Chapter (non-refereed)

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Tropical

Use of the cotton strip assay at 3 altitudes on an ultrabasic mountain in Sabah, Malaysia

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1 *Summary*

The cotton strip assay was used in tropical rainforests at 3 altitudes on Gunung Silam (5°N, 119°E), a small coastal mountain (884 m above sea level (asl)) in Sabah, Malaysia. The soils were derived from ultrabasic bedrock (which has low concentrations of phosphorus (P), potassium (K) and calcium (Ca), and high concentrations of magnesium (Mg) and nickel (Ni). The forests on these unusual soils were species-rich, but their stature diminished rapidly with altitude. There was a large variation between replicate cotton strips inserted, particularly at the lowest altitudes, but decomposition was generally rapid with days to 50% loss (CT50) at 0–4 cm depth of 16.2 (280 m), 14.1 (610 m), and 25.0 (870 m). Unexpectedly, the highest rate occurs at the intermediate altitude, suggesting that low nutrient supply is not a cause of the relatively small forest there, but may account, at least partly, for the stunted trees at 870 m.

2 *Introduction*

Gunung Silam is a small coastal mountain at the eastern end of the Segama Highlands, an area of rugged country built up of igneous, metamorphic and sedimentary rocks. Most of Gunung Silam (including all the plots discussed here) is ultrabasic rock, which supports soils bearing primary rainforest. There is large-stature lowland dipterocarp forest near the base of the mountain, and small non-dipterocarp lower montane forest near the summit. The vegetation shows a classic 'Massenerhebung effect' (Grubb 1971), which refers to the depression of the altitudinal limit of montane forest on small mountains compared with large ones. The physical environment, vegetation and forest processes on Gunung Silam have been described by Proctor *et al.* (1988a, b).

Gunung Silam was visited by Stirling University Expeditions in July–September 1983 and the same

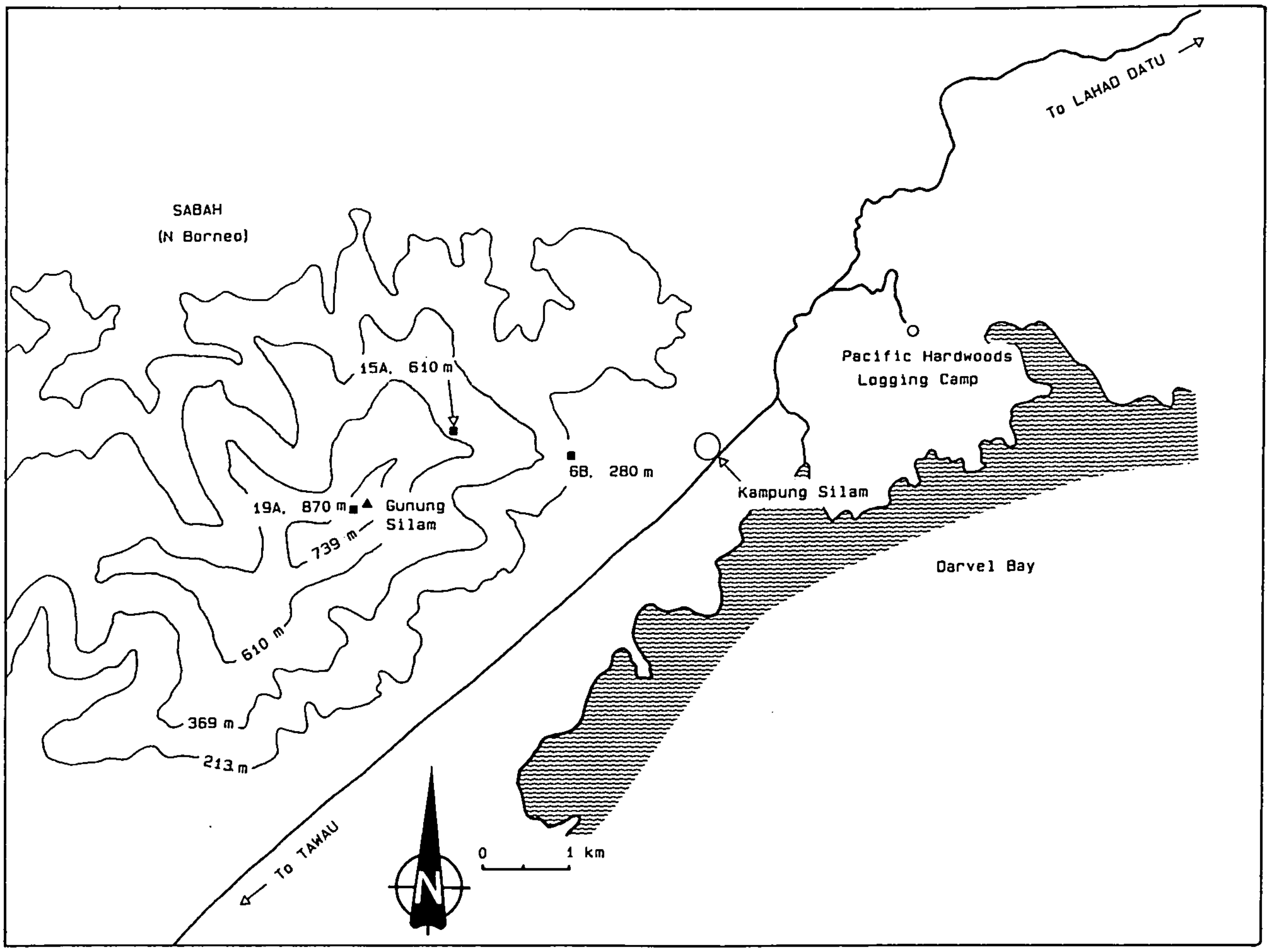

Figure 1. Location of study sites (▪)

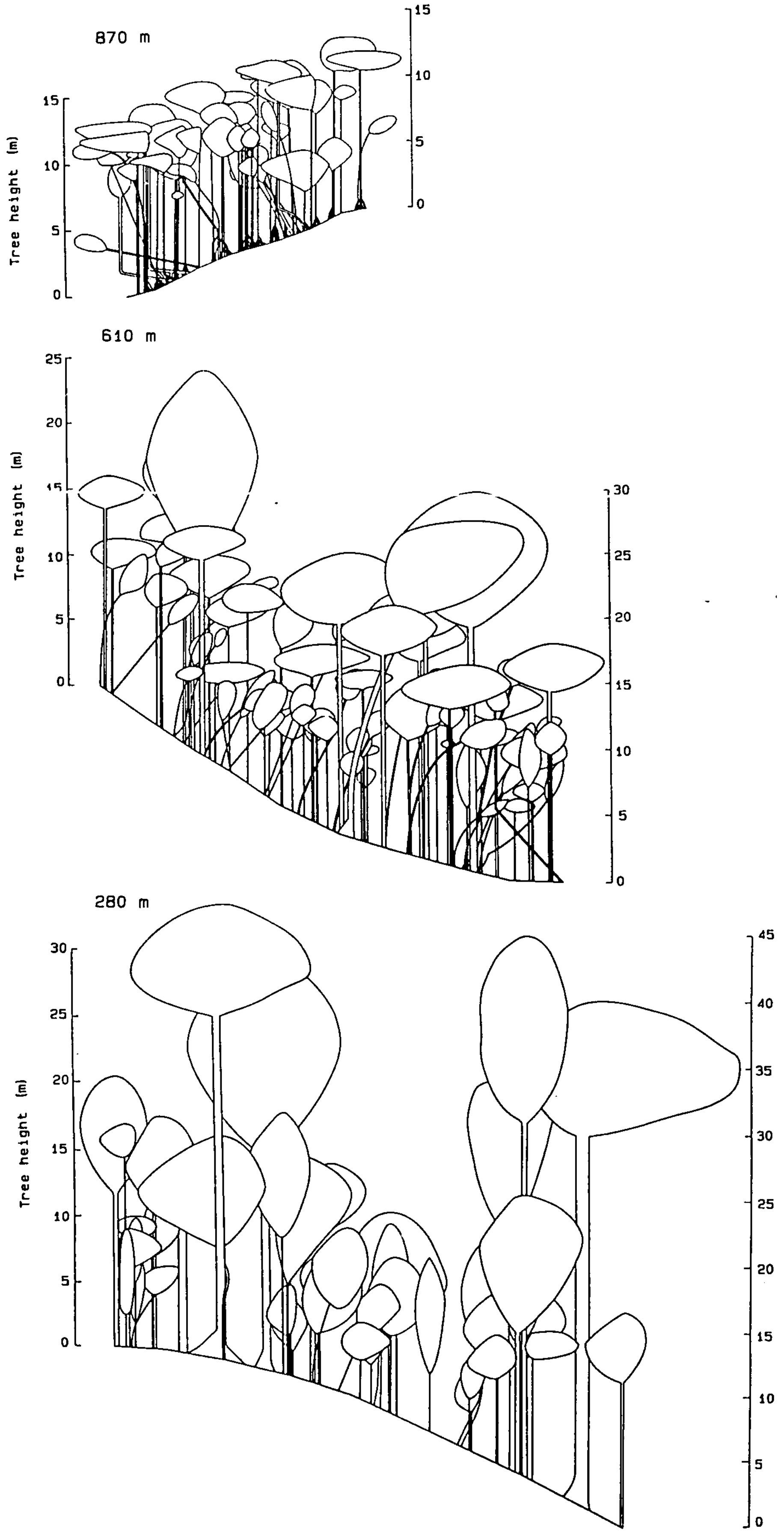

Figure 2. Profile diagrams of forest canopies at the 3 plots at Gunung Silam, Sabah, Malaysia
i. Plot 6B lowland rainforest at 280 m
ii. Plot 15A, tall lower montane forest at 610 m
iii. Plot 19A, short lower montane forest at 870 m

Table 1. The Sabah Forest Department plot numbers, the altitudes, the dimensions and a summary of structural and floristic features of 3 rainforest plots on Gunung Silam, Sabah

Sabah Forest Dept plot number	Altitude (m)	Dimensions (m)	Height of highest emergent tree (m)	Height of main canopy (m)	Main families (% basal area)
6B	280	40 x 100	49	30–35	Dipterocarpaceae (27.9) Anacardiaceae (21.5) Verbenaceae (7.8) Leguminosae (7.1)
15A	610	40 x 60	39	20–25	Dipterocarpaceae (27.1) Euphorbiaceae (23.8) Anacardiaceae (12.4) Myrtaceae (10.1)
19A	870	20 x 20	16	10–12	Myrtaceae (60.7) Rutaceae (24.0) Theaceae (5.7) Elaeocarpaceae (2.5)

months in 1984. The influence of the ultrabasic rock on the structure and species composition of the forest was investigated, along with the causes of the 'Massenerhebung effect'. This paper reports our application of the cotton strip assay to test the hypothesis that decomposition rates decrease with altitude, even on small mountains. Grubb (1977) had suggested that low supply rates of nutrients (which would be likely to be directly linked with decomposition rates) might partly account for the occurrence at low altitudes of small-stature vegetation on wet tropical mountains.

3 *The study plots*

Three plots were selected from several established on the main east ridge of Gunung Silam by the Sabah Forest Department: plot 6B, lowland rainforest at 280 m asl; plot 15A, tall lower montane forest at 610 m asl; and plot 19A, short lower montane forest at 870 m asl (Figures 1 & 2). A summary of the plot features is given in Table 1. Unlike the often stunted or sparse vegetation on ultrabasic soils (Proctor & Woodell 1975), there is no barrenness, and the stunting of the forests near the summit seems part of a general montane effect that occurs on a range of substrata, including ultrabasics.

4 *Climate and soils*

The mean annual rainfall at a site at 20 m asl about 5 km from the base of Gunung Silam is 2011 mm. There is no regularly defined dry season, although the period June–September (which encompasses the assay dates) is relatively dry. The rainfall for the 1984 assay period for a station at 10 m altitude (5 km from the base of Gunung Silam) and for another at 884 m (on the summit) was 159 mm and 91 mm respectively. Above 650 m, the dryness is offset to some extent by the presence of a frequent cloud cap. Temperature data for the assay period are summarized in Table 2, and are probably representative of the whole year. Fox (1978) has commented that average daily temperatures in Sabah show little variation through the year.

Table 2. The mean screen maximum and minimum temperatures and the mean diurnal range for sites in the open at 10 m and 887 m on Gunung Silam, Sabah. Ranges are given in brackets. The data are for 24 July–12 September 1984

Altitude (m)	Mean maximum (°C)	Mean minimum (°C)	Mean diurnal range (°C)
10	31.7 (27.1–33.9)	23.4 (21.6–25.1)	8.4 (6.2–10.9)
884	27.7 (22.3–31.5)	18.8 (17.3–20.5)	8.9 (3.1–14.0)

The soils on Gunung Silam are brown to yellow-brown, with darker-coloured surface horizons. They are freely drained and have a high proportion of sand (ie particles <0.063 mm), which, in the 0–15 cm depth samples, ranges from about 30% of the dry weight at 280 m to about 25% of the dry weight at 610 m and 870 m (excluding the mor layer). The soils are stony and the average depth (measured at 50 randomly selected points in each plot) to the first stones is 32.6 cm (280 m), 6.1 cm (610 m) and 30.8 cm (870 m). However, sharp stakes could be driven down to 1.8 m at a soil pit in all the plots. At 280 m, the upper horizons had a well-developed crumb structure with a mull humus form and frequent earthworm (Lumbricidae) casts. The forest at 610 m had a weaker crumb structure and more stratification of organic matter in the upper soil horizons. Exposed rock and scree are prevalent at this plot, and the soil there is very stony. At 870 m, there is a brown mor humus (not peat) which is well drained and loosely packed, with extensive fine-root networks which often reach substantial depths (up to one m over prop roots).

The chemical analyses (Table 3) show several important features, including many which are typical of ultrabasic soils (Proctor & Woodell 1975). In general, the samples were mildly acid (pH range 5.3–6.0), but the pH was much less in the mor humus at 870 m (mean 4.0). There was a marked excess of Mg at

Table 3. The means ± SE of pH; loss-on-ignition; exchangeable potassium, sodium, calcium, magnesium; acetic-acid extractable phosphorus, cobalt and chromium; exchangeable nickel; and cation exchange capacity (CEC) in 15 cm deep samples collected from each of 3 plots on Gunung Silam, Sabah. Values are expressed on an oven dried (105°C) basis where appropriate
(n = 10 for acetic acid extractable elements and CEC; for other analyses, n = 18 for 870 m and n = 20 for 280 m and 610 m)

Altitude (m)	pH[1]	Loss-on-ignition (%)	Exchangeable cations (m-equiv 100 g^{-1}) K	Na	Ca	Mg	Acetic-acid extracted elements (µg g^{-1}) P	Co	Cr	Exchangeable Ni (µg g^{-1})	CEC (m equiv 100 g^{-1})
280	5.7±0.1	12.4±0.8	0.14±0.01	0.10±0.01	7.7±1.1	24.6±1.4	4.1±0.4	2.5±0.3	0.5±0.1	13±2	49±3
610	6.0±0.2	23.9±3.3	0.42±0.08	0.17±0.03	12.4±2.8	10.6±1.0	7.1±1.3	4.1±0.6	0.5±0.2	15±2	102±3
870[2] (mor)	4.0±0.1	52.0±6.2	0.53±0.06	0.41±0.07	1.2±0.3	5.6±0.8	16.8±3.4	2.7±0.5	1.0±0.2	1.6±0.2	105±2
870[2] (mineral layer)	5.3±0.1	12.1±0.6	0.06±0.01	0.05±0.01	0.17±0.05	1.6±0.2	1.1±0.5	5.6±0.8	1.0±0.2	1.9±0.4	104±2

[1] in H_2O

[2] the combined mor and mineral layers' depth was 15 cm, but the depth of each layer varied between samples

280 m and 870 m, but the soil at 610 m was more calcareous. Exchangeable Ni showed relatively high concentrations at 280 m and 610 m.

5 *Method*

The cotton strip assay was first carried out in July–August 1983. However, the sampling periods of 24 and 34 days used then were too long, as many strips were decomposed well beyond the point when tensile strength (TS) measurements are valid. We repeated the work in 1984 with shorter sampling periods, and this timing proved to be more satisfactory. Only the 1984 work is reported in detail. In July 1984, 4 strips were placed at random within each of 10 subplots in each of the plots at 280 m, 610 m and 870 m. The methods followed those of Latter and Howson (1977). The strips were inserted vertically in the soil after removing the surface litter (ie recognizable plant remains but not soil organic matter). Sometimes (at 610 m and 870 m), the soils were too stony to allow the strips to be inserted to the full depth. The cotton strips were carefully removed from each subplot after 14 days and 20 days (610 m) or 21 days (280 m and 870 m). Two field control strips were used on each retrieval date at each plot. The strips were returned to the base camp, washed in tap water, air dried using a fan, and then stored between sheets of newspaper for 8 weeks. Some cloth control strips were kept at the Institute of Terrestrial Ecology's Merlewood Research Station to allow changes caused by transport, washing and storage to be assessed. After cutting, fraying and drying, the TS of 4 cm substrips frayed to 3 cm was tested at a relative humidity of 60–70%, using a Monsanto Type W tensometer with 5 cm wide pneumatic jaws.

The method of Hill *et al.* (1985) was used to calculate CT5O, the time in days for the strips to lose 50% of their TS. This method allows comparisons between soils where the cotton has not been buried for the same length of time. First, the cotton rottenness function (CR) was calculated using the following formula:

$$CR = \sqrt[3]{\frac{\text{field control TS} - \text{final TS}}{\text{final TS}}}$$

where the field control TS is the mean TS of the 20 substrips from the 4 field control strips which had been placed (2 on each sampling date) in each site, and where the final TS is the median final TS of the samples for each depth, sample date and plot. (The median is used to avoid the bias due to non-linearity of change in TS with time and, as will be seen later, is further justified here in view of the high variability of the data.)

The CT5O was calculated using the formula:

$$CT50 = \frac{\text{no. of days in soil}}{CR}$$

6 *Results*

The cloth control strips had a mean TS of 46.7 ± 0.9 kg, and the field control strips a mean TS of 42.6 ± 0.8 kg. These values are significantly different ($P<0.001$) and demonstrate a TS loss during transport, storage and burial in the soil.

The experimental strips showed a very high within-plot variability (see Lindley & Howard 1988) between replicates, particularly at the lower altitudes. The results (Table 4) show that decomposition rates are ranked in the order 610 m, 280 m and 870 m. The data are simplified (by combining results for the 14 day and 20 or 21 day samples) in Figure 3. The plots at 280 m and 610 m show fairly similar patterns, whilst at 870 m decomposition is much slower and decreases markedly with depth.

The overall CT5O values are generally rapid compared with those in temperate areas (Hill *et al.* 1985; Ineson *et al.* 1988).

Table 4. The median tensile strength (TS) and CT50 (time in days to 50% loss of tensile strength, calculated by a method explained in the text) of cotton strips inserted to 20 cm depth (from the soil surface scraped free of litter) for 14, 20 or 21 days in 3 plots at different altitudes on Gunung Silam, Sabah. Field control value = 42.6 ± 0.8 kg

Altitude (m)	Sample dates (1984)	Days in field	Sample depth (cm)	No. of strips lost	No. of strips eaten by termites	No. of strips tested	Median TS (kg)	CT50
280	24 July– 7 August	14	0–4	0	1	19	25.0	16.1
			4–8			19	25.0	16.1
			8–12			19	30.0	19.3
			12–16			19	31.0	20.1
			16–20			19	37.0	28.3
280	24 July– 14 August	21	0–4	2	2	16	13.0	16.2
			4–8			16	20.5	20.8
			8–12			16	18.3	19.4
			12–16			16	20.3	20.7
			16–20			16	27.5	26.3
610	26 July– 9 August	14	0–4	0	2	18	20.8	13.6
			4–8			18	21.3	13.8
			8–12			18	14.8	11.2
			12–16[1]			12	25.0	15.5
			16–20[1]			6	28.0	17.0
610	26 July– 15 August	20	0–4	0	1	19	12.0	14.5
			4–8			19	–7.5	11.8
			8–12			19	14.5	15.9
			12–16[1]			17	23.8	21.2
			16–20[1]			8	17.8	17.6
870	25 July– 8 August	14	0–4	0	1	19	38.0	27.9
			4–8			19	40.5	36.4
			8–12			19	42.0	52.4
			12–16			19	44.0[2]	—[2]
			16–20[1]			15	42.5	73.0
870	25 July– 15 August	21	0–4	1	0	19	23.0	22.1
			4–8			19	26.0	24.3
			8–12			19	37.0	38.9
			12–16			19	42.0	78.6
			16–20[1]			14	36.0	36.6

[1] Several strips could not be buried to these depths

[2] Because the value for median TS did not differ from that of the field controls, the CT5O would be infinity. Only 21-day data were therefore used in Figure 3

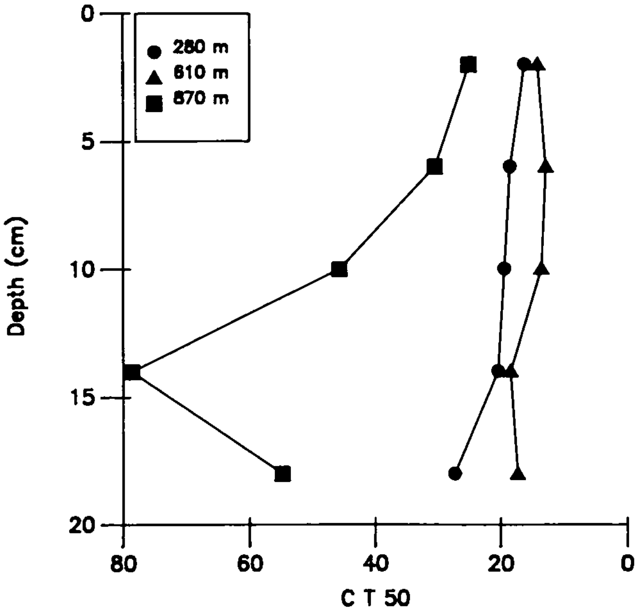

Figure 3. The mean CT5O for cotton strips inserted for 14 days and 21 days at 3 plots on Gunung Silam, Sabah. Supporting information is given in Table 4

7 *Discussion*

On Gunung Silam, a clear altitudinal trend in decomposition rates is lacking as the intermediate plot at 610 m had the highest rates. The differences are greatest between the plots at 610 m and 870 m, and yet the latitudinal difference is least between these 2 plots. Our 1983 data showed a similar pattern, in that the cotton strips lost TS more slowly at 870 m but there was no clear difference in that year between the results for 280 m and 610 m. The causes of the different rates (Table 4 & Figure 3) are probably complex. Some climatic factors (associated with the frequent cloud cap), such as solar radiation, change abruptly above 610 m. The rainfall patterns are very different between the summit and the lower parts of the mountain, and the former receives less rainfall (at least during much of July–September 1983 and 1984). The tree family composition at 870 m (Table 1) contrasts with those of the other 2 plots, and there is likely to be an important difference in litter quality which results in the observed slower rates of decomposition of the cotton strips and the accumulation of mor humus there. Leakey and Proctor (1987) have shown that the soil invertebrate biomass is much lower at 870 m (1.5 g m^{-2} alcohol wet weight) than at 610 m (4.5 g m^{-2}) or 280 m (7.1 g m^{-2}). Earthworms accounted for only 0.3% of the biomass at 870 m, 18% at 610 m and 85% at 280 m. These differences must reflect substrate quality, but are difficult to reconcile with the high rate of decomposition at 610 m. The lower plots are less acid and more calcareous than that at 870 m, and the distinctly calcareous plot at 610 m may favour a more active soil microflora. However, there is a higher mean loss-on-ignition (Table 3) at 610 m than 280 m. The results support the hypothesis that relatively low decomposition rates (and hence release of nutrients by mineralization) are likely to occur at higher altitudes on tropical mountains. The importance of this slower process on forest stature and composition needs further investigation, and it is apparently not the explanation of the substantial differences in forest stature between the plots at 280 m and 610 m. The cotton strip assay is seen to be a useful preliminary tool for investigating forest changes on mountains, and has led to the suggestion that, even along a forest continuum, the causes of the changes may differ from one part to another. The assay serves as a guide for the more detailed work which is a prerequisite for a full explanation of rain-forest altitudinal zonation.

8 *Acknowledgement*

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9 *References*

Fox, J.E.D. 1978. The natural vegetation of Sabah, Malaysia. 1. The physical environment and classification. *Trop. Ecol.*, **19,** 218-239.

Grubb, P.J. 1971. Interpretation of the 'Massenerhebung' effect on tropical mountains. *Nature, Lond.*, **229,** 44-45.

Grubb, P.J. 1977. Control of forest growth and distribution on wet tropical mountains with special reference to mineral nutrition. *Ann. Rev. Ecol. Syst.*, **8,** 83-107.

Hill, M.O., Latter, P.M. & Bancroft, G. 1985. A standard curve for inter-site comparison of cellulose degradation using the cotton strip method. *Can. J. Soil Sci.*, **65,** 609-619.

Ineson, P., Bacon, P.J. & Lindley, D.K. 1988. Decomposition of cotton strips in soil: analysis of the world data set. In: *Cotton strip assay: index of decomposition in soils,* edited by A.F. Harrison, P.M. Latter & D.W.H. Walton, 155-165. (ITE symposium no. 24.) Grange-over-Sands: Institute of Terrestrial Ecology.

Latter, P.M. & Howson, G. 1977. The use of cotton strips to indicate cellulose decomposition in the field. *Pedobiologia*, **17,** 145-155.

Leakey, R.J.G. & Proctor, J. 1987. Invertebrates in the litter and soil at a range of altitudes on Gunung Silam, a small ultrabasic mountain in Sabah. *J. trop. Ecol.*, **3,** 119-129.

Lindley, D.K. & Howard, D.M. 1988. Some statistical problems in analysing cotton strip assay data. In: *Cotton strip assay: an index of decomposition in soils,* edited by A.F. Harrison, P.M. Latter & D.W.H. Walton, 25-27. (ITE symposium no. 24.) Grange-over-Sands: Institute of Terrestrial Ecology.

Proctor, J. & Woodell, S.R.J. 1975. The ecology of serpentine soils. *Adv. ecol. Res.*, **9,** 255-366.

Proctor, J., Lee, Y.F., Langley, A.M., Munro, W.R.C. & Nelson, T. 1988a. Ecological studies on Gunung Silam, a small ultrabasic mountain in Sabah. I. Environment, forest structure and floristics. *J. Ecol.* In press.

Proctor, J., Phillipps, C., Duff, G.K., Heaney, A. & Robertson, F.M. 1988b. Ecological studies on Gunung Silam, a small ultrabasic mountain in Sabah. II. Some forest processes. *J. Ecol.* In press.