Table 1. Physicochemical soil properties.

		Secondary forests	Rubber farms	Pepper farms	Oil palm farms[a)]	Oil palm estate
No. sites		30	25	24	9	19
		Surface soil, 0-10 cm depth				
pH(H_2O)		4.10 ± 0.14a	4.23 ± 0.14b	4.39 ± 0.36bc	4.42 ± 0.36	4.59 ± 0.27c
pH(KCl)		3.32 ± 0.17a	3.48 ± 0.10b	3.59 ± 0.25bc	3.58 ± 0.18	3.73 ± 0.14c
EC	mS m^{-1}	5.3 ± 1.4b	3.9 ± 1.7a	5.6 ± 2.1b	5.5 ± 2.8	3.8 ± 1.3a
Clay	%	31.4 ± 10.8a	31.2 ± 10.8a	39.3 ± 14.2a	25.9 ± 7.9	32.9 ± 6.5a
Silt	%	19.2 ± 8.1a	25.5 ± 10.2ab	29.0 ± 7.4b	22.4 ± 6.5	28.3 ± 9.8b
Sand	%	49.5 ± 15.9b	43.3 ± 19.4ab	31.7 ± 13.4a	51.7 ± 12.3	38.8 ± 13.6ab
T-C	g kg^{-1}	33.1 ± 14.8a	30.7 ± 9.3a	25.0 ± 10.6a	29.5 ± 11.0	31.6 ± 12.6a
T-N	g kg^{-1}	1.81 ± 0.82a	1.98 ± 0.74a	1.87 ± 0.90a	1.57 ± 0.39	1.84 ± 0.61a
C/N		18.9 ± 3.7c	16.2 ± 3.1ab	13.8 ± 3.4a	18.3 ± 4.1	17.0 ± 3.5bc
CEC	$cmol_c$ kg^{-1}	15.8 ± 5.6a	13.3 ± 3.2a	14.0 ± 3.5a	10.8 ± 3.0	13.1 ± 3.1a
Exch. Ca^{2+}	$cmol_c$ kg^{-1}	0.08 ± 0.14a	0.07 ± 0.07a	0.89 ± 1.07b	0.52 ± 0.66	1.04 ± 1.14b
Exch. Mg^{2+}	$cmol_c$ kg^{-1}	0.13 ± 0.18a	0.13 ± 0.11ab	0.23 ± 0.23b	0.12 ± 0.05	0.19 ± 0.12ab
Exch. K^+	$cmol_c$ kg^{-1}	0.15 ± 0.06ab	0.15 ± 0.11a	0.24 ± 0.15b	0.18 ± 0.11	0.16 ± 0.05ab
Exch. Al^{3+}	$cmol_c$ kg^{-1}	6.66 ± 2.32b	6.17 ± 1.14b	3.93 ± 2.07a	4.59 ± 1.68	5.22 ± 2.52ab
Exch. NH_4^+	$cmol_c$ kg^{-1}	0.11 ± 0.11b	0.08 ± 0.03b	0.05 ± 0.01a	0.04 ± 0.02	0.09 ± 0.03b
ECEC[b)]	$cmol_c$ kg^{-1}	7.05 ± 2.27b	6.55 ± 1.21ab	5.30 ± 1.52a	5.44 ± 1.25	6.65 ± 1.99ab
Al saturation[c)]	%	93.0 ± 8.7b	94.2 ± 3.3b	68.9 ± 30.5a	81.7 ± 19.2	75.5 ± 20.7a
Available P	mg P kg^{-1}	11 ± 7a	12 ± 13a	83 ± 110b	67 ± 123	11 ± 6a
Bulk density	g mL^{-1}	0.88 ± 0.18a	0.87 ± 0.15a	1.01 ± 0.13b	0.92 ± 0.16	0.90 ± 0.14a
Soil hardness[d)]	mm	10 ± 4a	10 ± 3a	14 ± 3b	15 ± 5	15 ± 3b
		Subsurface soil, 30-40 cm depth				
pH(H_2O)		4.32 ± 0.14a	4.48 ± 0.13b	4.46 ± 0.22ab	4.68 ± 0.11	4.76 ± 0.19c
pH(KCl)		3.56 ± 0.17a	3.69 ± 0.18ab	3.65 ± 0.18ab	3.82 ± 0.25	3.77 ± 0.12b
EC	mS m^{-1}	2.0 ± 0.5b	1.3 ± 0.4a	2.0 ± 0.7b	1.4 ± 0.5	1.2 ± 0.4a
Clay	%	32.7 ± 10.3a	32.4 ± 11.2a	42.8 ± 15.0b	32.6 ± 15.7	40.0 ± 9.1b
Silt	%	21.3 ± 9.6a	24.0 ± 8.5a	27.3 ± 7.8a	20.4 ± 5.6	26.8 ± 9.2a
Sand	%	46.0 ± 16.0b	43.6 ± 18.3b	29.9 ± 13.9a	47.0 ± 17.3	33.2 ± 12.5a
T-C	g kg^{-1}	7.9 ± 3.7a	8.0 ± 2.0a	7.0 ± 4.1a	7.2 ± 2.3	7.5 ± 3.4a
T-N	g kg^{-1}	0.59 ± 0.28a	0.63 ± 0.18a	0.80 ± 0.57a	0.59 ± 0.13	0.71 ± 0.29a
C/N		14.9 ± 8.1c	13.3 ± 3.7bc	9.2 ± 2.6a	12.2 ± 3.6	10.6 ± 2.1ab
CEC	$cmol_c$ kg^{-1}	9.2 ± 3.3a	7.6 ± 2.7a	9.2 ± 3.6a	5.0 ± 1.6	9.0 ± 2.8a
Exch. Ca^{2+}	$cmol_c$ kg^{-1}	0.03 ± 0.01b	0.01 ± 0.01a	0.17 ± 0.23c	0.06 ± 0.11	0.21 ± 0.31c
Exch. Mg^{2+}	$cmol_c$ kg^{-1}	0.02 ± 0.04a	0.04 ± 0.03ab	0.08 ± 0.10b	0.02 ± 0.01	0.05 ± 0.05b
Exch. K^+	$cmol_c$ kg^{-1}	0.05 ± 0.03a	0.05 ± 0.04a	0.09 ± 0.06b	0.05 ± 0.02	0.05 ± 0.02a
Exch. Al^{3+}	$cmol_c$ kg^{-1}	4.58 ± 1.59a	4.35 ± 1.54a	3.55 ± 1.29a	2.68 ± 1.15	4.82 ± 2.05a
Exch. NH_4^+	$cmol_c$ kg^{-1}	0.05 ± 0.02b	0.04 ± 0.01b	0.04 ± 0.01b	0.02 ± 0.00	0.03 ± 0.01a
ECEC[b)]	$cmol_c$ kg^{-1}	4.70 ± 1.61a	4.47 ± 1.57a	3.91 ± 1.21a	2.82 ± 1.14	5.13 ± 2.00a
Al saturation[c)]	%	97.2 ± 1.1b	97.4 ± 1.3b	88.7 ± 12.5a	94.5 ± 5.9	93.0 ± 7.4ab
Available P	mg P kg^{-1}	3 ± 1a	2 ± 1a	7 ± 8b	4 ± 2	3 ± 1a
Bulk density	g mL^{-1}	1.30 ± 0.15a	1.24 ± 0.11a	1.28 ± 0.17a	1.29 ± 0.15	1.24 ± 0.11a
Soil hardness[d)]	mm	20 ± 3b	16 ± 4a	18 ± 1a	19 ± 4	18 ± 3ab

Means ± standard deviations. Values in the same row followed by different letters are significantly different at $P < 0.05$ (Scheffe's multiple comparison test). [a)]The results from oil palm farms of the Iban were not included in the test. [b)]ECEC, sum of exchangeable bases and Al. [c)] Exchangeable Al in percent of ECEC. [d)]Determined using a Yamanaka type penetrometer.

Table 2. Comparison of soil properties at 0-10 cm depth in pepper farms and the oil palm estate with respect to the duration of farming, and for oil palm farms with respect to fertilizer application.

	pH(H_2O)	T-C	T-N	C/N	Exch. Ca	Exch. Mg	Exch. K	Al sat.	NH_4-N	Avail. P	Bulk density	Soil hardness
		($g\ kg^{-1}$)			($cmol_c\ kg^{-1}$)			(%)	($cmol_c\ kg^{-1}$)	($mg\ P\ kg^{-1}$)	($g\ mL^{-1}$)	(mm)
Center point in pepper farms of local farmers												
1-4 years (n=8)	4.14a	22.5	1.54	14.8	0.35	0.12	0.19	88.8a	0.05	26a	1.02	14
7-10 years (n=9)	4.40ab	23.2	1.72	14.1	0.98	0.30	0.21	68.0ab	0.05	71ab	1.04	15
12-22 years (n=7)	4.66b	30.2	2.45	12.3	1.38	0.25	0.33	47.2b	0.05	165b	0.98	14
Fertilizer circle in pepper farms of local farmers												
1-4 years (n=8)	4.26	22.7	1.68	13.8	0.71a	0.55	0.32a	70.6a	0.05	251	1.02	
7-10 years (n=9)	4.49	29.6	2.35	12.7	1.45ab	0.69	0.52ab	46.4ab	0.05	425	1.01	
12-22 years (n=7)	4.97	35.5	3.09	12.2	4.15b	0.57	0.91b	31.6b	0.07	556	0.96	
Center point in oil palm estate												
Phase 7 (9 years, n=7))	4.80a	29.8	1.87	15.4	1.96b	0.28	0.15	56.8a	0.09	13	0.95	14a
Phases 5&4 (16 &17years, n=7)	4.44ab	33.6	1.89	18.1	0.49a	0.14	0.15	88.6b	0.09	7	0.86	13a
Phase 1 (28 years, n=5))	4.54b	31.5	1.75	17.6	0.72a	0.16	0.18	79.6ab	0.09	14	0.87	18b
Fertilizer circle in oil palm estate												
Phase 7 (9 years, n=7)	4.85b	20.3a	1.36a	15.1a	1.57	0.54	0.21	53.3	0.09	162	1.23c	
Phases 5&4 (16 &17 years, =7)	4.46a	27.6ab	1.77ab	15.6a	1.35	0.63	0.42	67.0	0.07	228	1.05b	
Phase 1 (28 years, n=5)	4.62ab	50.8b	2.64b	19.4b	2.23	0.40	0.27	55.8	0.13	142	0.83a	
Oil palm farms of local farmers												
Center point (n=9)	4.42	29.5	1.57*	18.3	0.52	0.12**	0.18*	81.7*	0.04	67	0.92	15
Fertilizer circle (n=9)	4.39	38.6	2.10	18.0	1.07	0.34	0.26	66.7	0.03	56	0.89	

For pepper farms and oil palm estate, values with different letters are significantly different at $P < 0.05$ (Scheffe's multiple comparison test). For oil palm farms, * and ** indicate significant differences at $P < 0.05$ and $P < 0.01$, respectively (paired t-test).

Table 3. Nutrient stocks in crops and soils.

Crops	Age of stand	Density	Total biomass	N	P	K	Mg	Ca	Reference[a)]
	years	No. ha^{-1}	t ha^{-1}	kg ha^{-1}					
Rubber	29	270	158	825	106	766	154	995	Yew (2001)
Pepper	10	1680	17.8	342	22	274	35	210	Sim (1971)
Oil palm	18	136	61.5	574	50	779	108	131	Corley and Tinker (2003)

Soils (0-40 cm)[b)]	T-N	Exch. NH_4-N	Avail. P	Exch. K	Exch. Mg	Exch. Ca
	kg ha^{-1}					
Secondary forest	3753	39	22	129	24	34
Rubber farm	4039	31	49	127	29	19
Pepper farm	4949	28	269	288	86	396
Oil palm estate	4304	26	110	156	66	416

[a)] Data for pepper farming quoted from Sum (1971) was collected in Sarawak while all other data were collected in peninsular Malaysia.
[b)] Average values for all sites. Amounts of ~~the~~ nutrients in soils were calculated as the sum of the value determined for 0-10 cm depth plus 3 times the value determined for 30-40 cm depth. For the surface soils (0-10 cm) of pepper farms and the oil palm estate, the average of the values determined for the center sampling points and the fertilizer circles was used.

Table 4. Annual nutrient budgets comparing fertilizer application, harvesting and pruning.

		Total amount	N	P	K	Mg	Ca	Reference[a)]
		t ha^{-1} y^{-1}	kg ha^{-1} y^{-1}					
Rubber farming								
Input	Fertilizer application[b)]	small						Present study
Output	Latex production	0.85[d)]	7	3	10	3	n.d.	Hartemink (2003); Sim (1971)
Pepper farming								
Input	Fertilizer application[b)]	4	480	209	565	48	200	Present study
Output	Fruit spike production	6.84	132	9	87	9	13	Sim (1971)
	Pruning leaves and branches	4.63	102	7	75	9	62	Sim (1971)
Oil palm plantation								
Input	Fertilizer application[c)]	0.8	96	21	146	14	n.d.	Present study
Output	Bunch production	25[e)]	72	11	91	19	20	Corley and Tinker (2003)

[a)]Data for pepper farming quoted from Sum (1971) was collected in Sarawak while all other data were collected in peninsular Malaysia. [b)]Types and application rates of fertilizers varied between farmers. In rubber farming, a small amount of fertilizer was applied at planting. In the estimates for pepper farming, 12-5.2-14-12-5.0 % of N-P-K-Mg-Ca and the average application rate obtained from the interviews were used. [c)]Based on the record of the Lemanak estate in 2005. [d)]800 to 900 kg ha^{-1} for small holdings (Hartemink 2003). [e)]Fresh bunch weight.