# *Cover Plants in Rubber Cultivation*

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*A review is given of the literature concerning the probable effects of cover plants on tree growth and soil conditions in relation to rubber cultivation. Particular attention is paid to the cultivation of leguminous creepers and to the comparative effects of leguminous and non-leguminous cover plants.*

THE USE OF PERMANENT COVER PLANTS interplanted with the main crop is common practice in tropical plantations, their presence serving to protect the crop and soil from the more extreme climatic conditions. In tea and coffee plantations shade trees are provided to protect the plants from excessive heat, and in oil palm, rubber, coffee, tea, and sisal plantations a ground cover of creeping plants or upright shrubs is maintained to protect the soil from insolation and erosion effects. With some of the richer tropical soils a catch crop can be used as the ground cover; for instance, gambier, tapioca, bananas, hemp, and pineapples have been planted at times in rubber plantations (ALLEN 1955), but this is now exceptional and the practice is mainly restricted to smallholdings.

Much investigation into the cultivation of cover plants in rubber plantations has been carried out in the former Dutch East Indies territories of Java and Sumatra, and for a review of the agronomical aspects of this work the reader is referred to M. J. Dijkman's book *Hevea**. The present text refers more particularly to such cultivation under Malayan conditions.

The policy of growing cover plants in conjunction with rubber has not always been in favour in Malaya. The early planters found that young rubber trees grew best in the absence of competition from other plants and so a clean weeding system developed in which the ground surface in rubber plantations was maintained completely bare of all weeds. Soil erosion became a serious problem and was countered by the use of elaborate silt pit systems designed to check the wholesale loss of top soil. This method had its limitations however and, partly due to the economic depression of the late 1920s when the maintenance of clean weeded areas became too expensive, the value of growing a cover plant together with rubber became recognised.

Two main practices have since developed, one making use of indigenous plants as the cover, the other involving the maintenance of specially sown leguminous creepers or shrubs for at least the first few years in the life of a plantation.

The first practice took its most extreme form in the 'forestry' system of planting as advocated by a practical forester F. Birkemose. This system (R.R.I.M. 1932) was based on the belief that a system of cultivation which allows the natural environment of the rubber tree to develop should be of maximum advantage to its growth. Accordingly as the rubber tree is a plant of the tropical rain forest, it was thought that the young rubber seedlings which spring up in plantations should be allowed to develop and after selective thinning to eliminate low yielders they should be used to replace the older trees as those passed out of tapping. In some cases the young seedlings were to be budded with selected material so as to raise the general standard of the plantation. Other plants growing in association with the rubber were either selectively eliminated on the basis of their supposed effects on soil acidity, on their rooting characteristics or on their degree of woodiness, or alternatively slashed to provide a general ground cover.

* See bibliography, page 17.

This system attracted some attention (VAN HEUSDEN 1932, ROELOFFS, 1936, EATON, 1935) but because of the great difficulty experienced in bringing self sown seedlings to tappable size it was not adopted in practice. However, the value of Birkemose's system, in allowing the development of a cover of indigenous shade-tolerant plant species in rubber plantations, was recognised, and the term forestry is still applied to the system which permits the development of natural covers as discussed in W. B. Haines' revised edition of *The Uses and Control of Natural Undergrowth on Rubber Estates* between the rubber tree rows. In some cases such growth consists mainly of creeping plants and small shrubs, but at times quite heavy bush growth develops; both are controlled by periodical slashing and selective thinning.

The second main practice is the use of creeping legumes as cover plants. Such cover plants are expensive to establish and to maintain and much controversy centres on the advantages to be gained by undertaking their cultivation in preference to retaining and encouraging non-leguminous indigenous cover plants.

It must not be assumed from the foregoing that a simple choice exists between establishing on the one hand a cover of indigenous creepers and shrubs, and on the other hand a cover of specially sown leguminous creepers or shrubs. There are many factors that can affect the issue; regeneration of indigenous covers will be more vigorous in new clearings from jungle and in a 'no burn' clearing than in a 'burn' clearing, and in replanted areas will be more vigorous and composed of more varied species when the clearing is near a jungle site than where it is surrounded by rubber plantations or other cultivated land. On the economic side the selective weeding carried out in a cover of indigenous plants may initially be more expensive than that carried out in a sown cover of leguminous creepers, but as these creepers tend to be succeeded by troublesome grasses as the shade of the maturing rubber trees develops, eventual weeding costs may be more for the leguminous cover plant. The succession of plants in both types of covers may be markedly affected by soil type, and the soil nutrient and moisture status, and whereas over the years on one site a cover of indigenous plants may show advantages over a cover of leguminous plants, the reverse may be true on another site. The choice of the cover plant system to be adopted may be influenced largely by such practical points as are outlined above, but in order to understand some of the more fundamental factors affecting the performance of the two broad classes of cover plants the relevant practical and experimental observations on the subject are reviewed.

The respective merits of the different cover plant systems are of main concern during the initial years in the life of a plantation, perhaps up to the time of commencement of tapping. At this stage the increased shade under the trees will increasingly restrict all but the most shade tolerant of plants and soil protection becomes mainly dependent upon the litter of fallen rubber leaves. Exceptions occur, depending on climate and soil conditions, and constitute special cases which will be discussed.

As an introduction to the use of cover plants brief consideration will be given to the two types of planting; planting in a recently cleared jungle area (new planting) and planting in a former rubber growing area (replanting).

## NEW PLANTING

The sequence of soil degradation likely to follow the clearing of virgin jungle in tropical countries has often been stated and only a recapitulation need be given here. In Malaya, a large proportion of soils are highly leached and possess low nutrient and organic matter reserves. Under jungle the closed canopy maintains cool, moist, soil conditions and with the constant circulation of mineral nutrients and organic matter effected by the abundant and varied plant growth a stable, reasonably fertile condition exists. However, when the jungle is cleared the cycle is broken and insolation and leaching increase to such an extent that reserves of fertility may be quickly exhausted. The rate of deterioration will vary widely depending on the soil type and topography and it is essential that some protection be afforded to the soil as soon as possible after clearing. In most jungle clearings all valuable timber is extracted and the remaining logs are roughly stacked in heaps for burning or are piled between the rubber tree planting rows and are allowed to rot down. The remains of these logs and stumps provide some protection to the soil immediately beneath them and seedlings of indigenous creepers and upright growths quickly appear. In addition planters often sow leguminous cover plants immediately after clearing, particularly where a burn has been carried out which may check the development of indigenous plants, and the two types of cover plants quickly produce a vigorous and luxuriant ground cover which affords ample protection to the soil. The luxuriant growth of the cover stems from the reserves of fertility left in the soil by the original jungle flora.

## REPLANTING

Old rubber plantations, originally planted in cleared jungle, will have had little or no fertiliser applications for many years and the reserves of fertility will be near exhaustion except on the very best soils. If the old rubber wood is not removed but burnt or allowed to rot in situ certain amounts of nutrient and organic matter will be returned to the soil (AKHURST 1939, DYCK 1939) and its immediate fertility will be slightly enhanced thereby. However, the rapid establishment of cover plants on such impoverished soils is imperative so that protection can be afforded against erosion and the organic matter status of the soil can be built up again. Few seeds are found in the surface soil in such areas, especially after periods of clean weeding under which system many of the old rubber areas were originally maintained, but there may be sufficient to regenerate and form a useful cover after the shading effect of the old trees is removed; in general, however, fresh sowings of legume seeds need to be carried out. On poor soils difficulty is sometimes encountered in the establishment of the cover plant and it may be some six months or more before a satisfactory cover is obtained.

## ESTABLISHMENT AND MAINTENANCE OF COVER PLANTS

Indigenous covers are generally of spontaneous development but when required they can be introduced by seeding or by the use of cuttings The only maintenance they receive under normal estate practice is that of regular slashing and selective weeding, carried out in order to encourage growth of the softer tissued plants and to keep out unwanted grasses and other plants. Leguminous cover plants on the other hand generally require to be specially sown, although sometimes a good leguminous cover can regenerate from dormant seed in the ground. The seed is preferably pretreated (R.R.I.M., 1954) and inoculated with nodule bacteria and is often sown together with a phosphate dressing. Once established the creeping leguminous cover plants will usually smother other plants and during their period of maximum vigour, the first three years, can generally be maintained by broadcast applications of rock phosphate and some selective weeding.

The cultivation of cover plants in association with the rubber trees involves a number of problems In the first year after planting the young rubber trees are generally grown along clean weeded strips some four to six feet wide. In between the tree rows vigorous cover plants develop which may offer serious competition for the reserve of soil moisture, and on freely draining sandy soils drought conditions may result in the planting row. A depressive effect of leguminous cover plants on the growth of rubber trees at this stage has been reported (HAINES 1932, 1933). It cannot easily be countered by slashing or spraying to restrict the growth of the cover plants for such operations at this stage might check the cover and permit invasion by undesirable species. In general, however, the maintenance of clean weeded areas around the rubber plants, the encouragement of vigorous growth by the regular application of fertilisers, and the use of mulching practices, will ensure satisfactory growth of the rubber. Where these measures are omitted the competition offered by the cover plants may become serious.

After the first year of growth the rubber tree roots spread into the inter-row areas occupied by the cover plants. By this time creeping cover plants, if well maintained, should show a continuous mat of growth, perhaps standing two to three feet high and completely covering all logs and other decaying debris in the area. Under this mass of vegetation a layer of decomposing leaf and stem litter will have developed and cool, moist top soil conditions will exist. Rubber roots ramify easily through the upper soil and organic matter layers and the beneficial conditions contrast sharply with inter-row areas where vigorous grasses and hard woody shrubs have been allowed to develop.

As the rubber trees grow and the leaf canopies develop, the increasing shade depresses growth of the cover plants and, if a leguminous cover plant has been established, increasing difficulty is found in maintaining its purity. Indigenous plants that are more shade tolerant than the legumes are favoured by these conditions and grasses may become established. The maintenance of purity of a stand of leguminous cover plants by selective weeding becomes more expensive and in the great majority of cases the cover plants die out and a sparse stand of a few shrub species and a thin covering of grasses remain. Where the rubber develops a very heavy canopy even the few remaining cover plants may be shaded out leaving the bare soil protected only by decaying rubber leaf litter. These conditions are not fully satisfactory for during the subsequent life of the plantation, which may be thirty years or more, it is possible for marked soil deterioration to occur. On some of the freely draining sandy soils, which have supported reasonable growth in one generation of rubber trees, difficulty can be experienced in establishing replantings. It appears that in addition to physical effects such as surface soil wash occurring on hilly sites, nutrients tend to be leached out of the upper soil layers in the mature rubber plantation on these soils. There is too little evidence to say in what degree the deterioration is due to the absence of covers or to other factors, and in what way the condition can be remedied, but the subject seems worthy of further investigation.

The preference for leguminous cover plants shown in most estate policies during the early years of the life of a plantation is guided by recommendations based on general field experience and by inferences drawn from experimental work on leguminous plants mainly done in temperate climates and only to a lesser extent in the tropics. Until conclusive results are obtained from experiments carried out in Malaya the advantages of leguminous over non-leguminous cover plants will continue to be the subject of controversy. Field observations on estates are often of little value for rarely can direct comparisons of the two systems be found on adjacent areas. Planters have conflicting views on the subject; those who are not impressed by the advantages claimed for legumes suggest that rather than incur the expense of establishing and maintaining leguminous cover plants, indigenous creepers and shrubs should be allowed to develop naturally, and that selective elimination of certain recognised undesirable species should be carried out. It is argued that if a plant is naturally fitted to a particular ecological association it will maintain as good a growth as an imported legume plant and be much less expensive to establish and maintain.

This is reasonable and the hypothesis receives considerable support particularly in areas where leguminous cover plants can be established only with difficulty. Planters who favour leguminous cover plants argue that few plants can produce such a satisfactory cover so quickly and that in addition the legumes may add nitrogen to the soil. As Malayan soils are often low in nitrogen the latter is an important point.

A cover of creeping legumes may be several times more expensive to establish and maintain than a cover of mixed indigenous shrubs and definite advantages must be offered by the leguminous cover plants before this difference can be ignored. In the following sections the comparative effects of the two types of cover plants upon the soil and upon the growth of the tree are discussed in an attempt to assess the position.

### EFFECT OF COVER PLANTS ON THE ORGANIC MATTER CONTENT AND STRUCTURE OF SOILS

Many Malayan soils, particularly those that have carried one generation of rubber trees and are due for replanting, have low reserves of plant nutrients and organic matter and are of poor structure. As a result of their low permeability to rainfall such soils are susceptible to drought and erosion, and cover plants are used in an effort to re-establish satisfactory soil conditions.

Cover plants, by protecting the soil surface against compaction by heavy rain and by virtue of the binding affects of their roots on soil particles, safeguard and improve soil structure. The organic matter that they add to the soil as dead leaf, stem, and root material, also plays a very large part in the improvement of soil conditions by a summation of chemical, physical, and biological effects (BREMNER 1956, CORNFIELD 1955, DULEY 1952).

Most plants could be expected to improve soil structure but wide variations in their individual effect are found, as dicussed by W. B. Haines in *The Uses and Control of Natural Undergrowth on Rubber Estates*. With a few exceptions most grasses do not greatly improve the soil under rubber planting conditions. Their mat of surface roots competes strongly for available moisture and the hard dry conditions observed under grass do not encourage free surface rooting by the rubber tree (VAN HEUSDEN 1934). Grasses can check soil erosion (SMITH & ABRUNA 1955) but there is little else to recommend them in rubber plantations (VAN DER VEEN 1935).

Creeping cover plants on the other hand, leguminous or otherwise, exert a marked beneficial effect upon soil structure. No detailed figures are available but observation seems to show that such cover plants return much more organic matter to the soil as dead leaf and stem material than do the grasses. In addition the dead material has a higher nutrient concentration than does that of the grasses. The dense growth of a vigorous, creeping cover plant ensures cool and moist conditions at the soil surface, and a loose, permeable, top soil layer, with a high organic matter content, develops. Soil erosion under such a cover is low.

Under forestry methods of cover plant control, upright woody plants often develop and their use is sometimes recommended on compacted soils where their strong rooting characteristics help to break up and aerate the soil. Such cover plants are controlled by periodical lopping and considerable amounts of material, perhaps up to 20 tons per acre, can be returned to the soil in this way. The litter of fallen stems, leaves, and loppings, protects the soil against heavy rain but erosion control is not likely to be so good as under a creeping cover plant (HAINES 1932).

The above comments are based mainly on practical observations as little experimental evidence is available on the effect of cover plants on soil structure under conditions such as exist in Malaya.

## EFFECT OF COVER PLANTS ON SOIL NUTRIENT STATUS

In the first year of growth in a rubber plantation, clean weeded or mulched areas are maintained in the immediate vicinity of the tree and there is little competition beween the nutritional demands of the tree and those of the cover plant. As the tree grows, however, its root system spreads into the inter-row area under the cover plant and it seems likely that competition for the available nutrient supply will develop, particularly as the greater proportion of both root systems exists in the top twelve inches of soil. Such competition need not necessarily be harmful over a long term period, as the nutrients taken up by the cover plant, and rendered unavailable to the rubber tree in the first instance are eventually returned to the soil in dead plant material and will again become available for uptake by either the rubber tree roots or cover plant roots. Such action will minimise the leaching of nutrients and, by conversion of mineral nutrients in the soil into components of decaying plant material, their eventual availability to the rubber tree may be actually increased (DE GEUS 1941). This may be particularly so in the case of phosphate (FULLER et alii 1956) which can be very rapidly fixed by certain Malayan soils. The suggestion receives particular support from the fact that rubber roots spread freely through the litter layer underneath a cover plant; decaying leaves, stems, and woody material are all penetrated by the roots and the direct uptake of nutrients from this litter seems possible. This effect may have major implications in fertiliser practice. The levels of fertiliser at present applied to immature rubber plantations are based on experiments using current estate methods of cultivation, that is, the system of applying fertilisers in the main to the clean weeded planting rows, either broadcast or applied in pockets. Few experiments have been carried out applying fertilisers broadcast on the cover plants with the intention of encouraging vigorous growth of these plants. If such a system were used the increased amounts of dead plant material returned to the soil surface might have a marked effect on rubber tree growth. It may be reasoned that frequent application of fertilisers to the clean weeded planting rows is a more direct and efficient method of supplying nutrients to the rubber tree, but as the use of cover plants is essential for protection of the soil there may be advantages in deliberately applying the fertilisers to the cover plants.

A new approach to the problems of plant competition for soil nutrients is suggested by recent work on the cation exchange capacity of plant roots (MEHLICH & DRAKE 1955). Theory suggests that plant roots have differing specific absorptive capacities for mineral nutrients in the soil and an electrometric titration method can be used to determine these capacities. As a result of these differences, intensive competition for soil nutrients can exist between the roots of grasses and those of legumes (GRAY et alii 1953); so intense was this competition between bentgrass (*Agrostis palustris*) and Ladino clover that it was found impossible with practicable rates of application of potassium fertilisers to supply the full potassium requirement of the clover when grown in association with the bentgrass. This approach may be applied to problems of rubber cultivation. Thus it has been suggested on the evidence of chemical analysis that *Mikania scandens* has a high potassium requirement; investigation of the cation exchange capacity of its roots might show whether nutrient competition is the cause of its suggested ill effects on rubber or whether some other factor is involved.

## EFFECT OF COVER PLANTS ON SOIL NITROGEN

Cover plants can affect the soil nitrogen status by:

*a* interference with nitrification processes in the soil;

*b* the symbiotic fixation of nitrogen from the soil air by bacteria of the genus *Rhizobium* found in the root nodules of leguminous plants.

In addition to (*a*) and (*b*), cover plants can modify the soil nitrogen status by absorbing nitrogen from the soil, hence minimising the loss of soil nitrate by leaching This function has been discussed in the previous section.

*Interference with Nitrification Processes in the Soil*

Nitrification of organic matter in tropical soils can be very rapid and in dry seasons a considerable accumulation of nitrate occurs (AP GRIFFITH & MANNING 1949). Nitrate may be produced from organic residues such as dead leaf, stem, and root material by bacterial and possibly photochemical processes, or it may appear as the end product of the nitrogen fixing activities of *Azotobacter* and, perhaps, the blue green algae (MEIKLEJOHN 1955).

Some tropical grasses and plants are said to be able to suppress nitrification; in Uganda soils on which elephant grass (*Pennisetum purpureum*) and *Paspalum* spp were growing little nitrate could be detected in the top six feet (MILLS 1953). After the grass was cleared, nitrification began quite quickly in the soil that had grown elephant grass but the soil formerly under *Paspalum* took much longer to recover its nitrifying properties, and maize grown on it shortly after clearance gave a very poor yield (MEIKLEJOHN 1955). The existence of such differences is confirmed in some studies of poor nitrification in orchard soils under permanent grass which have shown that water extracts of the roots of *Panicum maximum* inhibit nitrification whereas extracts of *Sporobolus pyramidalos* do not (MARLOTH 1956). The slow decomposition of dead material and sterility of the soil under lalang (*Imperata arundinacea*) and other grasses may be due to this effect.

If nitrification of litter mixed with the top soil layer is suppressed by the presence of certain plant roots, it must be presumed that the rubber roots take up some nitrogen as ammonium or amino radicals. In this connection it is interesting to note the finding (BOLLE-JONES 1955) that rubber plants can tolerate high levels of ammonium ions and will respond rather better, in some respects, to the supply of this ion than to that of the nitrate ion.

*Nitrogen Fixation by Legumes*

Nitrogen fixation by leguminous plants is an established fact in temperate climates and has also been qualitatively demonstrated in pot experiments in Malaya (HAMILTON & PILLAY 1941). In New Zealand it has been found that under good conditions clover may fix about six hundred pounds per acre of nitrogen per year, and that the nitrogen needed for high production pastures is derived almost entirely from clover present in the pasture (WALKER 1956). Six hundred pounds per acre of nitrogen is more than sufficient to meet the nitrogen requirements of the rubber tree, and even assuming that considerable leaching losses occur it would seem that tropical legume plants of a similar nitrogen fixing capacity to the clovers could make a useful contribution to soil nitrogen in rubber plantations.

In the Annual Report of the Rubber Research Institute of Malaya for 1939 it is noted that inoculated *Centrosema pubescens* plants were found to contain the equivalent of 1185 lb of ammonium sulphate per acre after four months' growth in sand culture with no added nitrogen fertiliser In the Annual Report for 1952 comparisons of bare soil plots and plots covered with leguminous creeper are reported which showed that soil in the latter contained more nitrogen, the equivalent of one ton of ammonium suplhate per acre, than the former. This latter comparison makes no allowance for variations in soil nitrogen content caused by the cover plants' effect upon nitrification and leaching of nitrates, but it seems likely from these two experiments that major levels of nitrogen fixation are involved. If the findings can be confirmed strong arguments will be offered in favour of the cultivation of leguminous cover plants in rubber estates.

The low soil pH of many tropical soils has been suggested as a factor that might limit nitrogen fixation by legumes, but it has been reported (REGAL & STRAFELDA 1955) that legumes do not show any impairment of vigour or nodulation on natural sites with pH values as low as 4. Beneficial effects due to liming in their experiments are attributed to improved decomposition of organic matter rather than to an increase of pH value. Other investigations show that calcium plays an important part in legume nutrition (ALBRECHT 1933, BROWN & MUNSELL 1942), and that the concentration of available calcium needs to be relatively high to sustain an active population of the root nodule bacteria (McCALLA 1937). It would be expected that legumes and associated *Rhizobia* indigenous to the tropics would have lower calcium requirements than would leguminous plants from the lightly leached more calcareous soils of temperate climates. More recent work (HARSTON & ALBRECHT 1942) suggests that soil acidity is not detrimental, but rather beneficial to nitrogen fixation by the legume. Proper nutrient supply is found to be a more important factor than the soil acidity in ensuring satisfactory nitrogen fixation.

The provision of a satisfactory soil nutrient status for optimum nitrogen fixation by leguminous plants is by no means certain with Malayan soils. On the coastal clay type of soil generally satisfactory nutritional conditions exist, but on some of the extensive areas of sandy and lateritic soil it is possible that certain important nutrients will be at deficient levels.

Calcium is important in legume nutrition and is at a low level in many Malayan sandy and lateritic soils. Magnesium seems to play a closely analogous role to that of calcium and is known to be deficient in many soils, but potassium is only rarely deficient. Phosphorus plays a most important part in legume nutrition; it is closely connected with the metabolism of symbiotically fixed nitrogen and also greatly influences the numbers and motility of the flagellated *Rhizobia* in the soil (THORNTON & GANGULEE 1926). In most Malayan soils phosphorus is at a low level and applied phosphate is rapidly fixed, while practical experience has shown that regular dusting of the cover crop with a phosphate fertiliser is most beneficial.

Of the minor elements, molybdenum, zinc, sulphur, and copper are important in legume nutrition (ANDERSON & MOYE 1952, MULDER 1950, JENSEN 1949) and all can be expected to occur at limiting deficiency levels under certain Malayan soil conditions (GREENE 1954). Molybdenum and zinc may be segregated in relatively unavailable form together with iron in the formation of lateritic soils (PRESCOTT & PENDLETON 1952); a response by leguminous cover plants to applications of these two elements on Malayan soils has been reported (FLINT 1930, SANDISON & HANLEY 1954).

Australian work suggests (WALKER 1955) that sulphur deficiency may be widespread in areas growing tropical legumes. No information is available concerning such an effect in Malaya but since under conditions of moderate to high rainfall soil sulphur is retained chiefly in the organic matter fraction (DURING 1955) the more sandy soils, low in organic matter, are likely to contain low levels of this element.

In some of the leached siliceous sands of Australia, zinc and copper deficiencies are found associated (RICEMAN 1949, ROSSITER 1951) but little information is available on the copper status of Malayan soils.

Nitrogen fixation by leguminous cover plants is not assured merely by providing the correct nutritional conditions. The fixation depends upon the symbiotic association of root nodule bacteria with the legume, the plant leaves supplying carbohydrate and the bacteria supplying nitrogen. Infection of the legume roots by nodule bacteria in the soil results in the rapid division of cortical root cells and characteristic nodules are formed (RUSSELL 1950a). Within these nodules a process of development and decay of both host and bacterial cells proceeds, the bacteria exhibiting several different forms (THORNTON 1954). The actual nitrogen fixation process is associated with the development of haemoglobin and methaemoglobin pigments together with a third green pigment containing iron, related to bile pigments formed from haemoglobin in animals, but the actual function of these pigments remains unexplained (VIRTANEN & LAINE 1946, KEILIN & SMITH 1947).

In an active nodule, elaborated compounds containing nitrogen fixed from the soil air are either excreted into the soil or are taken up by the plant tissues. It has been found in some experiments that as much as 60 to 70% of the nitrogen gained by fixation is excreted (WYSS & WILSON 1941) whilst in soya beans there is a continuous transfer of nitrogen from the nodules into the plant, most of the fixed nitrogen passing from the bacteria without appreciable delay (BOND 1936). The quantity in which nitrogen is fixed, and its eventual fate, is intimately connected with the growth rate of the plant. Satisfactory plant growth demands the maintenance of an optimum carbohydrate/nitrogen balance in the sap, so that, under normal conditions of photosynthesis where the carbohydrate supply to the plant roots and nodules is assured, an effective symbiotic association will permit the fixation of nitrogen at a rate which maintains the carbohydrate/nitrogen balance. If photosynthesis increases, carbohydrate supply is increased and the nitrogen demand is raised accordingly; if carbohydrate falls to a low level, or alternately if extraneous sources of nitrogen are freely available, the carbon/nitrogen ratio decreases and the rate of fixation is depressed until it may cease entirely. The operation of this balance may largely direct the fate of fixed nitrogen. Under cool climatic conditions excretion of fixed nitrogen has been found particularly as aspartic acid and alanine (VIRTANEN & LAINE 1939, THORNTON 1954) and it is possible that this is the result of low photosynthetic activity, causing an unbalanced carbon/nitrogen ratio. With the high temperatures and long hours of sunshine of the tropics the carbon/nitrogen ratio is thought to remain sufficiently high to preclude possibilities of significant excretion of nitrogenous compounds (WHYTE et alii 1953). If this is so, fixed nitrogen can only become available to plants growing in association with the legumes after the mineralisation of the dead leaf, stem and root material returned to the soil.

This last suggestion leads to consideration of the possibility of taking advantage of the nitrogen fixing properties of the legumes by ploughing them in as green manures. Such cultivation has been proposed or carried out at various times according to the Reports of the Rubber Research Institute of Malaya (1930, 1939, 1941-5, also WILSHAW 1934) but as this text is primarily concerned with the long term association of semi-permanent cover plants with rubber, a discussion of the comparative values of legumes and non-legumes as green manures cannot be undertaken. It should be borne in mind however that the ploughing in of cover plants introduces a number of problems regarding plant succession, apart from the immediate effects on soil conditions.

A point of incidental interest to the subject of excretion of nitrogenous compounds is that under certain conditions a non-legume (wheat) has been shown to excrete a variety of such compounds (TESAR & KUTACEK 1955, KATZNELSON et alii 1955).

The question of nodulation and subsequent nitrogen fixation is not a simple one. Approximately 90% of legumes are capable of forming nodules (ALLEN & ALLEN 1950, ALLEN & BALDWIN 1954) but even a legume species capable of nodulation cannot form nodules unless the right strain of *Rhizobium* is present (MEIKLEJOHN 1955). The genus *Rhizobium* has been divided into several 'species.' Each species is characterised by its capacity to form nodules on a given group of legumes (FRED et alii 1932). There are for example clover, lucerne, and pea *Rhizobia* each forming nodules on a few legume species. The rigidity of such a classification is questioned however as bacteria have been found that can effectively nodulate legumes from different groups (WILSON 1944, THORNTON 1954). If a legume cover plant is indigenous, or established in the country for many years, a satisfactory strain of *Rhizobium* will nearly always be present in the soil; however a newly introduced legume requires to have its seed inoculated with a suitable strain of *Rhizobium* if good growth is to be depended upon. Furthermore strains of *Rhizobium* even within one of the main groups vary a great deal in the effectiveness with which they operate in the nitrogen fixing process (THORNTON 1954). Leguminous weeds in the tropics often belong to genera which contain nodule forming species, but it is not known if the weeds bear nodules nor, if they do, whether the nodules contain effective bacteria (MEIKLEJOHN 1955). If a legume were newly introduced and grown without prior seed inoculation, it would be possible for the plant to be infected with inefficient bacteria from the local leguminous weeds. In such a case the roots of the new legumes might possess many nodules but the plant would add nothing to the nitrogen supply of the soil and a potentially valuable species might be dismissed as useless.

Even if legume seeds are inoculated with an effective strain of *Rhizobium* the cultivated strains must compete after sowing with the wild strains which exist in the soil. Strains of *Rhizobium* appear to differ greatly in their ability to infect the plant roots and even though the inoculated bacteria may be advantageously placed their numbers are often small compared with the number of wild *Rhizobium* strains present in the soil (WILSON 1926) and complete infection with the desired strain cannot be guaranteed (THORNTON 1954). In this connection inoculation of the soil with an effective strain has been reported to be more effective than inoculation of the seed (MARLOTH 1956).

Inoculation processes, which involve pre-soaking of the seed, make the seed sensitive to dry soil conditions and many planters do not bother to inoculate their seed. How far subsequent disappointing growth can be ascribed to this omission could only be answered by detailed study of the nodules found on the resulting legume roots.

## EFFECT OF COVER PLANTS ON SOIL MOISTURE

Despite the fact that Malaya has an annual rainfall of some 100 inches with no pronounced wet and dry seasons, soil moisture content can sometimes fall to growth limiting levels and water conservation is an important requirement, particularly on the more coarsely textured soils. This is due in large measure to the fact that most of the rain falls in heavy showers or thunderstorms and surface run-off on bare soils can be serious. With the provision of a cover such run-off can be much reduced but the extra losses of moisture caused by transpiration losses through the foliage of cover plants can, in turn, be appreciable. Some experiments in Malaya have shown that young plantings of *Centrosema pubescens* and *Mikania scandens* did not significantly reduce the soil moisture content to levels below those found under a bare surface (BELGRAVE 1930). In Ceylon, however, a comparison of the moisture content of soil under a clean weeded surface and under a cover of the creeping legume *Centrosema pubescens* showed that for the first two years after establishment of the cover there was more moisture in the first six inches of soil under the cover than in the corresponding region of the bare soil, but that the reverse was true for soil below a depth of six inches (JOACHIM et alii 1927, 1930). The greatest total moisture in the top eighteen inches was found under the bare soil. It was evident that more moisture was lost by transpiration from the cover plant than was conserved by the surface mulch it produced. However during the second two years of the experiment the mulch under the cover plant developed to such an extent that eventually more moisture was found at all levels down to twentyfour inches under the cover plant, than under the bare surface. These findings have been confirmed (Prillwitz 1930, Simons 1955). The continued use of a non-mowing system of cultivation in grassed down orchards was found to have a cumulative retentive effect on the available soil moisture due to the addition of mulching materials and increase in organic matter content of the soil (Simons 1955).

In newly planted rubber plantations it would seem therefore that the top soil in the planting row will tend to be dry and that the reserves of water in the subsoil are likely to suffer depletion by lateral diffusion into the drying subsoil under the inter-row covered area. Both factors will contribute to drought susceptibility of the planting row and are strong arguments in favour of mulching being carried out around the young rubber trees. After the first year or two of growth, rubber roots spreading under the cover plants will be able to take full advantage of the water conserving properties of the mature cover and its litter mulch.

There is little information on the respective transpiration capacities of different cover plants. The transpiration from an actively growing crop is primarily dependent on meteorological conditions and similar amounts of transpiration will occur from different plants, placed under the same conditions, provided that both give a complete ground cover (Penman 1948). Experiments (Joachim et alii 1927, 1930) which found a greater conservation of water by a four year old cover planting than by a two year old planting, both presumably of similar transpiration capacities (Russell 1950b), seem to show that relative moisture conservation by cover plants is dependent on the capacity to produce a good water-conserving mulch. Creeping cover plants might be expected on account of this to decrease surface evaporation to a greater extent than upright covers.

On waterlogged soils cover plants are sometimes grown in an effort to dry out the soil and increase aeration, and strong woody growths with deep rooting systems might show advantages in this respect compared with the shallow rooting creepers.

## COVER PLANTS AND DISEASE

### Root Diseases

The common cover plants are all susceptible to one or more of the root diseases of rubber but experiments at the Rubber Research Institute of Malaya (Annual Report 1940, page 91) indicate that their presence reduces the incidence of such diseases on the rubber tree. However it is stated (Young 1955) that in Ceylon they may assist in the spread of disease if not properly controlled.

A definite danger can arise when covers are allowed to grow thickly round the base of a tree. The cool moist atmosphere under such cover plants allows the fungal mycelium to extend externally up the stem and round the collar of the tree. Under such conditions Fomes lignosus may rapidly ring the tree and kill it.

### *Leaf and Stem Diseases*

The majority of cases in which leaf and stem diseases affect both cover plants and the rubber tree involve the woody plants found in forestry systems of cultivation. Some of these shrubs are susceptible to pink disease (*Corticium salmonicolor*) and need to be pruned or cut out when affected. The humid conditions found in plantations where vigorous covers have developed, particularly under the forestry system, may favour the development of leaf, stem, and tapping panel diseases. In this respect low creeping cover plants would show some advantage over the taller cover plants which interfere with the free movement of air through the plantation.

*Legumes and 'Sickness'*

If legumes can definitely be shown to assist rubber tree growth then attempts must be made to extend the persistence of such cover plants up to, and if possible after, maturity. At the moment planters feel discouraged from carrying out rigid maintenance of a leguminous plant cover by the feeling that the legumes will inevitably become weaker and eventually disappear as the rubber trees approach maturity. In other countries of South East Asia the persistence of leguminous cover plants in mature rubber plantations appears to be more general than in Malaya; how far this is due to variation in fertility, climatic conditions, and other factors is however unknown.

The poor seed set found in most parts of Malaya might be a contributory cause of this lack of persistence and it would be interesting to compare the persistence of leguminous cover plants in the north of Malaya, where good seed set can be obtained, with that in other areas showing poor rates of seeding. Beneficial effects might be obtained by supplying seed to a deteriorating cover.

There is a common belief that because of the development of 'clover sickness' (VAN BAALEN & HEUBEL 1938, RUSSELL 1950c) soils may be unable to support a legume crop for more than a few years. This effect has been attributed to the accumulation in the soil of toxic substances produced by the legumes themselves (YOUNG 1955). It is stated that saponin is released into the soil by lucerne and that cotton, but not grain crops, are sensitive to saponin (MISHUSTIN & NAUMOVA 1955). In addition saponin kills many soil organisms. It may be that concentration of such substances over a period of time can adversely affect a leguminous cover plant. Such clover sickness can be remedied by heating the moist soil to 70°C or by air drying the soil in thin layers, or alternatively by adding large amounts of farmyard manure to the soil (RUSSELL 1950c). Bacteriophages which lyse the nodule bacteria in the soil have been suggested as the cause of this sickness and a remedy can often be obtained by inoculating the soil with a new and vigorous strain of *Rhizobium* (DEMOLON & DUNEZ 1935, 1939). Benefits obtained from periodic applications of phosphate fertiliser to leguminous cover plants may, in part, be due to the phosphate's effect in maintaining the numbers and motility of the *Rhizobia* (THORNTON & GANGULEE 1926) in the presence of such adverse soil conditions.

An alternative explanation for the non-persistence of legumes may be the simple one of pest accumulation. It is known that eelworms attack legume cover plants in Malaya (BEELEY 1939) and growth may be severely affected in some cases. Attacks by ladybird beetles (*Epilachna indica* Muls) and their larvae are widespread and growth is often badly affected. Such attacks could be expected to develop to an increasing extent the longer a particular cover plant is maintained on one area.

General experience in Malaya would seem to indicate that it is the development of shade and increasing competition for moisture by the maturing trees which are the main causes of the deterioration of legume cover plants after some years' growth. However there is scant information on the effect of any fertiliser and cultivation treatments carried out in order to counter those effects and the subject would seem worthy of investigation. There is evidence which shows that shade can limit growth response to added fertilisers (BLACKMAN & WILSON 1951, EVANS & MURRAY 1953) but as legumes are known to persist under mature rubber in some of the more fertile soil areas there is reason for hoping that fertiliser treatment could encourage a similar persistence in the poorer soils.

## CONCLUSION

The above review has surveyed some of the factors to be considered when assessing the value of the different classes of cover plants commonly grown in rubber plantations, and also some of the difficulties encountered in cultivating the introduced legumes. Some of the problems involved in this aspect of rubber tree cultivation are under investigation at the Rubber Research Institute of Malaya.

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