia mangium	-	-	37.6	75.2	Planted in 1993
Calliandra calothyrsus	0.5	0.1	17.5	6.3	Planted in 1995
Gmelina arborea	14.1	10.1	0.5	0.3	Planted in 1994
Pterocarpus indicus	4.9	1.9	2.6	1.0	Planted in 1994
Swietenia macrophylla	0.5	0.1	1.0	0.2	Planted in 1999
Syzygium nitidum	-	-	1.0	0.5	Planted in 1994
Fagraea fragrans	-	-	3.1	2.0	Natural
Ficus nota	-	-	0.5	0.1	Natural
Ficus septica	5.4	2.0	28.4	11.4	Natural
Ficus variegata	-	-	0.5	0.2	Natural
Gliricidia sepium	0.5	1.6	-	-	Natural
Leucaena leucocephala	4.3	1.5	5.2	2.1	Natural
Neonauclea bartlingii	-	-	2.1	0.8	Natural
Stand density	1 533 trees ha^{-1}		1 617 trees ha^{-1}		
Total basal area	19.1 m^2 ha^{-1}		14. 8 m^2 ha^{-1}		
Acacia spp. mean DBH [cm]	10.3		9.2		
mean height [m]	8.0		5.7		

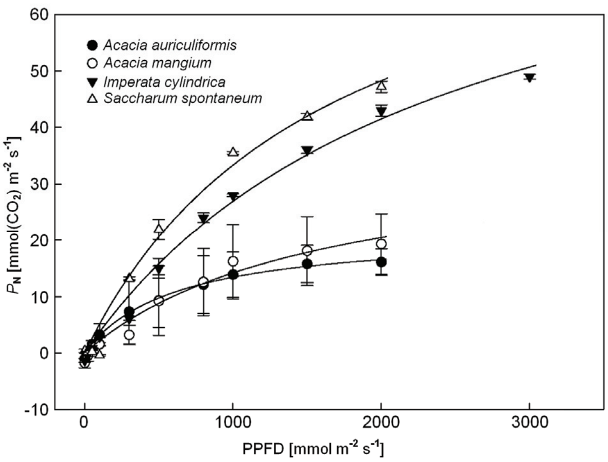

Fig. 1. Irradiance response curves in net photosynthetic rate (P_N) of four species, *Acacia mangium* (○), *Acacia auriculiformis* (●), *Imperata cylindrica* (▼), and *Saccharum spontaneum* (△). *Bars* indicate standard deviation.

Soil enzyme activity: Dehydrogenase activity was significantly higher in soil under the *Acacia* plantations in the dry season *versus* the wet season (data not shown). Dehydrogenase and phosphatase activities were also significantly higher under the *Acacia* plantations than in grassland (p<0.05) (Fig. 4).

Microclimate: Total annual rainfall in 2003 was 1 811.5 mm at 100 m a.s.l. and 1 769.2 mm at 300 m a.s.l. Total annual numbers of rainy days were 210 and 119 d at 100 and 300 m a.s.l., respectively (Fig. 5). Thus the amount and pattern of rainfall and number of rainy days may differ according to altitude and location. Of the total annual rainfall, about 3 % (100 m a.s.l.) and 4 % (300 m a.s.l.) fell from January to April.

The mean air temperature in April was the highest air temperature at all of the sites. The annual fluctuation of air temperature was increased from December to April and was decreased after April. Grassland had both the lowest minimum air temperature and highest maximum air temperature in the study sites and exhibited a strong trend of air temperature variation (Table 2).

The relative humidity of the grassland was higher than that of the *A. mangium* plantation; however, this parameter exhibited a trend similar to air temperature where variation in the grassland was larger than in the *Acacia* plantation (Table 3). This indicates that the large variation of air temperature produced morning and night dew on the humidity sensor of *HOBO*.

Soil temperature in the grassland showed a higher value than the *Acacia* plantation, and the highest soil temperature was in April. Soil temperature also showed a trend similar to air temperature (Table 4). Changes of air temperature per hour and relative humidity per hour were larger in the grassland than in the *Acacia* plantations. In the grassland, air temperature changed 0.8 °C per h, which was about two times the change of air temperature per h in the *Acacia* plantations (Fig. 6). However, the change of soil temperature was not significant among the sites.

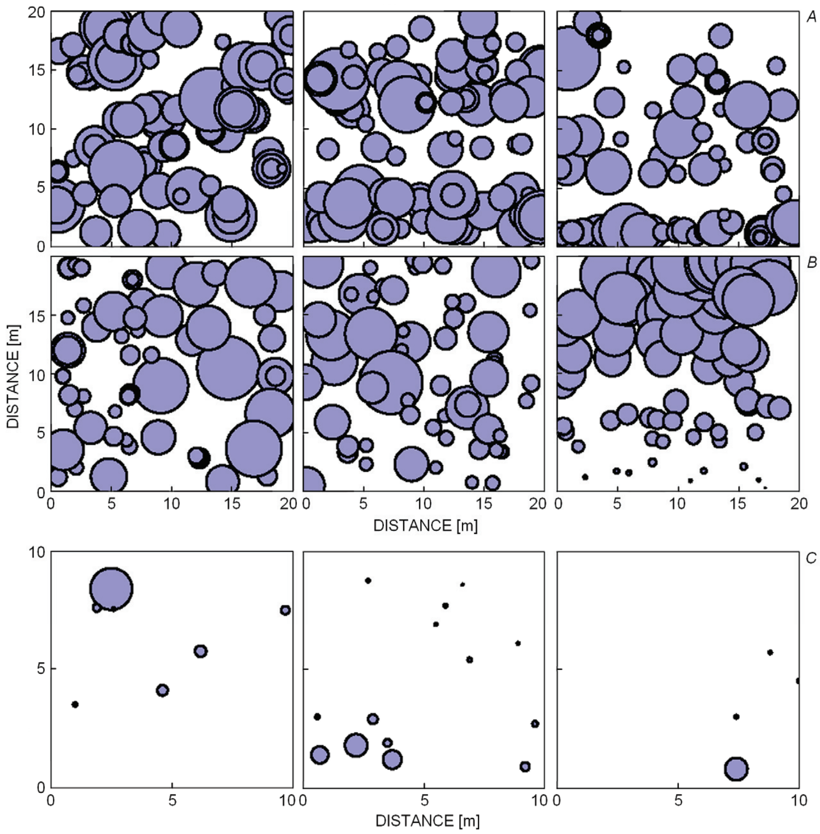

Fig. 2. Spatial distribution and canopy closure of tree species in the study sites: *Acacia auriculiformis* (*A*), *Acacia mangium* (*B*), and grassland (*C*). The distribution of tree species in both *Acacia* plantations and the size of the circle represent the crown diameter of the trees.

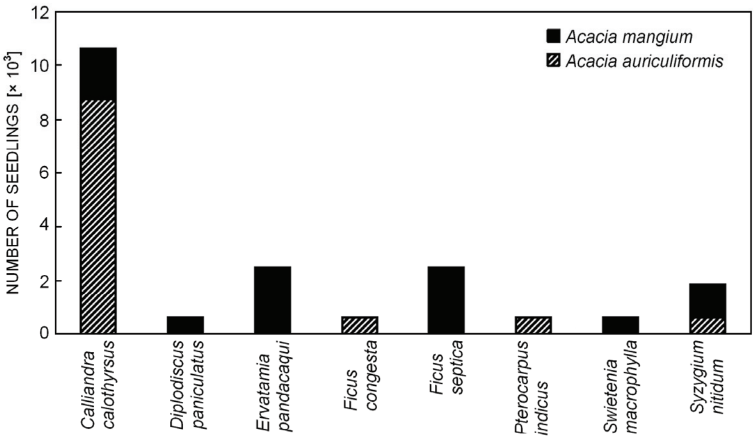

Fig. 3. Various seedling emergence in the both *Acacia mangium* and *Acacia auriculiformis* plantations.

Table 5 shows the results of ANOVA for air and soil temperature among the sites and by month. Differences in air and soil temperature were statistically significant between grassland and the *Acacia* plantations. Also, April and May, the dry and hot season in the Philippines, showed the highest values of air and soil temperature (Table 5). Soil temperature was strongly correlated with air temperature, and r^2 was 0.9088 (data not shown). This result indicates that we can estimate soil temperature using air temperature at this study site.

Discussion

We examined the characteristics of P_N in four dominant species at separate sites, change of tree species composition, and microclimate (air temperature, soil temperature, and relative humidity) ten years after planting *Acacia* species. Saturation PPFD of *A. auriculiformis* and *A. mangium* approached 15–18 mmol(CO_2) m^{-2} s^{-1} under 800–1 500 mmol m^{-2} s^{-1} PPFD (Fig. 1). In contrast, P_N of *I. cylindrica* and *S. spontaneum* increased until 3 000 mmol m^{-2} s^{-1} under PPFD. P_N of these two species was 3–4 times higher than those of *Acacia* species, which is the typical difference between C_3 and C_4 plant species (Kimmins 1996). *I. cylindrica* and *S. spontaneum* are typical C_4 plants in tropical grassland. If tropical forests are degraded because of human activity or natural disturbances, it is difficult to establish the next generation by natural regeneration (Kozlowski and Pallardy 1997).

The microclimate data suggest that planting pioneer tree species in degraded areas such as grassland, where there are no mature forests as a seed source, improves regeneration and air temperature, soil temperature, and relative humidity. In the study sites, the *A. auriculiformis* plantation had a fewer number of naturally regenerated species than the *A. mangium* plantation. This was due

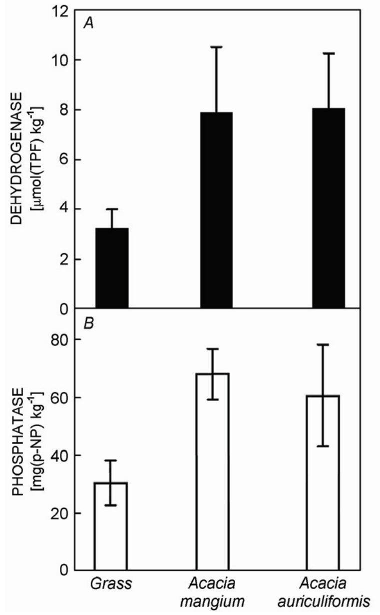

Fig. 4. Activities of soil enzymes dehydrogenase (*A*) and phosphatase (*B*) in the study sites.

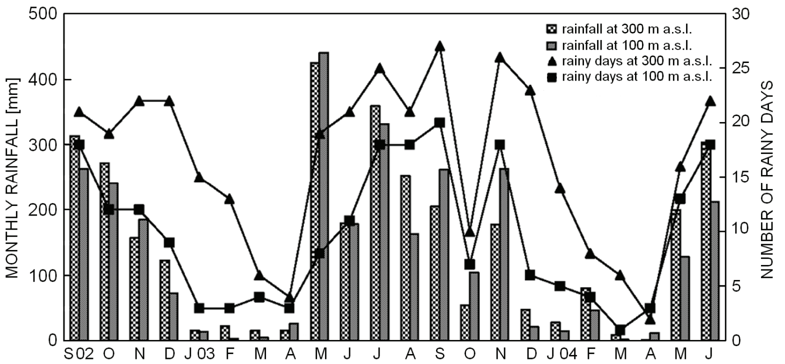

Fig. 5. Monthly rainfall September 2002–June 2004 at rainfall gage station located in Calamba near the study sites at 100 and 300 m a.s.l.

Table 2. Air temperature [°C] of the study sites by month.

	Acacia auriculiformis				*Acacia mangium*				Grassland			
	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
August, 03	23.8	1.873	20.2	31.9	23.9	2.038	19.8	32.8	24.8	2.972	20.2	38.3
September	23.4	1.680	20.6	30.3	23.4	1.757	20.6	29.5	24.4	2.933	20.6	36.6
October	23.8	1.807	20.2	31.5	23.7	1.683	20.2	29.5	25.1	3.559	20.2	37.0
November	23.6	1.774	20.2	30.3	23.5	1.603	20.2	30.7	24.9	3.612	20.2	37.0
December	21.1	1.703	17.9	26.0	20.9	1.554	17.5	25.2	22.0	2.992	17.5	31.5
January, 04	22.1	2.174	18.3	29.1	22.0	2.149	18.3	29.9	23.3	3.806	18.3	36.6
February	22.2	2.281	17.5	31.5	22.3	2.278	17.5	31.1	23.3	3.753	17.1	34.9
March	23.8	2.933	19.4	32.3	24.0	3.247	19.4	34.4	24.8	4.238	19.4	35.7
April	25.6	2.830	21.3	32.8	25.9	3.229	21.0	35.3	26.8	4.524	21.3	37.0
May	25.0	2.092	20.2	30.7	25.2	2.423	20.2	32.8	26.1	3.599	20.6	36.1
June	23.4	1.480	20.6	28.3	23.6	1.810	20.2	29.9	24.1	2.315	20.2	34.0

Table 3. Relative humidity [%] of the study sites by month. An asterisk (*) means loss of data due to a broken sensor.

	Acacia auriculiformis				*Acacia mangium*				Grassland			
	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
August, 03	93.6	5.749	70.3	100.5	96.4	6.950	65.5	103.9	92.9	10.801	49.4	103.8
September	*	*	*	*	97.7	5.218	74.1	103.1	95.0	10.375	52.0	103.8
October	*	*	*	*	85.9	7.542	58.3	100.9	84.8	15.242	39.7	102.6
November	*	*	*	*	75.3	12.977	33.3	99.6	88.5	16.608	30.8	103.8
December	*	*	*	*	65.7	10.787	29.9	83.1	90.3	13.720	31.8	103.5
January, 04	85.6	8.363	61.7	98.1	72.7	11.772	33.3	86.7	88.5	15.384	35.2	103.8
February	85.7	10.232	49.2	99.5	70.8	14.411	22.1	88.0	88.6	16.407	35.2	103.8
March	83.1	11.155	47.6	99.1	62.6	17.921	16.6	86.7	86.9	18.677	31.8	103.8
April	79.0	13.337	45.6	101.1	52.9	19.497	12.3	85.3	78.3	24.760	19.9	103.8
May	69.3	14.868	24.0	96.7	63.1	17.170	20.0	86.2	90.6	18.810	24.3	103.8
June	*	*	*	*	59.8	16.559	22.6	94.9	*	*	*	*

Table 4. Soil temperature [°C] of the study sites by month.

	Acacia auriculiformis				*Acacia mangium*				Grassland			
	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
August, 03	23.7	0.358	22.9	24.8	23.9	0.323	23.2	24.8	24.8	0.410	23.6	25.6
September	23.4	0.368	22.5	24.4	23.5	0.338	22.9	24.4	24.9	1.837	17.1	28.7
October	23.2	0.665	22.1	24.4	23.1	0.675	22.1	24.4	25.7	2.043	19.0	30.7
November	23.1	0.453	21.3	24.0	22.8	0.618	20.6	26.3	24.9	2.121	19.8	31.9
December	21.1	0.814	19.0	23.2	20.4	0.981	17.9	22.9	22.6	1.347	20.2	26.7
January, 04	22.1	0.864	20.6	24.4	21.7	1.240	19.8	26.0	25.1	1.350	22.5	28.7
February	22.3	1.009	19.8	25.2	22.4	1.723	19.4	29.5	24.9	1.400	21.7	29.5
March	23.2	1.098	21.0	26.3	23.2	1.794	19.8	29.5	26.0	1.786	22.5	31.1
April	24.6	0.698	23.2	26.3	25.5	1.698	22.9	31.1	28.0	1.696	25.2	32.3
May	24.4	0.734	22.9	26.7	24.9	1.659	22.1	30.3	26.6	1.292	24.0	31.1
June	23.6	0.628	22.5	25.2	23.9	1.331	21.7	29.1	25.4	0.939	23.6	27.9

Table 5. Mean air and soil temperatures [°C] by area and by month. Relative humidity could not be compared among treatments due to the loss of data from the *A. auriculiformis* plantation. Within columns, means with the same letter are not significantly different using Tukey's mean comparison test at the 0.05 level.

	Treatment	Mean air temperature±S.D.	Mean soil temperature±S.D.
Area	*A. auriculiformis* plantation	23.684 ± 2.565^{a}	23.155 ± 1.224^{a}
	A. mangium plantation	23.745 ± 2.711^{a}	23.211 ± 1.841^{a}
	Grassland	24.694 ± 3.716^{b}	25.373 ± 1.971^{b}
Month	April, 2004	26.086 ± 3.716^{a}	26.047 ± 2.036^{a}
	May, 2004	25.429 ± 2.820^{b}	25.292 ± 1.587^{b}
	October, 2003	24.228 ± 2.583^{c}	23.694 ± 1.517^{d}
	March, 2004	24.172 ± 3.543^{c}	24.187 ± 2.059^{c}
	August, 2003	24.165 ± 2.245^{c}	24.146 ± 0.608^{c}
	November, 2003	23.996 ± 2.580^{c}	23.331 ± 1.345^{e}
	June, 2004	23.715 ± 1.924^{e}	24.280 ± 1.295^{c}
	September, 2003	23.719 ± 2.245^{e}	23.882 ± 1.225^{d}
	February, 2004	22.625 ± 2.901^{f}	23.202 ± 1.868^{e}
	January, 2004	22.459 ± 2.874^{f}	22.937 ± 1.924^{f}
	December, 2003	21.310 ± 2.228^{g}	21.362 ± 1.420^{g}

mostly to a higher canopy coverage rate (Fig. 2) and a thicker litter layer, and slower decomposition rate. The *Acacia* plantation sites had less variation per h of both air temperature and relative humidity, while the grassland had the highest maximum and minimum values of both air and soil temperature. Thus introduction of tree species to grassland stabilizes the microclimate and accelerates natural regeneration and growth of seedlings.

After forest degradation, natural succession might eventually occur enabling the forest to recover by itself. However, as Lamb (1998) emphasized, the return to a mature forest or original forest could take a long time even if no further disturbances take place and sufficient residual forest remains nearby to act as a source of plants and animals. Lamb also mentioned that plantation species would limit soil erosion and aid nutrient cycling. In our previous study (Jang *et al.* 2004), we showed that total nitrogen content and available phosphorus were significantly higher in the plantation areas. These results indicate that *Acacia* planting affected the natural regeneration process and development of invasive seedlings. The *A. mangium* plantation had more naturally regenerated species than the *A. auriculiformis* plantation (Table 1). Lugo *et al.* (1993) reported that there is little difference in understory development beneath different plantation species, while others have found significant differences between species (Kuusipalo *et al.* 1995, Parrota 1995, Fimbel and Fimbel 1996, Keenan *et al.* 1997). Forest soil often contains inadequate soil N levels, limiting forest growth and productivity (Knoepp and Swank 1998). In the current study sites, the total N content in grassland was 0.15 % while the *Acacia* plantations measured above 2 %. A total N concentration below 0.2 % hampers plant growth (Jim 2001); therefore, this result could explain why tree species are difficult to invade and develop their seedlings in grassland.

The identification of enzyme activities in conjunction with soil respiration and composition of the soil microflora provides the most reliable index of microbial activity in soil (Casida 1977). We found that the *Acacia* plantations contained higher soil enzyme activity than the grassland (Fig. 4). Arunachalam *et al.* (1999) reported that dehydrogenase activity was higher in a 4-year-old alder plantation than in natural grassland and that dehydrogenase activity increased with increasing stand age in the forest re-growths. Fig. 2 shows that the *Acacia* plantations had larger plant cover than the grassland. This indicates that the *Acacia* plantations produce a greater amount of litter than that of grassland. In conjunction with another study (Maithani *et al.* 1998), our results suggest that increasing the plant cover, which produced a greater amount of litter, improved the soil nutrient pool.

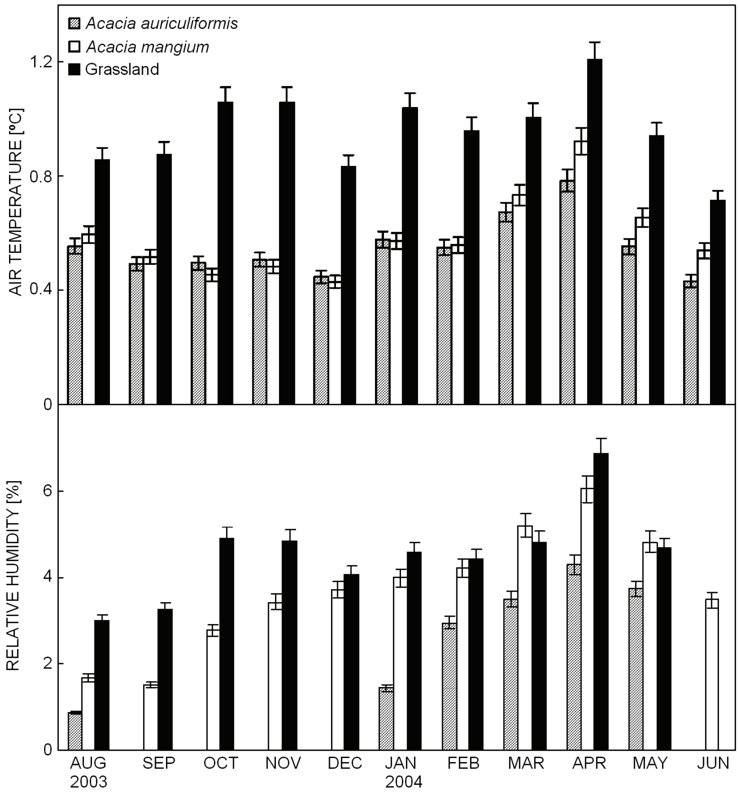

Fig. 6. Variations of air temperature (*A*) and relative humidity (*B*) per h by month in the sites.

Microclimate factors were significantly different between the *Acacia* plantations and the grassland. Grassland had the highest maximum and lowest minimum temperatures in both air and soil. Vegetation plays a critical role in shaping the microclimate through the change of energy and water balance across the landscape (Xu *et al.* 2002). Tree leaves protect against fluctuation of temperature through evaporation cooling or shading (Kimmins 1996). Air temperature affects growth and development of woody plants directly by inducing injury and indirectly by influencing physiological processes and yield and quality of fruits and seeds (Kozlowski and Pallardy 1997). This may explain why tree species composition and development of seedlings differ between the *Acacia* plantation areas and grassland. From the regression analysis, soil temperature was significantly correlated with air temperature (Fig. 6), and soil temperature was improved in the *Acacia* plantations compared to the grassland. Barber (1995) reported that the soil's physical and chemical properties as well as irradiance and soil temperature affect root growth which, in turn, affects nutrient uptake. We calculated the variation rate per h of microclimate factors (air temperature and relative humidity). Kimmins (1996) reported that the rate of temperature change is sometimes more important than the actual temperature. Grassland showed the highest values of both air temperature and relative humidity. Particularly, the variation rate was high during the dry season (Fig. 6). Additionally, the *Acacia* plantations played an important role as windbreaks for the regenerated tree species inside the study site. Benzarti (1999) reported that a tree windbreak allows increased water use efficiency of *Medicago sativa* inside the windbreak and decreases air temperature in the study site.

In conclusion, the *Acacia* plantations had a greater number of naturally regenerated species than grassland, and this showed that invasive tree species developed their growth and coverage. In the grassland, a total of 6 species (*Alstonia macrophylla, Cratoxylum sumatranum, F. septica, Macaranga tanarius, Neonauclea bartlingii,* and *Wendlandia uvariifolia*) were found. However, all species had DBH values below 5 cm except *F. septica* indicating more recent establishment and slower growth. *Acacia* planting improved soil enzyme activity and microclimate factors (air temperature, soil temperature, and relative humidity) and decreased the variation rate of these factors in the study sites. Therefore, our study suggests that this type of plantation is efficient in accelerating invasion of tree species and improving site qualities (microclimate, soil condition, *etc*.) However, in the longer term larger individuals may begin competing with the over-story plantation species for soil resources (Lamb 1998). These matters could be solved by technical management such as thinning.

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