Chapter 5

Upland rice and Pada (*Macaranga denticulata*) in fallow succession

5.1 Introduction

Rotational shifting cultivation has been shown to be a productive and sustainable in mountainous area where land is sufficiently plentiful to allow a fallow period of 10-20 year (Kunstadter, 1978). Population pressure combined with an increasing demand for conservation, however, has made certain that this luxury of very long fallows is now no longer an option for most shifting cultivation in Southeast Asia (Rerkasem and Rerkasem, 1995) and elsewhere. Considerable interest, therefore, has arisen in approaches that might maintain crop productivity with shorter fallow. Koutika *et al.* (2002) suggested that the fallow management plays a key role in supplying nutrients to the growing crop, suppressing weeds, reducing pests and diseases, and improving the sustainability of cropping systems in the humid forest. These included nutrient availability and storage (Woomer and Ingram, 1990).

In practice, three types of traditional enriched fallow can be identified by Kass *et al.* (1993): 1) multi species fallows similar to natural secondary vegetation but enriched with certain species; (2) less diverse fallow in which one species dominates the regenerating vegetation after burning and clearing; and (3) planted fallow in which one or more species with biological or economic value are introduced in order to shorten the fallow's regeneration period or increase its economic worth. For example, farmers in Sepone district of Laos managing solid stands of *Chromolaena* could improve soil fertility and soil structure substantially after 4 years re-growth the production of upland rice in the area may vary between 600-1500 kg of output per 50-60 kg of seed sown (Chansina, *et. al.,* 1991).

This chapter studied the use of a local enrichment tree species, called *Macaranga* for fallow improvement that has helped to maintain productivity of upland rice on a seven years rotation and set out to measure the effect of *Macaranga* on nutrient accumulation and upland rice yield in farmers' fields in the village where rotational shifting cultivation is still the dominant cropping system.

5.2 Materials and Methods

The study on vegetation composition of the fallow forests was carried out in February and March (the village's normal slashing and burning) of 2000. Trees were recognized as *Macaranga* or others from areas with densely and sparsely populated *Macaranga* (defined in collaboration with farmers and designated dense and sparse pada). Density of *Macaranga* and other species was determined in three replicates of 10m X 10m quadrants. Dominant other species were *Microcos peniculata, Lithocarpus sp., Phoebe lanceolata* and *Glochidion sphaerogynum*.

As field 2000 was about to be slashed and burned it was sampled for biomass and nutrient contents. Dry weight (sub-sample dried to constant weight at 80°C) of the above ground live biomass, divided into *Macaranga* and others and litter were determined. The samples, whole plants in case of pada and others were analyzed for N, P, K, Ca and Mg. Before burning soil samples were taken from the same area at 0-30 and 30-60 cm for determination of pH (water, 1:1), organic matter content (Walkley-Black), available P (Bray II, Wanatabe and Olsen, 1962), K, Ca and Mg (1 N NH_4Oac pH7). In addition, dry weight of the above and below ground of live biomass samples year 2001-2005 were also taken from densely and sparsely populated *Macaranga* areas.

A detailed study of the upland rice was carried out on the crop belonging to one farmer (Noppon's plot) in cropping year 2000. At 30 days from sowing, samples (whole tops) of ten rice plants each were taken from the dense and sparse *Macaranga* area for determination of N, P, K, Ca and Mg. At the same time soil samples were taken for determination of fertility characteristics at 0-30 and 30-60 cm depth. At maturity, sample of rice crop were taken in 2m X 5m quadrants from densely and sparsely populated *Macaranga* areas. In addition, 1m X 1m samples of rice at maturity were also taken from densely and sparsely populated *Macaranga* areas from five other farmers in the same village for confirmation. The rice samples were threshed in the field and separated into grain and straw. Grain yield was determined after 3 days of sun drying (to water content of about 12%), straw yield was measured after oven drying for 48 hours at 80^0C. Sub-samples of 10 plants were also taken to determine yield components, i.e. number of hills m^{-1}, tillers $hill^{-1}$, panicles $hill^{-1}$ and 1,000 seed weight, and the materials were used for laboratory analyzed to determine for N, P, K, Ca and Mg in the grain and straw.

Additional rice yields data were also obtained from sample plots (2m X 5m) with 3 replications during 2000-2004.

5.3 Results

5.3.1 Fallow biomass and nutrient content

After seven year of regrowth (the rice cropping year is considered year 1 of regrowth, as fallow regeneration begins with upland rice emergence), there was an average of 64.4 t ha^{-1} of total biomass in dense *Macaranga* patches compared with 36.7 t ha^{-1} in sparse *Macaranga* patches (Table 5.1). In both the dense and sparse patches, 3/4 of the biomass in both dense and sparse *Macaranga* was above ground and 1/4 below ground. In the cropping year 2000 where above ground biomass were partitioned into 3 components, it was found that *Macaranga* contributed more than half of the biomass in the dense patches, and only 39% in sparse patches (Table 5.2). There was also 36% more litter in dense than in sparse *Macaranga* patches. The above ground biomass in dense *Macaranga* patches contained 536 kg N, 38 kg P, 253 kg K, 132 kg Ca and 46 kg Mg ha^{-1}. This was 10% more N, 34% more P, 92% more K, 80% more Ca and 107 % more Mg than that in the sparse *Macaranga* patches (Table 5.3).

Table 5.1 Above and below ground biomass (t ha^{-1}) in the fallow vegetation after seven year of regeneration of cropping year 2000 - 2005.

Cropping year	*Macaranga* densities	Biomass (t ha^{-1})		
		Above ground	Below ground	Total
2000	Dense	42.8	nd	nd
	Sparse	35.7	nd	nd
2001	Dense	53.2	15.1	68.3
	Sparse	33.6	8.7	42.3
2002	Dense	nd[†]	nd	Nd
	Sparse	nd	nd	Nd
2003	Dense	57.2	16.2	73.4
	Sparse	22.0	8.5	30.5
2004	Dense	41.0	nd	nd
	Sparse	20.1	nd	nd
2005	Dense	49.4	nd	nd
	Sparse	28.9	nd	nd
Average	Dense	48.7	15.7	64.4
	Sparse	28.1	8.6	36.7

Note: nd = no data record in that year.

Table 5.2 Above ground biomass (t ha^{-1}) in the fallow vegetation after seven year of regeneration of a rotational shifting cultivation in year 2000.

	Above ground biomass (t ha^{-1})		Significant difference by T-test
	Sparse area	Dense area	
Macaranga	9.4	22.2	$P < 0.01$
Other species	21.6	14.2	$P < 0.01$
Litter	4.7	6.4	$P < 0.01$
Total	35.7	42.8	$P < 0.05$

Table 5.3 Above ground nutrient contents in the fallow vegetation after seven year of regeneration of a rotation shifting cultivation in year 2000.

Vegetation type	Nutrient element	Nutrient content (kg ha^{-1})		Significant difference
		Dense	Sparse	by T-test
Macaranga	N	289	131	P < 0.01
	P	21	6	P < 0.01
	K	97	32	P < 0.01
	Ca	72	21	P < 0.01
	Mg	10	6	P < 0.05
Other	N	191	297	P < 0.01
	P	12	18	P < 0.05
	K	118	85	P < 0.01
	Ca	28	36	NS
	Mg	23	6	P < 0.01
Litter	N	56	59	NS
	P	5	4	NS
	K	38	14	P < 0.01
	Ca	32	16	P < 0.05
	Mg	13	10	NS
Total	N	536	488	P < 0.01
	P	39	29	P < 0.05
	K	253	132	P < 0.01
	Ca	132	73	P < 0.01
	Mg	46	22	P < 0.01

5.3.2 Soil fertility characteristics before slashing and burning and under rice

Soil samples collected from every fallow regrowth in year 2002, are generally poor with pH varied from 4.75 to 5.99 and OM between 3.07% to 9.24% (Table 5.4). Mineral nitrogen content varied between 0.29-0.43 % with even more variation in other nutrients; phosphorus 3.07-15.15 ppm (Bray II, Watanabe and Olsen, 1962), potassium 90.33-214.33 ppm, calcium 0.19-4.19 me 100g $soil^{-1}$ and magnesium 0.27-0.99 me 100g $soil^{-1}$ (Table 5.5).

The soil fertility characteristics before and after slashing and burning at the study site, from soil samples collected from in year 2000, was on a very acid soil, with pH 4.3 (1:1 water) before burning (Table 5.6). At 30 days from rice sowing, pH at surface increased slightly to 4.8. Soil organic matter content declined slightly from around 4% before burning to 3.6% by the time rice was 30 days old. The first rainfall of the season that germinated the rice may have contributed to this decline by stimulating microbial activity. Available soil P was generally very low 2-4 ppm. There was no significant difference in soil pH, organic matter and extractable K content between dense and sparse *Macaranga* patches (Table 5.6). On the other hand, dense *Macaranga* was associated with 47% more extractable Ca and twice to three times as much extractable Mg than in the sparse *Macaranga* patches.

Table 5.4 pH and OM (%) of the soil samples collected from every fallow regrowth in year 2002.

Cropping Year	Dense area				Sparse area			
	0-15 cm		15-30 cm		0-15 cm		15-30 cm	
	pH	OM[a]	pH	OM	pH	OM	pH	OM
1998	5.51	5.21	5.20	3.07	5.43	4.67	5.30	3.69
1999	4.87	9.24	4.85	7.51	4.75	9.04	4.91	6.86
2000	5.16	5.70	4.90	5.37	5.06	5.43	4.98	4.48
2001	5.41	6.02	5.26	4.54	5.30	5.75	5.02	4.73
2002	5.29	6.26	5.32	4.74	4.97	5.37	4.91	4.26
2003	5.99	7.55	5.72	4.45	5.29	6.70	5.05	3.83
2004	5.06	4.99	5.14	3.15	4.93	4.54	4.84	3.94
Average	5.33	6.42	5.20	4.69	5.10	5.93	5.00	4.54
SE[b]	0.14	0.57	0.11	0.57	0.09	0.59	0.06	0.41

Note: a = Organic mater (%), b = Standard error

Table 5.5 Nutrient concentration of rotational shifting cultivation of the soil samples collected from every fallow regrowth in year 2002.

a) at 0-15 cm from ground level

Cropping	Dense area					Sparse area				
Year	N[a]	P[b]	K[b]	Ca[c]	Mg[c]	N	P	K	Ca	Mg
1998	0.32	8.01	146.67	2.35	0.82	0.28	8.46	145.00	2.77	0.86
1999	0.43	5.20	140.00	0.43	0.49	0.42	4.72	110.00	0.19	0.27
2000	0.32	5.13	190.77	1.07	0.65	0.28	3.07	214.33	0.77	0.46
2001	0.29	9.25	149.93	1.91	0.80	0.29	7.51	186.33	1.86	0.77
2002	0.33	15.15	150.33	1.74	0.67	0.27	10.25	129.50	0.63	0.46
2003	0.41	9.83	186.00	4.19	0.99	0.36	7.48	200.33	1.60	0.67
2004	0.28	5.99	150.33	2.47	0.43	0.35	8.01	90.33	1.08	0.31
Average	0.34	8.37	159.15	2.02	0.69	0.32	7.07	153.69	1.27	0.54
SE[d]	0.02	1.34	7.69	0.45	0.07	0.02	0.91	17.96	0.33	0.09

b) at 15-30 cm from ground level

Cropping	Dense area					Sparse area				
Year	N	P	K	Ca	Mg	N	P	K	Ca	Mg
1998	0.24	5.79	85.33	0.39	0.3	0.25	4.48	143	1.19	0.57
1999	0.33	2.86	127	0.19	0.2	0.32	2.49	92	0.16	0.18
2000	0.27	2.77	137.33	0.33	0.33	0.26	2.16	137.33	0.27	0.22
2001	0.23	5.73	133.83	0.71	0.63	0.24	3.93	144.67	0.83	0.67
2002	0.27	16.23	148.43	2.12	0.64	0.22	5.58	124.83	0.25	0.34
2003	0.28	3.8	191.33	3.55	0.99	0.26	8.41	123.33	1.28	0.24
2004	0.2	1.73	112.33	1.36	0.32	0.24	2.25	62.33	0.19	0.15
Average	0.26	5.56	133.65	1.24	0.49	0.26	4.19	118.21	0.60	0.34
SE	0.02	1.87	12.34	0.46	0.11	0.01	0.85	11.51	0.19	0.08

Note: a = %, b = ppm, c = me 100 g soil^{-1}, d SE = Standard error

Table 5.6 Fertility characteristics of the soil before burning and after 30 days from rice sowing.

	Time	pH	Organic Matter (%)	P	K	Ca	Mg
				(mg kg^{-1})		(meq 100 g^{-1})	
Depth, 0-30 cm							
Sparse	Before[a]	4.30	3.96	2.23	133	0.53	0.27
	After[b]	4.79	3.60	3.34	181	0.64	0.48
Dense	Before	4.26	4.19	2.62	148	0.78	0.65
	After	4.83	3.84	3.70	198	0.75	0.67
Depth, 30-60 cm							
Sparse	Before	4.29	3.87	1.53	107	0.38	0.13
	After	4.41	3.43	3.00	156	0.47	0.49
Dense	Before	4.24	3.97	2.02	110	0.56	0.37
	After	4.58	3.73	4.29	178	0.59	0.50
Significant effects by analysis of variance							
Effect	Macaranga	NS	NS	*	NS	*	*
	Time	*	*	*	*	NS	NS
	Depth	NS	NS	NS	*	*	*
	PxT	NS	NS	NS	NS	NS	NS
	TxD	NS	NS	NS	NS	NS	NS
	PxT	NS	NS	NS	NS	NS	NS
	PxTxD	NS	NS	NS	NS	NS	NS

Note: a = Before burning, b = After burning at 30 days from rice sowing

5.3.3 Upland rice nutrition and yield

Rice plant at one month in dense *Macaranga* contained N and K at significant higher concentrations than those in sparse *Macaranga* patches (Table 5.7). No significant difference was found in the concentration of P, Ca and Mg. Based on published data (Reuter *et al.* 1997), the rice crop at 30 days was deficient in N and K in sparse *Macaranga* area, and deficient in P in both sparse and dense *Macaranga* areas.

Table 5.7 Nutrient concentration in the upland rice (whole tops) of the study area year 2000 at 30 days from sowing, in areas fallowing *Macaranga* at low and high densities in a rotation shifting cultivation system in northern Thailand.

Concentration (%)	Dense area	Sparse area
N	4.06 b	2.76 a
P	0.32	0.29
K	4.99 b	3.60 a
Ca	0.26	0.19
Mg	0.24	0.22

Note: For same nutrient element, different letters designate significant difference by LSD ($p < 0.05$).

In 7-year rotation, the positive effect of *Macaranga* density on the rice grain and straw yield were consistent from crop cutting data in 5 consecutive years from 2000-2004 (Table 5.8). The average grain yield from the densely populated *Macaranga* area was twice as much as than sparsely populated *Macaranga* area. There was considerable year to year variation in grain yield, especially in sparse *Macaranga* area, with coefficient of variation (CV) of 16% compared with a CV of only 3% for rice grain yield in dense *Macaranga* area.

Table 5.8 The yield of upland rice in seven years rotation of year 2000-2004, in area fallowing *Macaranga* at low and high densities during the fallow period, in a rotation shifting cultivation system in northern Thailand.

		Rice yield (t ha^{-1})						
		Year 2000	Year 2001	Year 2002	Year 2003	Year 2004	Average	SE
Grain	Dense	2.57	2.76	2.82	2.36	2.59	2.62	0.08
	Sparse	0.83	1.69	1.87	0.85	1.38	1.32	0.21
Straw	Dense	2.35	2.36	3.03	4.69	4.69	3.42	0.53
	Sparse	0.97	1.99	2.32	1.45	1.45	1.64	0.24
Total	Dense	4.92	5.12	5.85	7.05	7.28	6.04	0.48
	Sparse	1.79	3.68	4.19	2.29	2.83	2.96	0.44
Harvest	Dense	52.30	53.87	48.22	33.52	35.65	44.71	4.25
Index	Sparse	46.10	46.01	44.62	36.91	48.89	44.51	2.02

Note: SE = Standard error

The point in Table 5.9 is that dense *Macaranga* with 4 years of regrowth could not sustain rice yield above 2 t ha^{-1}. Similar effects of *Macaranga* density on the rice grain and straw yield were observed in 7-year rotation field belonging to five other farmers (Table 5.10).

The higher yield in dense *Macaranga* patches was associated largely with a higher number of panicles and percentage of fertile tillers, and to a less extent higher plant density and number of tillers hill^{-1} (Table 5.11).

Table 5.9 The yield of upland rice in seven and four years rotation of the study area year 2000, in area fallowing *Macaranga* at low and high densities during the fallow period, in a rotation shifting cultivation system in northern Thailand.

	Yield (t ha^{-1})			Rotation effect
Macaranga density	Dense	Sparse	Dense	
Rotation	7 years	7 years	4 years	
Grain	2.57 a	0.83 b	0.74 b	P <0.01
Straw	2.35 a	0.97 b	0.72c	P <0.01
Total	4.92 a	1.79 b	1.47 c	P <0.01
Harvest index	52.3	46.1	50.7	NS

Note: Numbers in same row followed by different letters are significantly different by LSD ($p < 0.05$).

Table 5.10 Range and variation of rice yield in seven years rotation of the study area year 2000, in areas following *Macaranga* at low and high densities during the fallow period, in a system of rotational shifting cultivation in northern Thailand.

	Yield (t ha^{-1})			
	Grain		Straw	
	Dense area	Sparse area	Dense area	Sparse area
Maximum	4.53	1.56	3.80	1.75
Minimum	2.48	0.71	2.21	0.86
Mean (of 8 fields, 6farmers)	3.04	1.15	2.74	1.19
Standard deviation	0.71	0.33	0.59	0.30

Table 5.11 Yield components of upland rice of the study area year 2000 in a rotational shifting cultivation in northern Thailand with dense and sparse *Macaranga* densities during the fallow period.

Yield component	*Macaranga* density		Significant different[a]
	Dense	Sparse	
Hills m^{-2}	6.2	5.5	**
Tillers hill^{-1}	13.9	10.3	*
Panicles hill^{-1}	12.3	7.1	**
Panicles m^{-2}	76.7	39.0	**
Fertile panicles (%)	90.1	66.6	**
1000 seed weight (g)	29.1	29.1	NS

a) NS = not significant ($p < 0.05$), * = significant ($p < 0.05$), ** = significant ($p < 0.01$)

At maturity, the rice crop accumulated twice as much N, P, Ca and Mg and four times K in the densely populated *Macaranga* as in the sparsely populated *Macaranga* patches (Table 5.12). However, the amount of N, P and K taken up by the rice crop accounted for a much smaller fraction of the nutrients accumulated above ground in 7-year old-fallow in the sparse (4%. 15% and 16%, for N, P and K, respectively) than in the densely populated *Macaranga* patches (9%, 25% and 20%, respectively). The rice Ca and Mg uptake relative to the nutrient in fallow biomass were somewhat closer between sparse (13% for Ca; 5% for Mg) and dense (8% and 15%, respectively) *Macaranga* patches. Although much of the above ground N in the fallow would have been lost with burning, most of the P, K, Ca and Mg could be assumed to remain in the ash. Much more nutrients would have been present in the root zone of rice than was taken up the rice crop. The much smaller fraction of fallow accumulated P and K taken up by rice in sparsely populated *Macaranga* area compared with densely populated *Macaranga* patches suggested that the uptake of these nutrients was limited by some factor(s). Such a factor may limit uptake through demand by depressing growth and yield of the rice or through availability of the nutrients released by burning.

Table 5.12 Nutrient concentration and contents of the study area year 2000 at maturity of the rice after fallow with dense and sparse *Macaranga* in a rotational shifting cultivation in northern Thailand.

	Grain		Straw	
	Dense	Sparse	Dense	Sparse
(a) Nutrient concentration (%)				
N	1.13 a	1.42 b	0.48	0.63
P	0.23 a	0.31 b	0.04 a	0.10 b
K	0.42	0.45	2.47 b	1.91 a
Ca	0.11	0.10	0.33	0.36
Mg	0.11 a	0.13 b	0.13	0.13
(b) Nutrient content (kg ha^{-1})				
N	34.1 b	13.9 a	13.6 b	7.3 a
P	7.6 b	3.3 a	2.1 b	1.0 a
K	13.1 b	5.4 a	62.9 b	16.1 a
Ca	3.1 b	1.1 a	8.1 b	3.5 a
Mg	3.4 b	1.4 a	3.3 b	1.5 a

Note: Different letters designate significant difference by LSD ($p < 0.05$) between dense and sparse *Macaranga* patches for grain or straw yield.

5.4 Discussion

5.4.1 Fallow biomass and nutrient content

After seven year of regrowth above ground biomass in densely populated *Macaranga* patches averaged 48.7 t ha^{-1} and below ground biomass averaged 15.7 t ha^{-1} higher than sparsely populated *Macaranga* patches 68 % and 69 % respectively (Table 5.1). In study year 2000, above ground biomass in densely populated *Macaranga* patches was 42.8 t ha^{-1} and contained 536 kg N, 38 kg P, 253 kg K, 132 kg Ca and 46 kg ha^{-1}. These are much higher in comparison with the mature fallow of 8 years rotation in the village of Pa Pae (18°15'N 98°3'E) in the same vicinity where no *Macaranga* was found (Sabhasri, 1978), and 143 kg N, 16 kg P and 176 kg K ha^{-1} were reported to have accumulated in the 63 t ha^{-1} of above ground biomass (Zinke *et al.*, 1978). The slight difference in total biomass N between sparsely and densely populated patches in this study is accounted for by other species, which in sparsely populated *Macaranga* contributed as much N as *Macaranga* in the densely populated *Macaranga* patches. *Macaranga* was clearly crucial to the accumulation of extra P, K, Ca and Mg, though not so much for N. The higher amount of nutrient accumulated in densely populated *Macaranga* came largely from *Macaranga* in the case of P, *Macaranga* and litter in the case of Ca, and from other species as well as *Macaranga* and litter in the case of K and Mg. *Macaranga* root were found to be associated with a diversity (genera and species) and abundance of arbuscular mycorrhizal fungi, both in the number of spore found in the rhizosphere and in root colonization (Youpensook *et al.*, 2004).

5.4.2 Soil fertility characteristics before slashing and burning and under rice.

This study site, especially some fields such as 2000, was on a very acid soil, before burning (Table 5.6). As others have previously shown (e.g. Nye and Greenland, 1964 and Sanchez, 1976), burning clearly had a strong liming effect. Thirty day after rice sowing, pH of the surface soil measured 4.8. Available soil P was generally very low 2-4 ppm. There were significant but very small effects of *Macaranga* density and burning on available P. The highest P value (Bray II) was 4.3 ppm in dense *Macaranga* patches after burning, which is very low indeed compared with about 12 ppm considered to be sufficient (Sanchez, 1976).

5.4.3 The effect of *Macaranga* dominant fallow on upland rice yield.

The rice yield *Macaranga* at 2.5 to 3.5 t ha^{-1} found in this study with dense is comparable or better than Thailand's national average lowland rice yield of 2.6 t/ha (FAO, 2006). The yields are also far better than the upland rice yield common in this mountainous region, e.g. 1.0-1.5 t ha^{-1} in Northern Thailand (Van Keer and Trebuil, 2006) or 1.7 t ha^{-1} in Lao PDR (NSC, 2004); and in the same range as the new improved upland rice varieties from the International Rice Research Institute, that were farmer-managed but fertilized with phosphorus (Saito et al, 2006).

Rice grown in densely populated *Macaranga* patches that were slashed and burned after three years of fallow have yielded only 0.74 t ha^{-1} of grain (Table 5.9). Clearly, the higher rice yield was not due to some pre-existing condition in the densely populated *Macaranga* patches. As discussed above, the growth of rice at 30 days in sparsely populated *Macaranga* patches may have been limited by N and K deficiency, and more severely by P deficiency. By maturity, the concentration of N and Mg in the rice grain and P in the both grain and straw were higher in sparsely populated than in the densely populated *Macaranga* area (Table 5.12). The concentration of straw N and Mg and grain K were not different between rice in sparsely and densely populated *Macaranga* area. Straw K was the only case of nutrient concentration in rice in densely populated *Macaranga* exceeding that in the sparsely populated *Macaranga* area. Critical K deficiency concentration has been reported at 0.4% in the grain and 1% in the straw (Reuter et al., 1997). Compared with these, K deficiency is not indicated by the grain K concentration at 0.45% and straw K at 1.91% in the rice in the sparsely populated *Macaranga* patches.

It is clear that the fallow system enriched by *Macaranga* can support productive upland rice crop with stable yield on acidic infertile soils of the uplands, even with shortened fallow. The extra nutrients accumulated in the biomass, both above and below ground, in dense *Macaranga* patches is the most likely explanation for the rice yield increase. In the next chapter I will explore how this enhanced nutrient accumulation by *Macaranga* has been achieved.