J. Rubb. Res. Inst. Malaysia, **24(3)**, 145-159 (1976)

Effect of Cover Management on Physical Properties of Rubber-growing Soils

N.K. SOONG and W.C. YAP

Comparisons of the residual effects of cover plants on the physical properties of soils showed that creeping leguminous cover generally had better residual effects than grass, naturals or Mikania *cover. The poorest residual effect was obtained with* Mikania *cover. Under mature rubber, the establishment of shade-tolerant cover plants,* e.g. *grasses and ferns, had beneficial effects on the physical properties of soil, leading to improved growth and yield of the rubber trees. The efficiency of cover plants in improving the physical properties of soil was found to be related to the amount of decomposable organic matter they could return to the soil.*

Cover management is an important aspect of rubber cultivation in a tropical country like Malaysia where both rainfall and temperature are high. A ground cover of grasses, creeping leguminous plants or upright shrubs maintained between the planting rows helps prevent the soil from erosion and reduces the effect of extreme climatic conditions. In addition, covers reduce the rate of decomposition of organic matter (WATSON, 1961), minimise leaching losses of nutrients (WATSON, 1961), recycle nutrients and add organic matter to the soil. Probably, the most important single effect of cover plants is in the improvement of the physical properties of soil, resulting in a more favourable soil environment for root growth and proliferation. The improvement in the physical conditions of soil is mainly due to the large amount of organic matter added to the soil and the associated chemical, physical and biological reactions that ensue with the decomposition of the organic matter.

In the last two decades a great deal of work on the effects of different cover plants on rubber growth and yield under Malaysian conditions has been reported (WATSON, 1963; WATSON *et al.*, 1964; MAINSTONE, 1963 and 1969; PUSHPARAJAH AND CHELLAPAH, 1969). The general conclusions were that among cover plants, leguminous covers, consisting of a mixture of *Pueraria phaseoloides* and *Calopogonium muconoides*, gave better growth of rubber trees during their early years and also increased significantly the early yields of rubber. The superior performance is attributed to the return of large amounts of easily decomposable organic matter to the soil by the legume covers, ensuring cooler and moist conditions in the top soil where most of the feeder roots of rubber are found (SOONG, 1971). From this it was also inferred that the legume covers improved the structure of the top soil. This study investigates the actual effect of different cover plants on various soil physical properties under rubber in Malaysian conditions.

MATERIALS AND METHODS

Six cover plant experiments were selected for this study. Details of the treatments and designs are given in *Table 1*. *Experiments SE.28/2* and *SE.4/2* were set up on replants in 1957 and 1959 respectively to study the effect of different types of cover plants on the growth and yield of rubber.

COMMUNICATION 588

In these two experiments, leguminous creeping covers were tested against non-leguminous covers. *Experiment SE.1/28* was a small-scale cover plant experiment established on a jungle clearing in 1959 to study changes in soil moisture content and nutrient status in the soil under four different cover systems. As the three experiments *(SE.28/2, SE.4/2* and *SE.1/28)* were established more than fourteen years ago, most of the cover plants had already died off; even shade-tolerant species like grasses were showing only sparse growth. Hence, it was only possible to study the residual effects of the initial cover systems on soil physical properties.

Experiments SE.67/4, SE.81/1 and *SE.87/1* were all set up in 1956 to investigate the effect of some shade-tolerant covers on the yield of mature rubber. In these experiments the influence of shade-tolerant covers, namely a grass *(Ottochloa nodosa)* and a fern *(Nephrolepis biserrata)*, were compared with clean cultivation obtained by regular spraying with chemicals. These cover conditions were superimposed on areas which during the immature phase of rubber had legume covers.

For each cover treatment two bulk soil samples were collected from plots having, as far as possible, similar cover density, slope of land and other agronomic conditions. The two bulk samples were then pooled together and sub-samples were taken for determination of various soil chemical and physical properties.

Mechanical analysis was determined by the pipette method and the soil particle sizes were classified according to the International Method of Classification. Organic carbon content was determined by the Walkley and Black's Rapid Titration Method. Soil structure was characterised in six parameters, namely percentage aggregation, mean weight diameter, bulk density, permeability, total porosity and air-filled porosity. Aggregate analysis was measured by the wet-sieving method described by RUSSELL (1949) on an apparatus modified by Low (1954). Two sets of six 5-cm screens having openings of 4.0, 2.0, 1.0, 0.5, 0.25 and 0.10 mm were used. The whole assembly was attached to a crankshaft that raised and lowered the screens in water through a distance of 3.8 cm at the rate of thirty strokes per minute for 30 minutes. The 'state of aggregation' or the percentage weight of aggregates in a given weight of soil (BAVER, 1956) was calculated for the soil sample obtained from each cover treatment. The aggregate size distribution was represented by a single parameter called the Mean Weight Diameter (VAN BAVEL, 1949) which was calculated from the following equation:

$$\text{Mean weight diameter (MWD)} = \sum_{i=1}^{n} \bar{x}_i W_i$$

where $\bar{x}_i$ = mean diameter of each size fraction

W_i = the proportion of the total sample weight occurring in the corresponding size fraction

n = number of size fraction.

Bulk density measurements were made on core samples obtained by a soil core sampler (LUTZ, 1947). Permeability measurements were also made on these soil cores using the method described by BOWER AND PETERSON (1950). Specific gravity of each soil sample was determined by the pycnometer method and the value was used for calculating total porosity by the relationship:

$$\%\ \text{porosity} = \left(1 - \frac{\text{bulk density}}{\text{specific gravity}}\right) \times 100$$

The amount of air-filled porosity was calculated by substracting from the total

TABLE 1. DETALIS OF SIX COVER PLANT EXPERIMENTS

Location and Experiment No.	Soil type and previous history	Experimental design	Plot size (ha)	Planting material and date of planting/budding	Cover plant treatments	Remarks
1. Sepang Estate (Expt SE.28/2)	Munchong series Rubber	4 × 2^2 factorial in triplicates	0.25	GG1 seedlings planted in Oct. 1957	1. Legumes – mixed leguminous creepers, *Pueraria phaseoloides*, *Centrosema pubescens* and *Calopogonium muconoides* 2. Grass – mixed *Axonopus compressus* and *Paspalum conjugatum* 3. *Mikania cordata* 4. Natural – mixed indigenous bushes, etc.	By Dec. 1964 legume covers had completely died off; *Mikania* persisted as a thin cover; the natural plots were invaded by *Nephrolepis biserrata*. By 1972 the legume and *Mikania* plots were overrun by *Nephrolepis* and grasses. The vegetation in natural plots was mainly wild ginger.
2. Bradwall Estate (Expt SE.4/2)	Malacca series Rubber	4 × 2^2 factorial in triplicates	0.20	RRIM 623 planted Sept. 1958, budded Sept. 1959	1. Legumes – mixed leguminous creepers, *Pueraria phaseoloides*, *Centrosema pubescens* and *Calopogonium muconoides* 2. Grass – mixed *Axonopus compressus* and *Paspalum conjugatum* 3. *Mikania cordata* 4. *Moghania*	By Dec. 1964 legume covers had died off; *Mikania* still provided a vigorous cover; grass covers were rather thin. The growth of *Moghania* was vigorous. By 1968 all the legume plots were invaded by grasses and *Mikania*. The *Moghania* cover still persisted.
3. RRIM Experiment Station, Sungei Buloh (Expt SE.1/28)	Rengam series Jungle	4 × 4 latin square	0.0004	RRIM 513 planted Sept. 1959	1. Legumes – mixed leguminous creepers, *Pueraria phaseoloides*, *Centrosema pubescens* and *Calopogonium muconoides* 2. Grass – mixed *Axonopus compressus* and *Paspalum conjugatum* 3. Natural – mixed indigenous bushes, etc. 4. Clean cultivation	By August 1964 legume covers became very thin and were being slowly invaded by grasses. Natural covers were very vigorous. Legume covers died off completely by 1966 and all the plots were invaded by grasses.
4. Kirby Estate (Expt SE.67/4)	Rengam series Rubber	3 × 4 triple rect. lattice	0.27	PB 5/51 budded onto seed at stake, planted Oct. 1957.	1. Clean cultivation – soil surface kept clean of vegetation by regular chemical spraying. 2. Grass – mainly *Ottochloa nodosa* 3. Ferns – *Nephrolepis biserrata*	In all these three experiments the clean cultivated plots were constantly invaded by various types of weeds. Regular spraying with chemicals was necessary to keep the plots free from vegetation.
5. Lothian Estate (Expt SE.81/1)	Serdang/ Munchong association Rubber	3 × 2^2 factorial	0.27	GT 1 budded onto seed at stake, planted Oct. 1957		
6. Rasak Estate (Expt SE.87/1)	Serdang series Rubber	3 × 4 triple rect. lattice	0.27	RRIM 623, planted Oct. 1958 budded Aug. to Oct. 1959		

porosity, the volume of moisture held in the soil two to three days after rainfall.

RESULTS AND DISCUSSION

Residual Effects of Cover Plants

The mechanical composition and organic carbon content of the soil samples collected from the various cover treatments in *Experiments SE.28/2, SE.4/2* and *SE.1/28* are shown in *Table 2.* The results show that for the same soil depth there are wide variations in soil texture between samples obtained from the same experimental area, the variations being greatest in *Experiments SE.28/2* and *SE.4/2* and least in *Experiment SE.1/28.* The variations were observed in the contents of fine sand and clay. Such textural variations would introduce complication in interpreting the effect of cover plants on soil structural conditions, as soil texture is considered to be one of the main factors affecting soil structure development (BAVER, 1956). This will be dealt in greater detail later.

Differences in organic carbon content of the soils between the various cover treatments were observed only in the topsoil. In *Experiment SE.28/2,* plots having natural

TABLE 2. TEXTURAL COMPOSITION AND ORGANIC CARBON CONTENT OF SOIL SAMPLES FROM COVER EXPERIMENTS SE.28/2, SE.4/2 AND SE.1/28

Experiment No	Soil series	Cover treatment	Soil depth (cm)	Textural composition				Organic carbon (%)
				Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	
SE.28/2	Munchong	Grass	0 – 15	26.4	42.5	5.0	27.1	1.35
			15 – 30	25.5	38.5	4.3	33.1	0.79
		Mikania	0 – 15	28.9	44.2	4.2	24.0	1.21
			15 – 30	26.8	36.2	4.0	34.8	0.75
		Legume	0 – 15	21.0	33.7	7.2	39.4	1.34
			15 – 30	18.3	29.8	7.8	45.8	0.83
		Naturals	0 – 15	25.8	26.0	9.5	40.2	1.53
			15 – 30	24.2	21.6	7.6	48.4	0.88
SE 4/2	Malacca	Grass	0– 15	29.9	31.6	12.8	27.1	1.26
			15–30	27.3	28.4	12.0	34.5	0.73
		Mikania	0 – 15	25.6	28.9	13.8	36.9	1.31
			15 – 30	23.2	23.8	13.0	42.1	0.71
		Legume	0 – 15	29.0	32.5	14.5	26.5	1.39
			15 – 30	25.6	28.3	14.5	34.1	0.76
		Moghania	0 – 15	20.9	18.9	13.3	47.2	2.01
			15 – 30	20.6	18.6	13.5	49.0	1.02
SE.1/28	Rengam	Grass	0 – 15	35.8	9.2	6.1	41.5	1.43
			15 – 30	34.8	9.2	5.7	44.2	0.81
		Clean cultivation	0 – 15	28.8	6.4	9.3	44.0	1.09
			15 – 30	30.4	6.4	12.6	41.7	0.63
		Legume	0 – 15	34.6	10.2	7.1	39.0	1.39
			15 – 30	38.0	9.5	7.5	38.0	0.76
		Naturals	0 – 15	36.0	9.1	7.3	39.2	1.28
			15 – 30	34.2	8.9	8.7	40.4	0.72

cover had the highest organic carbon content and those which had *Mikania* cover previously had the lowest carbon. Legume cover plots had almost similar organic carbon content as grass cover plots. This is expected as the legume plots had been sustaining a mixture of grasses since 1964 when the legumes were shaded out. In *Experiment SE.4/2,* the highest organic carbon content was found in plots with *Moghania,* a legume bush, followed by legume, *Mikania* and grass plots.

The value of cover plants in enhancing the organic carbon status of the soil was clearly shown in *Experiment SE.1/28.* Clean-cultivated plots had the lowest organic carbon content compared to grass, legume and naturals. In this experiment the grass cover returned a higher organic carbon content to the soil than legume and naturals.

The residual effect of different cover treatments on soil physical properties is shown in *Table 3.* The three experiments show that the covers had a more pronounced effect on the topsoil (0 – 15 cm depth) than in the subsoil.

Experiment SE.28/2. In *Experiment SE.28/2* the topsoil under leguminous cover had a significantly higher percentage aggregation of the finer particles than soil under grass, *Mikania* or natural covers. The aggregate size distribution, bulk density, permeability and air-filled porosity data also show that legume covers had a better residual effect on soil structure. Percentage aggregation was the lowest in *Mikania* plots, and bulk density value the highest, indicating poorer soil structure. The low air-filled porosity value confirms this. Natural covers were next to legumes in their effect on soil properties. Although it gave lower percentage aggregation of soils than that under grass, it increased the size of the aggregates leading to an increase in air-filled pores and higher permeability of the soil.

Legume covers also showed a greater effect than the other covers in improving soil structure in the sub soil. The poor effect of *Mikania* in the surface soil was again repeated in the subsoil. Bulk density value of 1.22 g/c.c. was the highest among the four cover treatments, while permeability and air-filled porosity the lowest.

Statistical analysis of the results show a highly significant ($P < 0.001$) interaction between covers and soil depths for percentage aggregation and permeability. This means that for these two soil parameters, the order of response obtained in the topsoil was different from that obtained in the subsoil. For MWD and bulk density the interaction was not significant.

Experiment SE.4/2. This experiment is situated on a shallow clay loam soil, with dense modular laterites. In this experiment, *Moghania* seems to have the best residual effect on soil structure compared to grass, *Mikania* and creeping legume. This is indicated by the significantly higher percentage soil aggregation, lower bulk density, and higher permeability in *Moghania* plots. Total and air-filled porosities were also much higher. The results were the same for both topsoil and subsoil with the single exception of permeability for subsoil. It must be pointed out that, at the time of sampling, *Moghania* was still persisting as a vigorous cover and, as such, was actively involved in the regeneration of soil structure, whereas the effect of the other three covers was slowly declining with time.

A comparison of grass, *Mikania* and creeping legume covers showed that legumes had more residual beneficial effect on soil structure. This was reflected in the higher percentage soil aggregation, permeability of the soil, and air-filled pores. Grass plots, although having the lowest percentage soil aggregation, had significantly larger aggregate size and lower bulk density. Permeability, however, was low and so were the total and

TABLE 3. RESIDUAL EFFECTS OF DIFFERENT COVER PLANTS ON SOIL PHYSICAL PROPERTIES

Experiment (Soil type)	Soil depth (cm)	Cover treatment	Aggregation (%)	M W D (mm)	Bulk density (g/cc)	Permeability (cm/h)	Total porosity (%)	Air-filled porosity (%)
SE.28/2 (Munchong series)	0 – 15	Grass	91.1	2.67	1.11	29.0	58.1	27.7
		Mikania	88.3	2.99	1.21	35.6	54.0	21.9
		Legume	93.9	3.77	1.04	110.7	60.6	31.0
		Natural	90.0	3.22	1.00	45.2	61.8	28.2
	15 – 30	Grass	82.6	1.04	1.17	25.7	55.7	24.9
		Mikania	76.9	1.54	1.22	7.9	54.0	21.9
		Legume	89.0	2.15	1.12	25.9	58.1	24.8
		Natural	75.4	1.56	1.07	23.6	59.8	26.2
	s.e. between means of covers within depths		1.30	0.085	0.028	2.51		
	L S D (P<0.05)		3.6	0.24	0.08	7.0		
	s.e. between depths		0.65	0.043	0.014	1.26		
	L S D (P<0.05)		1.8	0.12	0.04	3.6		
SE.4/2 (Malacca series)	0 – 15	Grass	86.0	3.28	1.13	43.1	49.6	16.4
		Mikania	87.1	2.89	1.15	52.8	52.1	17.0
		Legume	88.2	2.93	1.19	62.0	50.3	19.0
		Moghania	88.6	3.13	0.93	117.1	58.4	23.8
	15 – 30	Grass	79.7	1.64	1.26	14.2	48.9	14.4
		Mikania	81.9	1.23	1.23	14.5	51.0	12.6
		Legume	79.5	1.22	1.27	5.9	49.5	14.7
		Moghana	86.8	1.87	1.13	5.8	54.3	15.2
	s.e. between means of covers within depths		0.89	0.144	0.029	3.04		
	L S D (P<0.05)		2.5	0.40	0.08	8.5		
	s.e. between depths		0.45	0.072	0.014	1.52		
	L S D (P<0.05)		12	0.20	0.04	4.3		
SE.1/28 (Rengam series)	0 – 15	Grass	73.8	3.39	1.13	13.2	53.1	12.3
		Clean cultivation	66.2	0.95	1.21	8.4	52.7	16.4
		Legume	69.4	1.98	1.13	12.4	52.6	12.3
		Natural	72.4	2.20	1.16	2.0	52.1	11.5
	15 – 30	Grass	68.8	1.51	1.26	4.3	50.8	13.3
		Clean cultivation	68.2	0.93	1.15	2.0	51.1	16.8
		Legume	66.6	1.36	1.17	11.2	49.4	13.2
		Natural	67.3	1.18	1.21	6.9	50.2	14.5
	s.e. between means of covers within depths		0.73	0.065	0.018	1.10		
	L S D (P<0.05)		2.0	0.18	0.05	3.1		
	s.e. between depths		0.36	0.032	0.009	0.55		
	L S D (P<0.05)		1.0	0.09	0.03	1.6		

air-filled porosity values. The inferiority of *Mikania* cover was not so obvious as in *Experiment SE.28/2*.

In the subsoil, legume plots effected poorer soil structural conditions than grass and *Mikania* plots. Besides having low percentage aggregation, the size of the soil aggregate was also the smallest. Both bulk density and permeability values also indicated poorer soil structure. The effect of grass and *Mikania* on the structure of the subsoil was difficult to differentiate from the results obtained. There were no significant differences in percentage aggregation, bulk density and permeability of soil under the two covers, but grass plots had more air-filled pores and significantly larger aggregate size.

Experiment SE.1/28. The treatments in *Experiment SE.1/28* provided a good comparison between the effect of clean cultivation and maintenance of covers on soil structure. In the topsoil, clean cultivation led to deterioration of the soil structure by reducing significantly the percentage aggregation of the finer soil particles, decreasing the size of the soil aggregates and increasing bulk density. There was also an obvious case of soil crust formation in the clean-cultivated plots where the bulk density in the topsoil was significantly higher than that in the subsoil. Without the protection of a cover, the impact of rain had broken down soil aggregates, causing the finer soil particles to block soil pores and, ultimately, reducing infiltration of water. The low permeability values for both topsoil and subsoil seemed to bear out this point. However, it is surprising to note that there was a greater amount of air-filled pores in clean-cultivated plots than in the other three cover treatments. No explanation can be offered for this finding.

The grass cover had the best residual effect on soil structure, as reflected by the high percentage aggregation, large soil aggregate size, low bulk density and high permeability values. Total porosity was also slightly higher than in soils under the other cover treatments. The beneficial effect of creeping legume on soil physical properties seemed to have declined. The percentage aggregation and MWD of the soil aggregates were significantly lower than those under grass and natural covers. However, bulk density was still low and permeability of the soil was comparable to the surface soil under grass and much higher than the rest in the subsoil under grass.

The advantages of leguminous creeping cover over other cover plants in enhancing growth of rubber in the early stage of planting was discussed by WATSON (1963), WATSON *et al.* (1964) and MAINSTONE (1963). More recently, MAINSTONE (1969) and PUSHPARAJAH AND CHELLAPAH (1969) presented rubber yield figures to show that legumes have greater residual beneficial effect on soil, this being reflected by the consistently higher yield of rubber in plots with a vigorous growth of legume cover during the immature period. Examination of the rubber root system (MAINSTONE, 1969) showed that there was a significantly greater root development in the soil under legume cover than under natural cover, although the observation was made ten years after the legume cover had died off. Thus, it can be inferred that a good legume cover has a more durable improvement on soil physical properties than other cover plants. The physical soil parameters obtained from *Experiment SE.28/2* and *SE.4/2* partly helps explain the findings of the earlier workers. In both experiments, the legume plots definitely had better soil structure than plots under other cover treatments, the effect being more pronounced in the topsoil. However, in *Experiment SE.1/28* the beneficial effect of legume was on the decline.

Grass cover, with its vigorous rooting habit, also has significant improvement in the structure of soil. The results from

Experiment SE.1/28 show that the performance of grass can even surpass that of legume and natural covers. The reason why rubber does not perform as well with grass cover as with legume is probably due to the poorer return of essential nutrients to the soil by the grass cover (WATSON *et al.*, 1964) and the competition for moisture by its more dense root system (WATSON *et al.*, 1964). However, when compensatory nitrogenous fertilisers are applied, the growth and yield of rubber trees were seen to be comparable to those with legume cover (PUSHPARAJAH AND CHELLAPAH, 1969), thus overcoming a major weakness of a grass cover system. Among the various cover plants tested, *Mikania* had the poorest residual effect on soil structure. This could be due to the lower dry matter production of the plant, resulting in a lower return of organic matter to the soil. It will be shown later that organic matter plays an important role in soil structure changes. In addition, *Mikania* exudes a growth inhibitory phenolic compound (WONG, 1964) and this may, besides reducing nitrification, also affect adversely the microbial population in the soil.

Effect of Covers Established under Mature Rubber

When the canopy of the rubber trees closes, the light intensity reaching the ground becomes so low that many low-shade-tolerant plants, like leguminous creepers and *Mikania,* will die off. The ground would generally be invaded by many shade-tolerant plant species and their effect on rubber growth and yield are yet to be fully known. However, in some areas where a pure legume cover was maintained with all other plants weeded out no plant succession was possible and the soil under the closed canopy remained bare.

Experiments SE.67/4, SE.81/1 and *SE.87/1* were set up in 1964 to study the effect of three types of ground conditions on the yield of mature rubber. All the three experiments had the same cover treatments, namely grass, fern and clean cultivation. The effect of these three cover treatments on the physical properties of soil were investigated.

The mechanical composition and organic carbon content of the soil samples collected are shown in *Table 4.* There were variations in soil texture between samples obtained from the same experimental site, but the variations were not as wide as those in *Experiments SE.28/2* and *SE.4/2.* Clean cultivated plots had a consistently lower amount of organic carbon content than plots with grass and fern covers, at both soil depths examined. In the topsoil, grass plots generally had higher organic carbon content than plots with fern cover except for *Experiment SE.87/1,* but the reverse was true at the lower soil depth.

The effects of grass, fern and clean cultivation on soil physical properties are shown in *Table 5.* In *Experiment SE.67/4* grass cover had the best effect on soil structure at both soil depths by increasing aggregate size, lowering bulk density and increasing permeability of the soil to water movement. Total porosities in grass plots were the highest, whereas air-filled porosities were on the higher side. Plots with fern cover had almost similar physical properties to that of the clean cultivated plots, indicating that ferns had not improved soil structure at all. In fact, the bulk density and permeability figures obtained suggest ferns to have a detrimental effect on soil structure.

In *Experiment SE.81/1* grass cover gave lower percentage aggregation than in clean cultivated plots but MWD was significantly larger. Bulk density was significantly lower, leading to a higher permeability of the soil. In this experiment, fern cover improved somewhat the soil physical properties, as shown by the bulk density, permeability,

TABLE 4. TEXTURAL COMPOSITION AND ORGANIC CARBON CONTENT OF SOIL SAMPLES FROM COVER EXPERIMENTS SE.67/4, SE.81/1 AND SE.87/1

Experiment	Soil series	Cover treatment	Soil depth (cm)	Textural composition				Organic carbon (%)
				Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	
SE.67/4	Rengam	Grass	0 – 15	33.9	17.5	8.4	40.9	1.52
			15 – 30	40.1	15.0	5.5	40.4	0.65
		Fern	0 – 15	42.4	22.1	5.3	30.7	1.45
			15 – 30	38.7	18.0	6.0	38.6	0.95
		Clean cultivation	0 – 15	37.3	22.5	6.4	34.6	1.19
			15 – 30	33.4	17.5	8.3	41.0	0.58
SE.81/1	Serdang/ Munchong Association	Grass	0 – 15	23.2	39.4	5.5	32.9	1.42
			15 – 30	21.1	34.9	5.0	40.9	0.70
		Fern	0 – 15	33.7	40.5	3.9	31.1	1.23
			15 – 30	24.0	36.9	4.2	37.0	0.73
		Clean cultivation	0 – 15	20.5	49.9	4.1	26.9	1.19
			15 – 30	19.5	45.3	3.9	33.0	0.65
SE.87/1	Serdang	Grass	0 – 15	30.5	53.0	4.7	14.0	0.87
			15 – 30	28.6	51.7	5.5	16.1	0.52
		Fern	0 – 15	33.6	40.1	8.9	18.9	1.08
			15 – 30	32.6	38.9	9.0	21.3	0.57
		Clean cultivation	0 – 15	36.2	44.9	5.5	15.3	0.84
			15 – 30	34.2	43.8	6.5	17.8	0.54

total porosity and air-filled porosity values. The beneficial effects of fern were better exhibited at the lower soil depth.

On a sandy soil, like Serdang series, fern had better effect on soil physical properties than grass. The results obtained from *Experiment SE.87/1* clearly indicate this. Those plots with fern cover had higher percentage soil aggregation and larger MWD than grass or clean-cultivated plots. Bulk density was significantly lower and the amount of total and air-filled pores was greater. The physical properties of soil under clean-cultivated plots were very much poorer than those under grass or fern cover.

The results from these three cover experiments show that it is necessary to maintain some form of vegetative cover under mature rubber in order to improve or at least preserve the physical characteristics of the soil. Clean cultivation leads to deterioration of soil structure. The value of grass or fern in improving soil structure depends on the type of soil. Soil, having medium to high clay content, *e.g.* Rengam and Munchong series, seems to perform better under grass than fern, whereas with sandy soil, such as Serdang series, the situation is the reverse. This differential effect could be due to a complex cover-soil growth interaction.

Covers such as ferns and grass are likely to compete with rubber foı water and nutrients. However, it is also likely that their role in improving the physical characteristics of the soil could compensate for the earlier competition and hence this was investigated. The average yield (expressed in grams of dry rubber per tree per tapping) of the rubber trees in the various cover treatments are shown in *Table 6.* In

TABLE 5. EFFECTS OF GRASS, FERN AND CLEAN CULTIVATION ON THE PHYSICAL PROPERTIES OF SOILS UNDER MATURE RUBBER

Experiment (soil type)	Soil depth (cm)	Cover treatment	Aggregation (%)	M W D (cm)	Bulk density (g/cc)	Permeability (cm/h)	Total porosity (%)	Air-filled porosity (%)
SE.67/4 (Rengam series)	0 – 15	Grass	79.0	2.67	1.07	103.4	58.8	29.4
		Fern	76.5	2.54	1.12	56.1	57.1	24.8
		Clean cultivation	83.8	2.52	1.10	72.1	57.7	23.9
	15 – 30	Grass	61.4	0.95	1.12	36.1	57.1	26.2
		Fern	63.4	0.81	1.14	24.6	56.4	28.6
		Clean cultivation	69.3	0.70	1.14	31.8	56.0	22.5
	s.e. between means of covers within depths		1.38	0.106	0.034	3.59		
	L S D (P<0.05)		3.8	0.29	0.10	10.2		
	s.e. between depths		0.80	0.062	0.020	2.08		
	L S D (P<0.05)		2.2	0.17	0.06	5.9		
SE.81/1 (Serdang/ Munchong Association)	0 – 15	Grass	88.5	2.07	1.07	73.4	58.8	28.4
		Fern	84.5	1.76	1.09	60.7	58.9	27.9
		Clean cultivation	90.3	1.80	1.21	17.3	53.6	23.0
	15 – 30	Grass	83.1	1.04	1.19	23.6	55.4	24.6
		Fern	79.2	0.81	1.16	38.6	56.1	26.2
		Clean cultivation	85.5	0.78	1.24	16.3	52.8	23.0
	s.e. between means of covers within depths		0.64	0.087	0.030	3.37		
	L S D (P<0.05)		1.8	0.24	0.09	9.6		
	s.e. between depths		0.37	0.050	0.017	1.95		
	L S D (P<0.05)		1.0	0.14	0.05	5.5		
SE.87/1	0 – 15	Grass	87.8	1.86	1.24	36.6	52.9	20.0
		Fern	88.7	2.11	1.19	25.1	54.6	22.9
		Clean cultivation	85.2	1.83	1.36	6.6	48.1	12.6
	15 – 30	Grass	79.2	0.36	1.33	9.1	49.1	19.3
		Fern	82.0	0.83	1.32	11.2	49.6	20.0
		Clean cultivation	74.6	0.47	1.31	10.4	50.5	20.9
	s.e. between means of covers within depths		1.09	0.106	0.021	1.69		
	L S D (P<0.05)		3.0	0.29	0.06	4.8		
	s.e. between depths		0.63	0.061	0.012	0.98		
	L S D (P<0.05)		1.8	0.17	0.03	2.8		
Over three experiments	0 – 15	Grass	85.1	2.20	1.12	71.1	56.8	25.9
		Fern	83.2	2.14	1.13	47.3	56.7	25.2
		Clean cultivation	86.4	2.05	1.22	32.0	53.1	19.8
	15 – 30	Grass	74.6	0.78	1.21	22.9	53.9	23.4
		Fern	74.9	0.82	1.21	24.8	54.0	24.9
		Clean cultivation	76.5	0.65	1.23	19.5	53.1	22.1
	s.e. between means of covers within depths		0.63	0.058	0.017	1.73		
	L S D (P<0.05)		1.7	0.16	0.05	4.8		
	s.e. between depths		0.36	0.034	0.010	1.00		
	L S D (P<0.05)		1.0	0.09	0.03	2.8		

TABLE 6. EFFECTS OF COVERS ON YIELD IN MATURE RUBBER[a]

Experiment No.	Yield (g/tree/tapping) (From Jan. 1966 to Dec. 1971)		
	Grass	Fern	Clean cultivation
SE.67/4	35.8	35.5	35.8
SE.81/1	47.7	46.0	47.4
SE.87/1	49.1	48.9	46.4

[a]After RUBBER RESEARCH INSTITUTE OF MALAYA, 1972

Experiments SE.67/4 and *SE.81/1* the results indicate ferns to have a slight depressive effect on the yield of the trees. Grass covers gave similar or a slight increase in yield compared to clean cultivation. This means that the soil structure improvement in grass plots had offset the competition for moisture and nutrients.

The beneficial effect of improved soil structure on rubber yield was clearly shown in *Experiment SE.87/1.* Yields were higher in grass and fern plots than in clean-cultivated plots.

Influence of Organic Carbon and Soil Texture on Physical Properties

The results from the six cover experiments show that there were marked differential effects of the several covers on the physical properties of soil. Studies made elsewhere relate such differential effects to the amount of organic matter returned to the soil by the different cover plants, and also the vigour of their root systems (HARRIS *et al.,* 1966). As there were wide variations in the organic carbon content of soils under the various cover treatments (see *Tables 2* and *4*), it would be of interest to establish some relationship between organic carbon content and the various soil parameters measured. Although such a relationship is only valid for this particular study, it can be used to give an overall picture of the effects of different cover plants under other situations on soil. It is also important to include soil texture in this relationship study as it is one of the main factors affecting the genesis of soil structure. Often, crop effects on soil structure have been interpreted without considering the variations in soil texture between soil samples, thereby leading to a misinterpretation of the results obtained. The interactions between the various components of soil texture and organic carbon have a great influence on soil structure formation and degeneration.

Using results from all the six cover experiments, it was found that percentage aggregation was significantly correlated with the percentages of coarse sand, fine sand, clay and organic carbon (see *Table 7).* MWD was significantly correlated with organic carbon only, and not with the various components of soil texture. Bulk density was significantly correlated with the percentages of fine sand, clay and organic carbon. The correlation coefficient between total porosity and organic carbon was also highly significant. From these simple correlation studies it appeared that organic carbon alone could account for a large part of the variations in percentage aggregation (15%), MWD (71%), bulk density (49%), and total porosity (22%). Coarse and fine sand contents were only important in explaining the variations in percentage aggregation but not in the other three parameters. Clay content was important only in bulk density where it accounted for 33% of its variations. However, each soil parameter is rarely influenced by one factor alone. More often than not, a combination of several factors and their interactions with one another influences the soil parameter. The relative importance of each factor could only be determined by comparison of partial linear regression coefficients in a multiple regression analysis.

Table 8 shows the partial regression coefficients of the four soil physical properties on mechanical composition and organic carbon content. Combinations of mechani-

TABLE 7. SIMPLE CORRELATION COEFFICIENTS BETWEEN MECHANICAL COMPOSITION ORGANIC CARBON AND SOIL PHYSICAL PARAMETERS

Soil constituents	Soil physical parameters			
	Aggregation (%)	M W D	Bulk density	Total porosity
Coarse sand	−0.61 ***	−0.08 NS	0.15 NS	−0.20 NS
Fine sand	0.69 ***	−0.04 NS	0.35 *	−0.01 NS
Silt	0.07 NS	0.21 NS	−0.12 NS	−0.29 NS
Clay	−0.33 *	0.07 NS	0.58 ***	0.38 *
Organic carbon	0.39 **	0.84 ***	−0.70 ***	0.47 **

No. of values used for correlation = 42
* – $P<0.05$
** – $P<0.01$
*** – $P<0.001$
NS – not significant

cal composition and organic carbon removed about 86% of the variations in percentage aggregation. The two main factors that had contributed to this successful variance removal were fine sand and organic carbon. Coarse sand content, although found to be significantly related to aggregation in simple linear regression analysis, had a diminished role. With MWD, 73% of the variations were accounted for by mechanical composition and organic carbon, but the latter was the only factor that was important in explaining the variations of MWD (71%).

About 80% of the variations in bulk densities were accounted for by regression on mechanical composition and organic carbon. Clay content was the most important in accounting for these variations and silt content, the least. Organic carbon was ranked third in importance, judged by the normalised partial regression coefficient. Similar relationships were also found with total porosity, although the relative importance of organic carbon is ranked fourth.

Partial regression analyses again confirmed the importance of organic carbon in influencing soil physical properties, especially the sizes of the soil aggregate and bulk densities. In the context of cover crop management, the efficiency of cover plants in improving soil structure therefore depends, among other factors, on the quantity of decomposable organic debris it can add to the soil. The regression analyses also showed that certain mechanical fractions, *e.g.* fine sand and clay of the soil, account for a large part of the variations in the physical parameters. As in the case of bulk densities and total porosities, clay and fine sand had more important influence than organic carbon. Therefore, variations in texture between soil samples have to be taken into consideration when interpreting the effect of covers on soil physical properties.

CONCLUSIONS

Cover plants established within the inter-rows of young rubber have beneficial residual effects on soil structure. They increase:

1. aggregation of the finer soil particles,
2. average size of the soil aggregates,
3. total porosities and
4. permeability of the soil to downward movement of water.

TABLE 8. PARTIAL REGRESSION COEFFICIENTS OF PHYSICAL PARAMETERS ON MECHANICAL COMPOSITION AND ORGANIC CARBON

Soil physical parameters (Y)	Variables	Partial reg. coefficient	S.E. of coefficient	Normalised partial reg. coefficient	t-value	Intercept	R^2
Aggregation (%)	x_1	−0.2770	0.2082	−0.2011	1.33 NS		
	x_2	0.5533	0.1472	0.8745	3.76 ***		
	x_3	0.6138	0.2254	0.2358	0.72 NS	51.6964	0.86
	x_4	0.1410	0.1880	0.1516	0.75 NS		
	x_5	11.0055	1.5597	0.4450	7.06 ***		
M W D	x_1	0.0072	0.0303	0.0506	0.24 NS		
	x_2	0.0110	0.0214	0.1829	0.56 NS		
	x_3	0.0372	0.0328	0.1380	1.13 NS	−1.3589	0.73
	x_4	0.0044	0.0274	0.0452	0.16 NS		
	x_5	2.1546	0.2273	0.8406	9.48 ***		
Bulk density	x_1	−0.0061	0.0027	−0.4335	2.25 *		
	x_2	−0.0052	0.0019	−0.8143	2.75 **		
	x_3	−0.0018	0.0029	−0.0669	0.61 NS	2.0504	0.78
	x_4	−0.0110	0.0024	−1.1679	4.54 ***		
	x_5	−0.1591	0.0202	−0.6331	7.88 ***		
Total porosity	x_1	0.4148	0.1255	0.7063	3.31 **		
	x_2	0.4140	0.0887	1.5352	4.67 ***		
	x_3	−0.1477	0.1359	−0.1331	1.09 NS	3.7202	0.73
	x_4	0.6575	0.1133	1.6586	5.80 ***		
	x_5	4.8775	0.9401	0.4628	5.19 ***		

x_1 = % coarse sand
x_2 = % fine sand
x_3 = % silt
x_4 = % clay
x_5 = % organic carbon

* = $P<0.05$
** = $P<0.01$
*** = $P<0.001$
NS = not significant

They are also effective in lowering bulk densities, thereby reducing the mechanical impedence of soils to root movement and growth. Of the various types of cover plants tested, creeping legumes had, in general, a better residual effect on soil structure than grass, natural or *Mikania* cover. The poorest residual effects were found in plots having *Mikania* cover. This was attributed to its low dry matter production, resulting in a low return of organic matter to the soil. Interactions between cover treatments and soil depths were found to be significant.

Shade-tolerant cover plants, *e.g.* grasses and ferns, established under mature rubber, improve or, at least, prevent deterioration of soil structure. Preventing the growth of vegetation in the interrows by regular chemical spraying destroys soil structure. The efficiency of grass and fern covers in improving soil structure depends on the type of soil. On a heavy or moderately heavy textured soil, grass covers perform better, whereas on a light textured soil fern covers are superior.

Simple and partial linear regression analyses of the results from the six cover experiments show that organic carbon content removes a great deal of the variations in the four soil physical parameters used to describe soil structure. This proves that the efficiency of cover plants in improving soil structure is primarily related to the amount of decomposable organic matter they return to the soil. The mechanical composition of the soil also accounts for some of the variations in the soil parameters which indicate that textural differences between soil samples have to be taken into consideration when interpreting the effect of covers on soil structure.

ACKNOWLEDGEMENT

The authors wish to thank Encik E. Pushparajah, Head of Soils Division, and Encik G.C. Iyer, Head of Statistics Section, for their comments on this paper. Grateful thanks are made to Encik-Encik K. Ratnasingam and Foo Jee Wang for analysis of soil samples; Encik S. Balasingam for collection of soil samples and Puan Shirley Tan for programming assistance.

Rubber Research Institute of Malaysia
Kuala Lumpur *August 1973*

REFERENCES

BAVER, L.D. (1956) *Soil Physics.* 3rd Edition. New York: John Wiley & Sons.

BOWER, C.A. AND PETERSON, R.K. (1950) Technique for determining the permeability of soil cores obtained with the Lutz samples. *Agron. Journ.*, **42**, 55.

HARRIS, R.F., CHESTERS, G. AND ALLEN, O.N. (1966) Dynamics of soil aggregation. *Adv. Agron.*, **18**, 107.

LOW, A.J. (1954) The study of soil structure in the field and the laboratory. *J. Soil Sci.*, **5**, 57.

LUTZ, J.F. (1947) Apparatus for collecting undisturbed soil samples. *Soil Sci.*, **64**, 399.

MAINSTONE, B.J. (1963) Residual effects of type of ground-cover and duration of nitrogenous fertiliser treatments applied before tapping on growth and yield of *Hevea brasiliensis. Plrs' Bull. Rubb. Res. Inst. Malaya No. 68*, 130.

MAINSTONE, B.J. (1969) Residual effects of ground-cover and nitrogen fertilisation on *Hevea. J. Rubb. Res. Inst. Malaya*, **21(2)**, 113.

PUSHPARAJAH, E. AND CHELLAPAH, K. (1969) Manuring of rubber in relation to covers. *J. Rubb. Res. Inst. Malaya*, **21(2)**, 126.

RUBBER RESEARCH INSTITUTE OF MALAYA (1973) Rep. Rubb. Inst. Malaya 1972.

RUSSELL, M.B. (1949) Methods of measuring soil structure and aeration. *Soil Sci.*, **68**, 29.

SOONG, N.K. (1971) A study of the root distribution of *Hevea brasiliensis* in relation to its nutrition and growth on some typical Malayan soils. Thesis submitted for the degree of M.Agr. Sc., University of Malaya.

VAN BAVEL, C.H.M. (1949) Mean weight diameter of soil aggregation as a statistical index of aggregation. *Proc. Soil Sci. Soc. Amer.*, **14**, 20.

WATSON, G.A. (1961) Cover plants and the soil nutrient cycle in *Hevea* cultivation. *Proc. nat. Rubb. Res. Conf. Kuala Lumpur 1960*, 352

WATSON, G A. (1963) Cover plants and tree growth, Part I. The effect of leguminous and non-leguminous cover plants on the period of immaturity. *Plrs' Bull. Rubb. Res. Inst. Malaya No. 68*, 123.

WATSON, G.A., WONG PHUI WENG AND NARAYANAN, R. (1964) Effects of cover plants on soil nutrient status and on growth of *Hevea* III. A comparison of leguminous creepers with grasses and *Mikania cordata. J. Rubb. Res. Inst. Malaya*, **18(2)**, 80.

WONG, P. W. (1964) Evidence for the presence of growth inhibitory substances in Mikania cordata (Burm. F.) B.L. Robinson. *J. Rubb. Res. Inst. Malaya*, **18**, 231.