

## THE MANAGEMENT OF PLANT DISEASES WITH SPECIAL REFERENCE TO *HEVEA*

by

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### INTRODUCTION

The concept of crop disease management, rather than disease control, has gained prominence recently amongst scientists and teachers (Horsfall and Cowling, 1977). However, the idea of managing a crop as an entity, taking disease control merely as a part of the problem, is not yet fully understood by farmers; and rubber planters are no exception. This paper is therefore written to familiarize growers with the current thinking on the problems of diseases and their reduction to uneconomic levels, so as to make more money from the crop for the country and the grower, which is the basic reason for growing it (Chee, 1980).

It is important to understand certain basic principles on plant diseases, the causes for their development in epidemic proportions and methods of control, so as to discuss the subject of disease management. We will explain these clearly here, so that this paper will have the necessary impact on the readers. Plant disease epidemics occur in the first place, because man, in his attempts to feed, clothe, shelter and entertain more and more people has had to adopt the system of monoculture for the production of food and the basic material for his other requirements, like clothing and shelter. Plants, as they grow in the wild state or even in a system of subsistence farming, consist of a number of genetically heterogeneous varieties, which may be low yielding, but have a high degree of tolerance or resistance to diseases and pests. Disease epidemics can rarely if ever occur in such a diverse population, where the nutrition of the plants is also poor. Intensively managed agricultural systems, on the other hand, consist of large areas of genetically homogeneous plants, where nutrition is artificially maintained at high levels, resulting in soft tissue, susceptible and attractive to pests and diseases. Further, because a single genetic variety is planted over a large area, the pathogen or pest has virtually only to fall off one susceptible plant to land on another, which is equally vulnerable. Therefore, dissemination presents no problem whatsoever. This is one of the primary reasons why *Hevea*, a native plant of South America, cannot still be grown on a commercial scale in that country because of its susceptibility to South American leaf blight (SALB). In the jungle, where it originated, the widely dispersed trees would have been infected by SALB, but all trees would not have succumbed, because the pathogen was not easily transferred from one *Hevea* tree to another.

It is also true that a large number of high yielding varieties of crop plants are also highly susceptible to diseases and pests, require a high level of nutrition and have a limited capacity to compete successfully with weeds. Some of the early varieties of plants introduced during the green revolution illustrated this well e.g. the variety of paddy, known as IR-8, one of the first to be introduced during that stage, required 16 steps (inputs)

including fertilizers, herbicides and fungicides to be applied at the correct stage of growth, to produce anywhere near its potential yield. This was too exacting for the general smallholder who owns the bulk of paddy lands all over the world. Therefore, IR-8 was replaced with new varieties, that were less demanding of fertilizer and other inputs, but were still high yielding.

The necessity to feed large populations, has made it mandatory for many developing countries to use all land available for growing food crops or primary industrial products — this is certainly true of Sri Lanka, where all land that can be taken out of forests, has already been used for cropping. Therefore, any increase in total production in agriculture has to come from increased yield per unit of land. This calls for the breeding of high yielding varieties of crop plants, which are generally more demanding of inputs, including more efficient methods of disease management.

Our concept of disease management is to use all the available knowledge there is on the plant, the pathogen, the environment the fungicides and the interaction between these factors to reduce disease incidence and maintain its damage below economic levels. It is important to note that this is quite a different result than that required by plant pathologists even in the recent past, where the aim was to control a disease irrespective of cost and the level of damage caused. The most important considerations then were the pathogen and the means of killing it, the fungicide. We will expand on this theme in this paper drawing our examples from the diseases of the rubber tree, wherever possible.

### DISEASES AND THEIR SPREAD

There are several factors that contribute to the incidence of diseases of crop plants and their spread. These may be described as: (a) the inoculum *i.e.* the disease causing particle; (b) the rate of spread of the inoculum; (c) receptivity of the host or its parts *e.g.* leaf, trunk or root; (d) the environment *i.e.* the temperature, humidity, wind, uv radiation amongst others; (e) the interaction between all these, resulting in the amount of disease and, finally (f) the control measures available. It was van der Plank (1963; 1972; 1975) in his classical papers, who described systematic methods for analysing plant disease epidemics, using mainly factors (a), (b) and (e) above *i.e.* inoculum, rate of infection and the amount of disease. Van der Plank (1972) pointed out that the rate of infection for a fungus disease depends on four factors namely: (1) the proportion of spores that, having landed on a host, starts a new infection resulting in sporulation; (2) the time required for a new infection to produce spores; (3) the number of spores produced by a lesion; and (4) the period of time over which an infection produces spores. As can well be imagined, the host and the environment have a great impact on all these factors *e.g.* the host surface may not be receptive, the atmosphere too hot and dry for the survival of the spores or even for their production and the effect of uv radiation on the survival of spores on the target area. All these aspects must be considered.

#### **Inoculum**

Most leaf diseases, *e.g.* *Oidium* and *Phytophthora*, start from fungal spores, as compared to root diseases like white root (*Rigidoporus*) which start from a large piece of inoculum or food base. Leaf diseases can spread fast, during weather conditions

favourable for the fungus, as large numbers of spores can be produced from each lesion, whether it be *Oidium* or *Phytophthora* (Peries, 1963; Liyanage *et al.*, 1983). A single *Oidium* spore landing on an immature rubber leaf can germinate in 6h, establish an infection in 24h and produce its own spores in 96h (Peries, 1974; Liyanage, *et al.* 1980). Similarly the zoospores of *P. meadii* can cause a new infection and start producing secondary zoospores within a period of 6 days (Liyanage *et al.*, 1983). Therefore, each infective body can produce millions of other such bodies within the space of 2 weeks. This lends credence to the assumption that inoculum is always present, and an epidemic will always develop under favourable conditions (Waggoner *et al.*, 1972); this obviously has to be favourable conditions not only of weather, but of the leaf surface too, in a foliage disease. Some fungi *e.g.* *Oidium heveae* and *Colletotrichum gloeosporioides* can infect only immature leaves, mature leaves being immune to infection by them (Peries, 1963; 1965; Liyanage, 1977a). Therefore, irrespective of the amount of inoculum, and good weather for the fungus, the latter cannot cause damage to mature leaves.

An important aspect of primary inoculum is to realize how a small source of infection can cause disease over a large area. It has been estimated that one source of inoculum is sufficient to cause an epidemic of potato late blight over 1 square mile (Boyd 1952). In this case, if the weather conditions are suitable for just 1 week for the spread of this disease, it can cause severe losses over several square miles, starting from a unit source. The fact that the plant is susceptible throughout, unlike in *Oidium* leaf disease, makes weather the only controlling factor here for the spread of the disease.

White root disease of *Hevea* is restricted in this respect; as the source of inoculum has to be a large piece of infected wood. Further, the root of a healthy tree must grow up to the inoculum or the fungus from the food base must grow out to a healthy root to cause an infection. Both pathways are fraught with hazards; therefore, the source of inoculum in this type of root disease is quite restricted in its scope and danger. Consequently control measures can be adopted. However, fungal diseases of the soil like those caused by species of *Fusarium* and *Pythium*, which produce spores in abundance, can spread much faster along with soil water and surface run off (Garrett, 1970).

### Rate of spread

**Weather:** The rate of spread of most foliar diseases is governed mainly by weather conditions, provided that the leaves are in the susceptible stage of development. Fungi produce spores so rapidly and in such profusion that, given a disease like *Phytophthora* abnormal leaf fall, where the infection site is generally the mature leaf stalk, and there is no restriction on age of leaf, the spread of the disease can be extremely rapid. An island-wide epidemic can be caused within a period of 2 weeks, in weather conditions suitable for the rapid multiplication of the fungus.

The spread of a leaf disease under the above conditions will depend on the rate of production of spores, their speed of dissemination, time taken to cause infection, and the lag period for production of the next generation of spores to start another disease cycle. As long as weather conditions remain suitable for rapid fungal propagation, repeated cycles of spore production and leaf infection can take place very rapidly as shown above, and this is the method of development of disease epidemics. Liyanage *et al.*, (1983)

have recently carried out very critical field studies to show how changes in weather conditions affect the development and progress of *Phytophthora* abnormal leaf fall. Infections that take place during wet weather develop quickly and produce spores rapidly and abundantly; whereas infections that occur just prior to dry weather periods develop more slowly and produce significantly less inoculum, so that disease spread is slow.

**Spread:** The spread of inoculum from the source of sporulation to the point of infection depends mainly on wind speed, irrespective of the mode of transport. This can be understood by considering *Oidium* and *Phytophthora* leaf diseases. *Oidium* spores are transported mainly in dry air and the speed of transport is governed almost entirely by wind speed. *Phytophthora* zoospores are disseminated in water dripping off infected pods, this water can also run down the trunk and infect the tapping panel causing bark disease. Tree to tree transport of the fungus is mainly by way of wind-blown water droplets. Therefore, the spread of infection by *Oidium* conidia is much greater than by *Phytophthora* zoospores. However, the higher the wind velocity and the more persistent it is, the greater the spread of the disease in both cases.

**Infection:** The shorter the time taken for host penetration and establishment of disease the more successful the pathogen; because it is less susceptible to external weather changes after infection has occurred. Further, the fungus is more difficult to control, with fungicides or other means, after disease establishment. Some varieties of plants depend on the difficulty of penetration of their surfaces by pathogens for their resistance to certain plant diseases. Clone RRIC 52 is a case in point, where its thick, shiny leaf cuticle renders it resistant to *Oidium* leaf disease (Peries, 1965a, b). Some *Hevea* clones produce phytoalexins (plant antibodies) and the longer the process of penetration takes, the more likely it is that the plant will resist infection (Satchuthananthavale, 1970). There is also the possibility that, with a prolonged period of pre-infection, in the presence of the pathogen on the leaf surface, the weather conditions will change to being inimical to the pathogen e.g. if the conditions change from rain to dry, sunny weather, *Phytophthora* infection can be prevented by the death of the zoospores in the absence of moisture and the action of uv radiation (Peries and Fernando, 1966; Liyanage *et al*, 1983).

**Reproduction:** One of the important factors contributing to the success of a fungus as a pathogen is its rate of reproduction, which is followed by the germination of spores and growth of the fungus, and profuse production of regenerative organs. *O. heveae* reproduces from spore to spore in less than 4 days, *P. meadii* does the same in 6 days, both fungi can produce thousands of spores from that point on. In the next period of gestation there will be literally millions of spores produced in a geometric progression. This ensures that, weather being favourable, the advance of the pathogen will not be hampered by a dearth of infective propagules.

Reproduction can be severely restricted by environmental conditions as shown by Liyanage *et al* (1983) for *P. meadii*, which produces sporangia in abundance in wet weather. However, the advent of dry weather retards sporulation significantly. On the other hand, *O. heveae* prefers dry conditions i.e. rainless days, but with high humidity — free water retards fungal growth, but high humidity is beneficial to the fungus. The causal agent of South American leaf blight (SALB), *Microcyclus ulei*, produces three spore types: conidia, pycnospores and ascospores in that sequence. The first and the last of

these are infective; the role of the pycnospore has not yet been defined. The numbers of conidia and ascospores can be controlled by various devices such as the use of selected fungicides, which act specifically on each spore type. The ascospore which is responsible for the carry over of the pathogen from one season to another, is produced on mature leaves, and the number of these spores available at the beginning of a season can be controlled by treating fallen leaves with an antisporeulant fungicide or by burning the leaf litter. The same effect can be achieved for *Oidium* by treating nursery plants with a fungicide to reduce infection at the beginning of the leaf fall season of mature trees; because it has been found that *O. heveae* overwinters mainly on nursery plants and new flushes of leaves on mature trees (Peries, 1965b). The latter, of course, will fall off at the time of wintering, and being an obligate parasite there is no question of *O. heveae* surviving on dead, fallen leaves. The control of *P. meadii* inoculum at the beginning of the south west monsoon season presents a more difficult problem; as this fungus can survive in the past season's mummified fruit stalks, in the bark of mature trees and in the soil (Peries, 1967; Liyanage, 1984). However, the important point at issue is that any device to reduce inoculum at the beginning of the disease season, can help in reducing the intensity of the disease to a certain extent, particularly if the weather conditions favourable for the disease lasts only for a short period.

#### Host receptivity

Irrespective of the weather and the availability of inoculum, the host plant must be in a receptive condition for the pathogen to establish an infection. *Oidium* leaf disease gives a good example here, because fungal inoculum is available throughout the year, as evidenced by the infection of young leaves on nursery plants and new flushes on mature trees all the year round. Weather conditions too are conducive for the spread of the fungus on several occasions during the year. However, *Oidium* leaf disease occurs in epidemic proportions only at the time of refoliation after wintering; because it is only during that time that a large number of leaves, in the vulnerable condition, are available for infection by the pathogen, which can only infect immature leaves. This is not the case with *Phytophthora* leaf fall, where the mature leaf stalk is the site of infection, and mature leaves are available throughout the year, except for 2-3 weeks during wintering. Here the restricting factor is the availability of the inoculum, which can multiply in sufficient quantity to cause epidemics, only on mature pods, which are available only during the period May to August, which coincides with the south west monsoon rains as a result of millions of years of fungal evolution and selection.

Host receptivity can be affected in other ways, and often by man's interference with nature. *P. meadii* affects *Hevea* bark causing black stripe disease. However, the intact bark is not susceptible to infection, as shown by Peries (1975) and Liyanage *et al* (1984), who also demonstrated that any injury on the bark is readily infected by the pathogen. The tapping cut provides an ideal entry point for the fungus to cause infection. Therefore, one of the most important precautions against black stripe disease, advocated by the Rubber Research Institute of Sri Lanka (RRISL), is to ensure that rubber trees, bearing mature pods infected by *P. meadii*, are not tapped soon after rain. This is to preclude the chance of zoospores swimming down the trunk in surface moisture and infecting the bark freshly injured by the tapping cut, which is known to be susceptible to infection by this pathogen for up to 72 h after tapping (Peries, 1975; Liyanage *et al*, 1984).

## Environment

The key role played by the environment, in the development of plant diseases, has already been referred to above in particular contexts. Temperature, relative humidity along with the presence of free water, uv radiation and wind velocity are some of the key factors of the atmosphere that affect disease incidence and spread. All these are natural conditions, which cannot be readily altered by man, except under restricted conditions e.g. in green houses. To these can be added soil pH and moisture, in the case of root diseases. These two factors can be altered relatively easily to assist man in the control of plant diseases.

It would be useful to study this subject in some detail, as the plant ecological system must be considered as a whole to devise suitable control measure against plant diseases as the organism and the non-living environment interact with each other in a special way, each influencing the other's properties in turn, and both are necessary for the development and maintenance of the system (Odum, 1959). Therefore, the overbalance of the natural situation, already contrived by man in introducing the monoculture type of agriculture, can be further upset by the massive inputs of fertilizers and fungicides, sometimes advocated by scientists, to the detriment of nature and thereby all human beings. It is with the intention of managing plants and suggesting methods of managing their disease problems that this paper was started, and it should be clear at this point why this is important rather than creating unnecessary environmental problems, by the use of massive quantities of fungicides at every turn.

**Temperature:** It would appear, on casual observation, that air temperature is a natural phenomenon and cannot be controlled by man. However, there are instances without number where we have used our knowledge on the biology of fungal pathogens and growth of plants to assist us manage plant diseases. The recommendations of the RRISL on rubber planting gives a good example. We advocate that, until we develop clones suitable for planting at high elevations, rubber planting be restricted to areas below 300 m above mean sea level (MSL). This is because temperature drops with elevation and relative humidities tend to remain high for longer periods in the mornings and evenings at such elevations, and both these factors encourage the growth and sporulation of *O. heveae*. The plant too is handicapped; as rubber leaves tend to mature more slowly and therefore remain susceptible to this fungus for a longer period at elevations above 300 m above MSL. We have now developed clones more tolerant to *O. heveae* and we are advocating the planting of clone RRIC 102 at elevations up to 400m above MSL. Clones like RRIC 100, 102, 103, 104 and 105 are sufficiently tolerant to *O. heveae* to resist infection without control measures at elevations below 300m above MSL. The development of these clones has enabled us to grow rubber successfully in the wet low country areas without any control measures against *Oidium* leaf disease, thus saving large sums of money (Peries, 1966; Liyanage 1977c) and reducing environmental pollution.

One of the reasons for the absence of SALB in the South East Asian rubber growing countries is perhaps that the optimum temperature for the growth and sporulation of the causal fungus, *M. ulei* is about 23°C (Chee, 1976), slightly lower than the ambient temperature in our part of the world. Of course, world opinion differs on this subject and the generally held view is, that the critical temperatures for the growth of this pathogen

are quite compatible with those obtaining in SE Asia, so that if it ever enters our area it will be a most successful pathogen.

The literature is replete with examples of how the knowledge of the critical temperatures for growth and propagation of pathogens has been used to avoid diseases or reduced the impact of others in various parts of the world. The effect of potato late blight, a devastating disease, caused by *Phytophthora infestans*, has been kept within acceptable limits, by growing seed potatoes in areas of the country, where the temperature is too low for the growth of the pathogen. The disease free seed is planted in the warmer, disease susceptible areas; and a further refinement is to harvest the crop before temperatures become warm enough for the pathogen to cause economic losses.

Shading is another method of controlling the temperature of the soil or of the leaf surface (Zentmeyer and Bald, 1977). This method can be used mainly in young rubber plantings or in nurseries, both stock and budwood. Shading affects the plant environment throughout the day and night, reducing radiation from soil and foliage and the exudation of moisture from leaves and dew formation on them. All these factors are critical for disease development.

**Relative humidity (RH):** The humidity of the air is controlled by the temperature, and is another natural phenomenon. Leaf surface wetness is a critical factor in infection by many fungi. In *Hevea*, *O. heveae* spores can germinate on wet leaves, but the hyphae can penetrate and establish on infection only when the leaf surface is dry (Liyanage, *et al* 1985). On the other hand *P. meadii* requires a wet surface for germination and disease establishment. Both fungi grow and sporulate best under conditions of high humidity.

One of the most important recommendations for the management of both diseases by the RRISL is to encourage air movement in rubber growing areas by judicious lopping of branches, careful weed control and removal of moss from tree trunks. All these help the rapid drying of leaves and trunks and help reduce disease incidence, particularly black stripe.

**Sunlight:** Bright sunlight has several important effects on disease incidence and spread. It increases temperature and reduces the RH of the atmosphere, two factors that have already been discussed. uv radiation has been shown to be injurious to many fungi, and, in Sri Lanka, we have shown that a very short period (a few seconds) of exposure to bright sunlight has a lethal effect on both *Phytophthora* and *Oidium* spores (Peries and Fernando, 1965, Liyanage *et al* 1985). The damage caused by *Phytophthora* leaf disease is not serious in Sri Lanka, mainly because the weather pattern here is such that bright sunny days occur frequently during the south west monsoon season in our country, causing rapid drying and having a lethal action on the fungus (Peries, 1969) unlike in India, where May, June and July are extremely wet and overcast, with hardly any sunlight, but with over 75 cm of rainfall being recorded in each month (Radhakrishnan *et al*, 1961) conditions ideal for the growth, multiplication and spread of the fungus. Therefore, *Phytophthora* leaf disease causes serious damage in South India, necessitating heavy expenditure on control measures, compared to Sri Lanka, where this disease causes little economic damage, so that control measures are not advocated (Peries, 1969).

**Wind:** Strong winds will assist the action of sunlight in reducing RH. On the other hand wind is an important mechanism for the spread of plant diseases, particularly of pathogens producing dry spores such as *O. heveae*. Therefore, depending on conditions, high winds can either assist in controlling or spreading plant diseases. It is the duty of the grower to recognize the conditions and use each factor to his advantage.

Some important aspects of the environment and their significance in disease development have been discussed here. It can be seen that, a knowledge of the biology of the fungus and the host can help in devising important methods of reducing disease incidence, development and spread. This is all that disease management is about: the use of our knowledge on disease development to reduce its severity. If this can be so effective as to reduce damage to levels below economic significance, then fungicides are not necessary, and this should be the ideal to aim at.

#### **Interaction of host: pathogen: environment**

It is the interaction between the host, the pathogen and the environment that will result in the level of disease that is registered. If the host is in a susceptible condition, the pathogen is present and the environment provides the ideal conditions for the propagation and spread of the pathogen, then an epidemic will result. The precise time the epidemic will occur can also be predicted, if the biology of the fungus and its behaviour in the field is known with some degree of accuracy. This is the basis of plant disease forecasting.

**Disease forecasting:** Disease forecasting is based entirely on environmental factors, confirming the importance of a critical study of weather on disease incidence, development and spread. Quite successful methods of forecasting several plant diseases have been devised, based mainly on temperature, RH, rainfall and incidence of sunlight, the most successful of these have been for forecasting potato late blight (Cox and Large, 1960). When the cardinal factors relating to the growth of a fungus, its behaviour in the field, the factors necessary for initiating a disease and the weather conditions conducive to its rapid spread are known, it can be predicted that, if a certain set of weather conditions occur for a certain critical period of time, then an epidemic of the plant disease in question will occur within a stated number of days of such a critical period. This enables the farmer to use control measures against the fungus, so as to reduce the damage that can be caused.

Apple (1977) has suggested that the method of disease forecasting can be an even more important tool in disease management, if the amount of damage that will be caused by a disease can be forecast, rather than the level of the disease. This is an important concept, and we entirely agree. One of the methods of forecasting disease loss is to consider the stage of development of a crop, if it is an annual like potatoes. If an epidemic is predicted at the tail end of the growing season, after the tubers are well developed, it may not be an economically sound decision to spend on control measures; as the epidemic will not cause a significant loss in yield. In such a case, it may only be necessary to take precautions while uprooting the crop to ensure minimum damage to the tubers, so that the disease will not affect the latter.

In the case of *Phytophthora* leaf fall of *Hevea*, where forecasting has been attempted (Peries, 1969; Liyanage *et al* 1983) if an epidemic is forecast at the end of the pod development season, control measures will be uneconomic; as we know that dry pods will not provide the ideal substrate for heavy sporulation of the fungus. Therefore, even if weather conditions are ideal, disease development will be limited by the lack of sufficient inoculum. This will obviate the use of control measures, increasing the profits from the crop and shows the effect of the human factor in disease control, for economic gain.

#### Amount of disease

It has been shown above that the amount of plant disease, that will occur in the field at any time, is entirely dependent on the interaction of the host, the pathogen and the environment. We have also seen that plant disease epidemics can be accurately forecast, when the biology of the host and parasite are known, as the level of disease will depend on environmental conditions favouring the rapid multiplication and dissemination of the pathogen, while the host remains highly susceptible.

#### Disease control

It is at this point that control measures can be used, depending on the net gain to be expected from the operation, and this will be determined by such factors as the stage of development of the crop, the time of the year, the importance of the organ which is the target of the pathogen, the value of the crop loss that can be caused by the disease at that time of the year, the cost of the fungicide and its application and many other factors. In all cases, however cheap the fungicide, it is always essential to look on the whole problem of disease control as an economic exercise and reduce control measures; because the use of fungicides always creates a pollution problem apart from all other hazards.

This brings us to the problem of disease management; because it should be quite apparent at this stage, that all methods of disease reduction, by manipulating the host, the fungus and the environment should be employed for economic containment of the disease. It may be possible to reduce loss to such an extent by such devices that control is not necessary or, in fact, uneconomic. This would be the ideal situation. So let us consider all factors that can be used for this purpose.

### MANAGEMENT OF PLANT DISEASE

The most important methods of disease management that are available to man are to: (a) reduce the amount of inoculum, (b) reduce the rate of spread of a disease in the field, or a combination of both, (c) breed resistant varieties of plants (d) avoid disease by manipulation of weather factors (e) prevent infection by various means (f) use fungicides minimally to help one or other of these temporarily. However, over a long period of time, we have concentrated on reducing disease incidence, essentially by the large-scale use of fungicides, and thus almost completely overlooked the importance of all the other factors. In disease management, we must concentrate on disease reduction and increase of crop by assisting nature in reducing inoculum and the rate of its spread. A detailed knowledge of the pathogen and its method of dissemination is essential for this. It is

only comparatively recently, since 1962, that we started systematic studies on the plant pathogens affecting *Hevea*, in Sri Lanka (Peries, 1965b). However, we have now built up a comprehensive body of information on the host plant, all important pathogens of the crop, the environment and the interaction between these factors. This knowledge has helped us to manage *Hevea* diseases at comparatively little cost (Peries, 1965b, 1966; Liyanage *et al* 1984, 1985; Liyanage, 1980). We have been able to contain the five most important diseases of *Hevea* in Sri Lanka by a judicious combination of inoculum reduction, prevention of infection, selected cultural practices, a study of the environment and the use of host resistance, with restricted use of chemicals. Whenever they are used, chemicals are meant to supplement the effects of cultural practices or host resistance and protect the plant for limited periods of time.

### **Reduction of inoculum**

The dread South American leaf blight (SALB), one of the most virulent plant diseases known to man, has been kept out of the South East Asian NR belt by effective plant quarantine measures. This is the classical method of reducing, in fact, eliminating disease inoculum *i.e.* by strictly ensuring that the pathogen does not enter a country on any type of plant material. The success of this method lies entirely on the vigilance of its plant quarantine service.

### **Resistant varieties**

Economic losses from *Oidium* leaf disease have been practically eliminated by the use of resistant clones and restricting the planting of rubber to areas below 300 m above MSL. The clone, PB 86, although it was selected in Malaysia from a seedling population, was developed, tested and recommended for planting by the RRISL. This clone has dark, shiny leaves with a comparatively thick cuticle, which hardens rapidly. It is an early winterer which defoliates uniformly and produces the new set of leaves within 1 week of leaf fall. The cuticle of the new leaves harden and become immune to penetration by the fungus within 1 week of bud burst, so that the time available for the fungus to infect the leaves is only about 10 days (Liyanage, *et al* 1985). The fact that this clone winters early ensures that it completes refoliation before the fungal inoculum has had time to multiply excessively. All this enables it to avoid the disease and also resist penetration by the fungus, thus restricting infection. The new clones of the RRIC 100 series, particularly RRIC 102 and 103, are more resistant to *Oidium* leaf disease than PB 86. These clones can be planted at elevations up to about 400 m above MSL. If some defoliation is caused by the disease in an exceptional year, the leaves of the second round of refoliation can be protected by spot dusting with sulphur. The use of the fungicide here is restricted to special areas, to a limited number of rounds at a specially reduced rate, compared to the massive doses used in the pre-1962 period, with susceptible clones like Tjir 1 and BD 5 (Liyanage, *et al* 1971).

### **Environmental factors**

*Phytophthora* secondary leaf fall caused a great deal of alarm in Sri Lanka during the 1950s and the early 1960s, until the causal pathogen and the epidemiology of the disease was studied in great detail together with the effect of weather on the progress of leaf infection (Peries, 1966; Lloyed, 1965). This showed that the inoculum for leaf fall

developed on infected pods, the spores were dispersed mainly in rain water drops washing off sporulating pods and that the spread of inoculum was restricted often to individual trees on which pods were present, and the major part of leaf fall occurred below the level of pods, even on infected trees. Studies on weather pattern showed that, in Sri Lanka, bright sunny days occurred frequently during the south west monsoon and these had an immediate and deleterious effect on the development of the pathogen, making a definite break in the course of the progress of the disease. Peries (1969) referred to sunny days during the monsoon season as "better than the action of any fungicide in the control of the disease". Other studies showed that rubber trees produced an excess of leaves and the loss of a few leaves as a result of *Phytophthora* infection had no effect in yield. In fact it was shown that a tree can withstand up to 50 percent leaf fall without showing a significant effect on yield (Peries, 1967; Liyanage, *et al* 1983). On the basis of all this evidence, the RRISL recommended that the use of fungicides for the control of this disease was not warranted, as it did not cause economic losses in our country (Peries 1963, 1969). This was a classic study in plant disease management, and laid to rest many myths on the problem that existed prior to 1960. The recommendation to withdraw all fungicidal treatment for the control of this disease has now stood the test of time for 25 years, proving the validity of the studies on which it was based.

### Prevention of infection

Black stripe, also caused by *P. meadii*, was a major disease problem in Sri Lanka till the early 1960s. However, the same studies as the above, on the biology of the pathogen, together with new information on the method of infection, led to a dramatic change in the recommendations for disease control and the reduction of disease incidence in this country to negligible levels. The two most important factors contributing to this happy state of affairs were (a) the observation that inoculum was produced mainly on infected pods and (b) the intact bark was immune to infection, an injury was essential to provide entry to the fungus and the tapping cut provided the ideal access to the pathogen. The new recommendation was to strictly prevent the tapping of trees, bearing infected pods, while there was still surface moisture on them after rain. This simple principle, based on sound scientific data, has reduced the incidence of black stripe in this country to negligible levels.

The tapping cut is susceptible to infection for up to 72 h after the operation (Peries; 1975; Liyanage, *et al* 1984). Therefore, during long periods of wet weather, when infected pods are profusely present on trees, it is advisable to make a prophylactic application of a recommended fungicide on tapping cuts, on every tapping day, as a precautionary measure (Peries, 1966; Liyanage, *et al* 1984). This is the only fungicide used for black stripe control in Sri Lanka now, thus reducing costs on control measure by some 90 percent.

### Selected cultural practices

White root disease is the most important disease of *Hevea* in Sri Lanka, at present. However, this disease can be kept down to very low levels, by the adoption of some simple management systems. We have confirmed that the causal fungus *R. lignosus* is a weak parasite, which requires a large source of inoculum to cause the infection of a healthy tree

(Peries, 1963; Liyanage, 1980). Infection is most common after replanting; therefore our recommendation is to prepare a disease free seed bed, by removing as many infected roots of the old stand as physically possible before replanting. In order to make this more feasible, we recommend that, at the time of uprooting, all infected trees be marked and special attention be given to those, as foci of infection when clearing, with a view to removing all inoculum from the field, prior to replanting with new material. This method can reduce disease incidence to 2—3 percent. The few infected plants too can be replaced with poly-bagged plants, so that a virtual 100 percent successful replanting can now be established by adopting proper management systems (Liyanage, 1980).

A further important contribution made by the RRI of Sri Lanka towards the management of root diseases on *Hevea* is in the area of biological manipulation of the soil by tilting the soil reaction in favour of fungal antagonists of *Rigidoporus*. This is done by adding about 100 g of sulphur per sq. m of soil surface, in known high risk areas for root disease infection. The sulphur reduces soil pH, and the acid conditions encourage the growth of species of *Penicillium* and *Trichoderma*, which parasitise and kill the causal fungus, thus reducing the possibility of infection (Peries, 1964; 1965; Liyanage, 1980).

Another method of reducing disease incidence is to change the planting points at each round of replanting. This results in the pathogen or the roots of the new replants having to grow further along the soil for infection to occur, when the two meet. During the meantime the food base has time to rot out. Here, once again, a knowledge of the biology of the fungus has enabled us to make a valuable contribution to controlling it (Liyanage, *et al* 1984).

We have also confirmed that the growth of a good legume cover in replanted areas reduces white root disease infection (Liyanage, *et al* 1984). The reasons for this are that the food bases rot out faster under the high humidity and more congenial temperature conditions, obtaining under the cover crops. The pathogen also dissipates its inoculum potential by growing on the roots of the cover plants and has less energy resources left over for infecting crop plants. So that this is another good management technique for reducing disease incidence.

Finally, we take advantage of the fact that *Rigidoporus* grows on the surface of rubber roots, for a considerable distance, before it penetrates and infects the latter, starting well behind the furthest point of superficial growth of the fungus. For this, we use a fungistat, in a grease base, to treat the healthy areas of roots of trees infected by the pathogen, as a part of the control treatment. The fungistat prevents the superficial growth, of the fungal pathogen on the roots, for upwards of 2 years, thus preventing infection. During this period the food base rots out, and then the tree is safe from infection.

It can be seen that a number of field management techniques are used in the control of *Rigidoporus* root disease of *Hevea*. Thereby, although it is the most important disease of *Hevea* in Sri Lanka at present (Liyanage, 1977b), using these techniques, we can bring replanted areas into bearing, with less than 1% losses, caused by root diseases. Therefore, root disease control is a good example of disease management in the field.

## DISCUSSION

The strategy of disease management lies in the reduction of the inoculum from which a disease starts or restraining the rate of spread of the disease in the field, by hindering the multiplication of the pathogen or increasing host resistance on the basis of a clear knowledge of the biology of both the host and causal fungus. The other important aspect of disease management is the study and manipulation of the environment, which affects both the host and pathogen. It is essential to note that it is the interaction between these three: the host, the pathogen and the environment that leads to plant disease epidemics. It is equally true to say that good crop husbandry lies in the successful manipulation of these three factors to man's advantage. For many years, most crop disease specialists have concentrated entirely on the reduction of crop disease incidence rather than disease management, so that optimum returns from the crop concerned have not been realized.

In this essay, we have seen the importance of the study of the growth, development, method of infection and the progress of the disease on the host and the reproduction and dissemination of the pathogen in addition to the same factors as the host's referred to here. Perhaps, the overriding factor in disease development is the effect of the environment on both the host and the pathogen. It is only from a careful assay of all these, that an economic method of disease containment can be developed. This is the reason why, in plant disease control today, the ideal is to use chemicals as sparingly as possible, giving heavy weightage to host resistance, cultural practices, the stage of development of the host, the possible development of the fungus and the effect of the environment on all these. This is the aim of modern plant pathology.

That being the ideal, there are certainly going to be occasions when a disease cannot be contained by management techniques alone. This can happen when environmental conditions are more or less ideal for the multiplication and dissemination of the pathogen and the host is in a susceptible stage of development. A chemical may be used at this stage, to swing the balance in favour of the host and give it the necessary respite from the ravaging pathogen. It has always to be remembered, as pointed out in our introduction, that crop production on a large scale is always in the face of an imbalance of nature; therefore, occasional life saving injections have to be given to maintain this *status quo*. However, such injections should be kept to a level only sufficient to weigh the scale in favour of the host over the pathogen, in order to be economically acceptable.

At this point it is important to note that a chemical must be used for disease control only when the anticipated loss from the disease is likely to be greater than the combined cost of the fungicide and its application. If the anticipated loss is calculated, on the basis of available data, to be limited, there is no advantage in using the control measure. The same decision *i.e.* not to adopt control measures should be taken if the disease season is coming to a close or the crop is already ripe, as in the case of an annual crop. These are the decisions that have to be taken by the management on the spot.

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