Cocoa Production
Present Constraints and Priorities for Research

R. A. Lass and G. A. R. Wood, editors
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(List continues on the inside back cover)
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Cocoa is produced almost exclusively by developing nations in the tropics. Although it is in many ways a suitable crop for small farmers, yields are seriously reduced by several major pests and diseases. This paper identifies the major constraints, summarizes the present state of knowledge, and suggests priorities for research that would be expected to have the greatest impact at the farm level. Financial constraints and thus lack of continuity in research have hindered progress.

The botany, historical development, social aspects, and environmental requirements of cocoa are covered. The agronomy section deals with rehabilitating old cocoa, the role of cocoa in farming systems, and the general husbandry of the crop. This is followed by discussion of cocoa physiology, and the relation of shade and nutritional requirements. There are both economic and social constraints to the adoption of more sophisticated farming systems by small farmers.

Much effort has been devoted to developing resistance to pests and diseases. The relative merits of Amelonado and the more recent hybrid varieties are discussed, and the genetic resource base is summarized. Priority should be given to further genetic prospection, broadening the range of genotypes in the current programs, as well as to establishing new collections. Conventional methods of vegetative propagation need more work on stock-scion relations, while micro-propagation techniques should be developed.

Black pod disease (Phytophthora spp.), is estimated to destroy 10 percent of the world crop annually. Research is required to improve current chemical and phytosanitary control measures. While breeding for resistance is the ideal long-term solution, there are many difficulties. The report also covers witches' broom, frosty pod rot, and vascular streak dieback. Of the viruses, swollen shoot disease receives the greatest attention. Pest management in cocoa is generally inadequate. For mirid control priority should be given to testing new insecticides and studying the present status of resistance to gamma-HCH. The possibility of biological control should be re-explored. For the other pests, the programs need to be intensified.

Primary processing is described and the shortcomings of the present methods are identified. Quality at the farm level could in many instances be improved by greater attention to the incentive system. Also proposed are closer contacts between producers and the major buyers to promote a better understanding of market requirements.
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PREFACE

The World Bank has forecast that cocoa prices will be low over the coming decade. Low prices impose a need for increased efficiency of production if many small scale cocoa producers are to continue to make a living from the crop.

Fifteen scientists have contributed to this paper which reviews the more important biological factors in production and takes a pragmatic view of how necessary improvements may be realized in the world's major cocoa producing areas. The document does not attempt to give a fully comprehensive review of every aspect of cocoa production but concentrates on those problems that have, or may be expected to have, a major impact on production at the farm level. It discusses the progress that has been made towards the solution of these problems and the major areas where difficult problems remain to be solved. In this way it is hoped that those involved in cocoa projects, either with new developments or with the replanting or rehabilitation of existing areas, will approach their task with a greater appreciation and awareness of the technical constraints and management problems involved.

The Bank is grateful to R.A. Lass and G.A.R. Wood who edited the text. It is also indebted to A.F. Posnette and R.W. Smith who gave generously of their own time in contributing papers and in writing the introductory "Perspectives" sections to each chapter, and the final sections entitled "Priorities for Research". They were also responsible for obtaining the participation of a number of other contributors in different specialist fields without whose help the work would have remained incomplete. The Bank is extremely grateful to all the contributors for the time and effort they have so freely given. Brief biographical notes on all those who collaborated in the production of this work are presented in the appendix.
I. INTRODUCTION

Cocoa provides a classical example of a major agricultural commodity that, while being produced almost exclusively by developing nations in the tropics - over 70% coming from five major producers: Brazil, Ivory Coast, Ghana, Nigeria and Cameroon - is largely consumed in the industrialised countries. Of approximately 1.6 million tons produced in 1980 over 930,000 tons came from the four countries of West Africa, a high proportion of this being grown by smallholders. There have been very important shifts in the production pattern over the past 20 years. In 1961 West Africa accounted for over 70% of world production of about 1.2 million tons, with only 7% of this total coming from the Ivory Coast. By 1980, the Ivory Coast had increased its share to 21%, but West Africa as a whole had lost ground, producing only 60% of world supplies.

Low elasticities of both supply and demand and the long adjustment lags that are inevitable with perennial crops have resulted, historically, in cyclical trends in production and prices. The high prices and stagnant production of the late 1970s lead to increasing production and the recent sharp decline in real prices. While the demand in traditional markets cannot be expected to increase substantially, major new markets could develop with the centrally planned economies if per capita incomes can be suitably increased. Because of the current low rates of consumption in the major producing countries themselves even high rates of growth would have relatively little impact on overall consumption in the coming decades.

Brazil, Ivory Coast and Malaysia have shown high rates of production increase. Much of this has come from new plantings, many with hybrid material but, as will be seen from the section on plant breeding, high yielding material per se may not make as large a contribution to the yield increases as is sometimes suggested. In fact the average yields in both Ivory Coast and Brazil remain far below the genetic potential of either Amelonado or hybrid varieties.

While cocoa is in many ways an ideal crop for the small farmer with limited resources it suffers greater losses from a number of serious pests and diseases than many other tropical tree crops. For the most part it is grown outside its center of origin in the Amazon basin, and in producing countries cocoa enjoyed a period of relative freedom from pests and diseases but as the years passed by these became more and more important limitations on production.

In most crops genetic improvement has been a major source of increased productivity. Cocoa is no exception but genetic progress in perennial crops is necessarily slow and although cocoa breeding has been underway for more than 50 years, it has lacked continuity due to intermittent financial and manpower constraints. Solutions to some of the major problems are likely to come through further breeding and selection but this will need to be based on a very much broader genetic base. Untapped sources of new germplasm still exist but the collection, evaluation, and maintenance of this material is a major task which is only now being addressed in an international context.
Pest and disease problems are discussed at some length in this paper since it is felt that, until these can be resolved, cocoa production in both the modern and traditional sector will continue to be very severely handicapped. Some pests and diseases are pan-continental, others are confined to one continent or one region of a continent but some have demonstrated the ability to spread easily, highlighting the importance of adequate quarantine facilities when moving breeding material around the world.

Cocoa is an interesting crop physiologically and a somewhat unusual crop in its reaction to shade. Many factors are involved in this but the proper management of shade is quite an intricate process. As a natural understorey species cocoa lends itself well to multiple cropping and combines particularly well with coconuts; in suitable environments this particular combination yields higher rates of return than any perennial tree crop grown as a monoculture.

Apart from the immediate impact on production, pricing policies and the social and family structure of cocoa producers have a very important influence on how the industry evolves over time. The trees, the capital of the industry, have to be replaced when they become too old, too damaged by pests and diseases or surpassed by newer varieties in their productive capacity. However, replacement programs in the shape of replanting schemes have lagged well behind the needs and there are many important questions on how best to organise the replacement of a crop of this kind in a period of falling prices and competition for land with alternative crops, particularly food crops which offer a quicker return on investment.

Overall improvements in the efficiency of production have made a major contribution to ensuring the continued viability of other tree crops such as rubber and oil palm. Cocoa, a major source of foreign exchange for all the traditional producing countries, has to compete both internally with other crops for land and farmers' labour, and externally with new producers, some of whom enter the field with a relative advantage due to more favorable soil and climatic conditions.
II. THE COCOA TREE AND ITS CULTIVATION

2.1 Botany

The cocoa tree—Theobroma cacao—is the only cultivated species in the genus which consists of small trees found in the forests of Central and South America, generally within 15° of the equator. In its natural habitat it grows under dense shade, where rainfall is heavy and well distributed, and temperature is relatively uniform.

The seeds of the cocoa tree develop inside a pod with a moderately thick husk. These pods do not open or fall off when ripe and dissemination of the seed depends on the pod being opened by some animal, usually a squirrel, which will discard the seed after sucking off the pulp which surrounds it.

The seed is non-dormant, germinating soon after removal from the pod. Growth is epigeal, the cotyledons being raised above the ground. Growth continues vertically with leaves in a spiral arrangement until the plant reaches a height of 1-2 metres. At this point vertical growth ceases and side branches develop at an angle to the horizontal. The point at which the change takes place is called the jorquette. The side branches, known as fan branches, have an alternate leaf arrangement; the vertical growth is called a chupon. Further vertical development occurs by chupons which emerge from just below the jorquette and these chupons also form jorquettes. Thus the tree will grow vertically in a series of stages and may reach a height of 10 metres or more.

Growth of fan branches is by a series of 'flushes', each of which consists of three to six pairs of leaves. All the branches tend to flush at the same time, a process which is initiated by moisture stress.

The root system comprises a tap root which goes down to a depth 1 to 1.5 m, and a mass of lateral feeder roots most of which lie in the top 20 cm of soil and may extend to several metres from the trunk.

The flowering habit is cauliflorous, that is, the flowers are formed on the trunk and main branches. The flowers are produced in large numbers especially at the start of the wet season. They open early in the morning and will fall off the following day if not pollinated.

The structure of the flowers is such that only certain insects can pollinate them effectively and the most important are very small midges belonging to certain genera of the family Ceratopogonidae. Only a small proportion of the flowers are pollinated and start to develop into pods. The young pods are called cherelles and many of these are lost due to physiological wilt, a fruit thinning process, referred to as cherelle wilt. Development of the pod takes about 5 months and it normally contains 30 - 40 beans or seeds.

It requires a certain minimum quantity of individual fertilisations to enable a pod to form and the pollen must be compatible with the female gamete. The mechanism of compatibility in cocoa is unusual
and is controlled by several genetic factors, the degree of incompatibility varying between types or populations. Amazon cultivars are all self-incompatible but are generally cross-compatible, while Amelonado trees are all self-compatible.

In countries without pronounced wet and dry seasons, Malaysia for example, some crop will be harvested throughout the year. In West Africa, where there is a pronounced dry season, cropping is more seasonal, the peak harvest coming 5 - 6 months after the start of the rains.

There are two major types of cocoa tree which are regarded as sub-species, namely Criollo and Forastero. There is also a third type, Trinitario, which is considered to have arisen from hybrids between the other two. Criollo trees are characterised by red pods and white or pale purple beans. The trees usually lack vigour and are susceptible to diseases. There are few pure stands of Criollo trees today. Forastero trees have green pods which turn orange when ripe and purple beans. They are vigorous and the group as a whole contain two major types: the Amelonado which is grown in Bahia, Brazil and in West Africa, and the Amazons which are more variable but provide many of the parents used in breeding work. Most of the world’s cocoa comes from Forastero trees. The Trinitario, being hybrids, are very variable and they make a significant contribution to world supplies from certain countries.

The flavours of the major types of cocoa differ. Forastero or bulk cocoas produce a good chocolate flavour, particularly suitable for milk chocolate. Criollo and Trinitario cocoas are called fine flavour cocoas and have other flavours favoured by some manufacturers for blending with bulk cocoas.

2.2 Historical Development

Cocoa has been cultivated for well over 1,000 years. By the 16th century the Criollo variety was being grown in several areas of Central America. The crop spread to the West Indies and northern South America with the development of a market in Europe. During the 18th century Forastero cocoa began to be grown in Brazil and Ecuador, which became the largest producer during the 19th century.

Early in that century cocoa was introduced from Brazil to Sao Tome, then on to Fernando Po and from there to the African mainland at the end of the century. The enterprising farmers of West Africa, particularly in Ghana, spread the cultivation of cocoa rapidly and West African production has dominated the market during the current century. However, a decline has set in during the past decade and seems likely to continue.

In other parts of the world recent high prices have stimulated planting. This is particularly true of Malaysia and the rise there may be followed by Indonesia. Thus the 'centre of gravity' of cocoa has moved eastwards from South America to Africa and may go on to South-East Asia. The changes during the past 10 years can be seen in the table of production (Table 1).
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<td>North, Central and South America</td>
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<td>.1</td>
<td>.1</td>
</tr>
<tr>
<td>Saint Vincent/Grenadines</td>
<td>.1</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Trinidad &amp; Tobago</td>
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<td>Venezuela</td>
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<tr>
<td>Others</td>
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<td>.5</td>
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<tr>
<td><strong>Total</strong></td>
<td>474</td>
<td>539</td>
<td>544</td>
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</tr>
<tr>
<td>Vanuatu</td>
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<td>.7</td>
<td>.7</td>
</tr>
<tr>
<td>Others</td>
<td>.5</td>
<td>3.0</td>
<td>6.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>61</td>
<td>84</td>
<td>142</td>
</tr>
<tr>
<td><strong>World Total</strong></td>
<td>1,542</td>
<td>1,660</td>
<td>1,537</td>
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</table>

Source: Figures published by the International Cocoa Organization (ICCO).
2.3 Social Aspects

Nearly all the cocoa produced in West Africa is grown by smallholders, with a wide range of farm size but generally only a few hectares. Cocoa is eminently suited to this form of production. It fits into the land tenure system, it allows food crops to be grown during the years of establishment, most of the crop is harvested during the dry season and can be processed on a small scale without capital equipment. These are important advantages but it is a system of low input and low output and intensifying production - raising yields - requires an effective extension organisation and a supply of inputs.

Research has depended largely on governments and research on a large scale did not start until 1945 and then as a result of disease. A large proportion of the research effort has been devoted to the problems of pests and diseases, although notable advances have been made in plant breeding.

In Malaysia cocoa has become a plantation crop which has intensified research in new directions and has improved methods of cultivation considerably.

2.4 Environmental Requirements

Climate

The following climatic conditions are desirable for cocoa:

(a) Annual rainfall preferably between 1500-2000 mm, with a dry season of no more than 3 months with less than 100 mm per month.

(b) Temperatures varying between 30 - 32°C mean maximum and 18 - 21°C mean minimum and an absolute minimum of 10°C.

(c) No persistent strong winds.

While cocoa can be grown satisfactorily in countries with wet and dry seasons, a uniform climate with well distributed rainfall is advantageous because growth is continuous and the trees come into bearing earlier.

Soils

Cocoa is grown on a wide range of soils and it is not possible to define precise soil requirements. The following points are intended as a guide rather than as definite limits:

(a) Depth of soil should be not less than 1.5 m.

(b) Texture: The soil must provide adequate moisture throughout the year, but at the same time it should be fairly free-draining as cocoa trees are sensitive to waterlogging. Where rainfall is well distributed the moisture-holding capacity of the soil is less important than in countries with a dry season. Therefore the suitability of soils varies with the climate, heavier soils being desirable where there is a dry season.
(c) **pH:** The optimum pH for cocoa is about 6.5 but a fairly wide range from 4.5 to 7.0 can be tolerated.

(d) **Nutrient status:** It is desirable that the soils for cocoa should meet the following minimum requirements:

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base exchange capacity</td>
<td>12.0 m.e. /100 g soil</td>
</tr>
<tr>
<td>Calcium</td>
<td>8.0 m.e. /100 g fine earth</td>
</tr>
<tr>
<td>Magnesium</td>
<td>2.0 m.e. /100 g fine earth</td>
</tr>
<tr>
<td>Potassium</td>
<td>0.24 m.e. /100 g fine earth</td>
</tr>
</tbody>
</table>

These figures apply to the surface soil. While cocoa can be grown in soils which fail to meet these requirements, good yields will depend on adequate fertilisers.

2.5 **Cultivation**

Cocoa originated as an understorey tree and traditionally it has been grown under shade. The type of shade and the amount of shade have been subjects of discussion among cocoa farmers for many decades. The present recommendation is that young cocoa must be shaded in order to promote the right form of growth and development. As the trees grow and form a continuous canopy the need for shade is reduced but only under the most favourable conditions of soil and climate can cocoa be grown without shade. It is normally necessary to retain some shade to reduce moisture stress and insect damage. This is further explained in the section on shade and nutrition, but it must be stressed that cocoa is a sensitive crop requiring careful judgment of shade in relation to climate and soil.

Shade is provided either by thinning the forest or by planting special shade trees - *Gliricidia sepium* is used in several countries but many other species are used. In either case the shade is supplemented during the establishment years, by food crops under thinned forest - the method used in West Africa - or under planted shade by an erect cover crop, which will shield the young cocoa from winds. Cocoa is also grown as an intercrop under coconuts, a combination of mutual benefit.

Cocoa trees are usually planted at 3 - 4 metres apart or about 1100 trees per hectare. Bearing in mind that shade may have to be planted at a similar density it will be seen that establishing cocoa is labour intensive.

During the period of establishment weeds must be controlled, usually by means of herbicides. A healthy mature farm will prevent weed growth by a thick canopy.

Pruning is another aspect of cocoa cultivation which is open to debate and for which there is little scientific guidance. Young cocoa needs no pruning but as the canopy forms, after 2 - 4 years, the low hanging branches should be pruned to make the trees accessible for harvesting and spraying where necessary.
Then comes the question as to whether to retain the height of the tree at the first jorquette or whether to allow the tree to grow up. There is no clear-cut answer. A low tree is convenient for harvest but a tall one may yield more.

2.6 Processing

Cocoa pods are harvested at intervals of 1 - 4 weeks depending on the size of the farm, amount of crop and incidence of pod disease. The pods are opened within a few days of harvest and the wet beans are fermented. This process is simple technically but chemically it is highly complex and not fully understood. It is, however, an essential process in the development of chocolate flavour.

During fermentation much heat is produced; therefore to ensure a degree of uniformity the wet beans are either placed in a box and covered with leaves or formed into a heap on banana leaves laid on the ground and covered with more leaves. Fermentation of Forastero beans takes 4 - 6 days during which time the beans are mixed once or twice; Criollo beans are fermented for only 1 - 2 days.

After fermentation the beans are dried in the sun if the climate allows or in some form of artificial dryer. After drying the moisture content of the beans should be 6 - 7%.
III. AGRONOMY AND PHYSIOLOGY

3.1 Perspectives

Future progress in the fields of cocoa breeding, crop agronomy and pest and disease control will depend upon a deeper understanding of the ecology of the cocoa farm. The relationship between the crop and its environment requires intensive study involving crop physiology, agro-climatology and soil science. To utilize the resulting knowledge in cocoa farming systems the boundary of the system must be extended to encompass social, economic and marketing factors.

Problem areas have been identified in all cocoa growing areas, some common to many situations, others specific to particular locations. Of the former - the most significant are:

The Problem of Declining Yields with Time

Whereas declining yields can often be attributed to the build-up of diseases and pests, in many areas the early promise of sustained yields from improved varieties is not realized. For no apparent reason trees become reluctant to flower and yield under the traditional management of the crop. Research into environmental physiology must be intensified to understand the reasons for yield decline, and thus to suggest the agronomic means to prevent it.

The Problem of Rehabilitating Old Cocoa

Can old low-yielding cocoa be rehabilitated and brought back into economic production, or should such material be replaced by new plants? Decisions can only be taken with confidence once the responses of old trees to treatments such as shade manipulation, pruning and coppicing are understood, and the effect of these and of the cocoa itself on the aerial and edaphic environment are known. Conditions for establishing new plants in old cocoa farms are very different from the conditions encountered when the original cocoa was established. Research should be intensified to investigate the complex interactions between soil, microclimate and physiological requirements for maximum growth and yield.

Cocoa Production and the Farming System

Smallholder cocoa production is traditionally a low input-low output system in which yield is limited by shade, poor nutrition and the presence of pests and diseases. However, a cocoa farm becomes a "mini-ecosystem" in which an ecological balance exists between the cocoa and its environment. To increase production, management of the environment becomes necessary involving shade manipulation and the provision of nutrients. At the same time, the buffering effects of the ecosystem diminish and further inputs in weed, pest and disease control become essential. Research must continue in order to increase the knowledge base, and thus enable extension workers and farmers to implement change when the consequences can be predicted and the appropriate inputs are available.
Location-specific problems are amenable to solution only within the areas concerned. Research must therefore take place within national agricultural research centres, and include the social and economic factors which determine the relevance of the outcome, and the potential for its local adoption. The important problems cannot all be listed here, but priority should be given to:

- The rehabilitation of old cocoa farms in West Africa, which differs from South America because of the presence of capsids and cocoa swollen shoot virus.

- Multi-cropping systems research, especially in India and elsewhere in South-East Asia where land is at a premium.

- The choice and management of temporary and permanent shade trees which not only create a suitable environment for cocoa, but contribute an income (especially during establishment) for the farmer.

- Cocoa nutrition in relation to soil type and the shade situation.

- Consideration of the requirements for sustaining adequate populations of pollinating insects.

3.2 Cocoa Agronomy

There is no single recipe for "how to grow cocoa" as so much depends upon the specific environment in which it is cultivated. The multitude of location-specific factors which individually and jointly affect production include:

- Climate
- Soil
- Socio-economic factors
- Market requirements
- Prevalence of pests and diseases
- Land tenure system
- Varieties

Recommended agronomic practices for any particular situation should take account of all these, and probably other factors as well.

For the past 50 or more years, several groups of scientists have investigated the effect of manipulating agronomic variables on the productivity of cocoa farms. The factors most often tested have been: crop density (and layout), nutrition, shade, pruning and variety, together with various factorial combinations of them. Less attention has been given to irrigation, cover cropping and multi-cropping systems. Control of pests and diseases has traditionally been left to the entomologist or plant pathologist, and only recently has "integrated pest control", involving a multi-disciplinary approach become popular.
The agronomist has, in the past, largely designed his experiments against a background of common sense, experience gleaned from other crops, and from earlier results of similar types of research. The physiological basis for the decisions he has taken and the physiological interpretation of his results have been largely absent. The physical, social and economic environments have also largely been ignored. It is unlikely that this ad hoc approach to cocoa agronomy will in the future lead to any major increase in yield or reduced costs of production.

As a result of experimentation and experience there is now a basic knowledge of cocoa agronomy. The main elements of this can be summarised as follows:

(a) In its wild state, cocoa is an under-canopy forest tree in the Amazon basin, and a forest-edge plant along the rivers. It is, in its natural habitat, a shy flowering tree which seldom produces a large quantity of fruit.

(b) Acceptable yields can be obtained by growing cocoa under shade: either thinned natural forest or planted trees. The presence of shade over mature trees, however, restricts them from producing their maximum yield, though it does buffer them against adverse environmental factors including some pests, desiccating winds and lack of adequate soil nutrients and water. Some form of shade is essential for establishing young cocoa in most climates and soils where the crop is grown.

(c) Some cocoa varieties produce better yields under shade than others. West African Amelonado, for example, is more tolerant of shade than many Amazon and Amazon hybrids. It becomes predominantly a trunk-bearer under shady conditions. However, all types produce more yield with increased solar radiation provided that pests are controlled, nutrients are supplied and protection is provided against wind.

(d) Responses of cocoa to fertilisers vary enormously, and the economics of fertiliser use are location specific depending upon soil factors, shade, variety, labour costs and the cost of fertiliser in relation to cocoa prices. Significant responses can be obtained, particularly to phosphate on phosphate deficient soils, and to complete NPK fertilisers on high yielding cocoa under reduced shade or unshaded conditions.

(e) The opportunities for mixed cropping systems are limited. The essential condition for a good field of cocoa is a closed canopy which, apart from the establishment period, prohibits the growth of inter-row or understorey crops. Cocoa can, however, be grown using an economic crop as either temporary or permanent shade. Plantains and bananas have successfully been used as temporary shade, and coconut palms, at appropriate densities as permanent shade.
Cover crops have been successfully used during establishment on some estates. However, unlike oil palms and rubber where legumes are now widely used, cover crops have not been shown to be superior to natural vegetation during cocoa establishment.

(f) Spacing of cocoa is critical for maximum yields - but has to be considered in relation to shade, variety and pruning systems. For varieties which are predominantly trunk bearing (Amelonado) a close spacing leading to tall trees with restricted development of the lateral fan branches is advocated. However, this leads to difficulties in harvesting from high in the canopy and makes the control of diseases and pests very difficult. With Amazon and Amazon hybrids, as well as many of the types grown in Brazil and elsewhere in South America, a wider spacing is advocated, coupled with restricting tree height to the first or second jorquette by pruning. Even so, as the trees age, there is a tendency for yields to fall off and for the trees to produce vegetative growth rather than fruit.

(g) Cocoa can be established by planting seed at stake, but much better results are obtained by planting seedlings raised in polythene bags in a nursery. The latter system permits better selection of planting material, but can result in some transplanting shock. During establishment the maintenance of soil cover in the inter-rows is important to prevent soil degradation and erosion. Natural vegetation is usually preserved to keep the rows weed-free, but more research on the use of inter-row cover crops or economic food crops is required and may produce a more economic and effective system. Initial shade is sometimes provided by "tents" of palm fronds when temporary shade is inadequate. Weed control by hand or herbicides is necessary until the cocoa canopy forms.

(h) Cocoa maintenance consists of managing the cocoa/shade complex. Field operations consist of pruning cocoa, thinning and regulating shade trees, pest and disease control, application of fertilisers and weed control. Possibilities for further increasing yields include stimulation of flowering by partial ring barking, hand pollination and irrigation. No tillage of the soil is required, and in fact cultivations damage the surface feeding roots.

(i) Crop losses due to pests and diseases can be reduced by efficient field sanitation, including the removal of infected trees (e.g. for swollen shoot), or diseased pods (black pod, Moniliophthora). Pest and disease control by spraying is usually only economic where damage is high (e.g. capsids in West Africa, black pod in certain areas) and/or where the yield potential and crop losses are very high. Regular and frequent harvesting is essential to obtain maximum yields. During the peak season of production, pods should be reaped at least every two weeks.
3.3 Cocoa Physiology

The current state of cocoa physiology cannot be considered in perspective without a brief review of the past, what has been done and what remains to be done. The first problem is to define cocoa physiology and what may justifiably be considered as coming within the scope of this survey. In its broadest sense physiology may claim to cover all studies relating to the growth and function of the cocoa plant and could therefore include nutrition, competition, environmental effects on growth, physiological effects of pests and diseases, all factors affecting yield, which would inevitably include breeding because the measurable expression of a genetic difference resulting in increased yield must involve the physiology of the plant. This is obviously so broad a field that a selection must be made.

The division of cocoa physiology into a series of separate subjects is completely artificial and has resulted in the fragmentation of research which is probably the most important reason why our present state of knowledge is so unsatisfactory.

It is logical to start with the physiology of the seed and then move through the seedling to the adult stage and finally consider decline and replanting.

Seed

Broadly speaking cocoa seeds do not present any specific physiological problems. Their epigeal germination does not differ fundamentally from many other forest seeds and germination requirements are not unusual for tropical trees. Storage of live seeds does however cause considerable problems and keeping qualities are poor. Standard techniques are available to study this problem and a combination of sterilisation and cheap methods of maintaining low humidity could produce results of universal application for the normally small amounts of seed involved in intercontinental travel. Where it is necessary to transport larger amounts of seed, (e.g. to open up large new areas of cocoa in Brazil), it may be useful to carry out a few simple trials but once the basic physical parameters of storage are established this work is very straightforward. Research being carried out at Birmingham University, England, has already shown how to more than double the previous longest storage period and the problem can be regarded as almost solved.

Seedlings

The seedling stage starts as soon as germination takes place and can be considered to continue through the nursery phase. This is a purely arbitrary definition and in practice planting may take place at any time between 5 and 24 months. Between these ages the plant may have increased its total dry weight at least eightfold. About 80% of published work on the physiology of cocoa has been carried out on seedlings, mainly for the very practical reason that seedlings can be handled with far greater ease and in far greater numbers than adult trees. Very few of the results can be applied directly to mature cocoa and the reasons are worth considering
in some detail as they illustrate one of the major limiting factors in the application of existing knowledge to solving problems of declining production in many of the older cocoa producing countries.

The establishment and early growth of seedlings in the field is the most critical stage in the life of a cocoa plant as well as the most expensive for the farmer. The aim should be to provide and maintain conditions which are as nearly ideal as practicable, but the difficulty of achieving this is demonstrated by the results of a comprehensive trial in Ghana on the light requirements of 25 progenies from the Tafo breeding program; light requirements were found to vary from 20% to 100% full sunlight. This result is probably representative of any group of seedling progenies so that, logically, similar trials should be carried out on every progeny. Theoretically this is possible but the real problem arises when trying to produce even approximately uniform shade of a given density in the field, even assuming that genetically uniform material will be planted. It also means that results cannot be transferred from one country to another as both genetic material and climatic conditions vary and 100% light intensity in Tafo may be very different in terms of radiation units to 100% in, for example, Ecuador. This suggests that breeders and physiologists should collaborate more closely.

The Tafo work also demonstrated the considerable differences in drought resistance between progenies, vital information for marginal areas with uncertain rainfall, and a factor which should be given more weight in selection criteria.

Seedlings have also been used in the study of anti-transpirant chemicals and the resultant information has slotted into existing knowledge with no surprises and very few prospects of commercial application in the immediate future.

Stomatal behaviour and water relations of seedlings have been studied in Trinidad and Ghana. Current work on the subject in Ecuador has concentrated on mature trees under different ecological conditions. Within the next year or two it should be possible to draw a fairly complete picture of what was, before the advent of the automatic porometer and the pressure bomb, a subject involving more speculation than hard fact. Research in Ecuador on the physiology of water stress has shown that, under the climatic conditions of the Ecuadorian coastal plain, stress symptoms are not manifest for about two months after the end of the rainy season. This finding could lead to great savings in irrigation costs. The results may also indicate that stress could be avoided by a fairly massive leaf-fall which would reduce the photosynthetic surface of the tree and therefore reduce growth.

For reasons of convenience a high percentage of work with seedlings has been carried out in either greenhouses, gauzehouses, growth rooms, (e.g. Trinidad), or under artificial shade. The ability to control partially some environmental factors has produced an impressive amount of data on transpiration, flushing, radial growth, shade requirements and differences in such parameters between different cultivars. Unfortunately controlled or partially controlled facilities are not available anywhere in
the world to study the same phenomena in adult plants and extrapolation
from seedlings to adults is probably more difficult in cocoa than almost
any other crop plant.

The practical applications of the work on seedlings directly
concerned with growers' problems can be summarised as follows:

(a) Seeds must be planted into a large enough volume of soil of the
correct physical and chemical composition as to allow rapid
development of the seedling root system. This volume will depend
on the age at which the seedling is to be planted into the field.

(b) At no time during the above period should the seedlings be
subjected to marked water stress. To ensure this it is almost
axiomatic that some form of shading will be required, the degree
of such shading depending upon climatic and soil factors which
will require individual experimentation.

(c) Plants which do badly in the nursery almost never do well in the
field and should be discarded.

Planting Out

Surprisingly little physiological work has been carried out on
this important stage in the life of a cocoa plant, probably because of
experimental difficulties. It is not uncommon for up to 40% of seedlings
to fail within a year of planting, necessitating enormous expenditure on
infilling, cost of raising new plants and subsequent higher nursery costs,
etc. so it would appear justifiable to carry out much more work on planting
techniques. A recent project on the 'replant problem' which is now
underway in Ecuador may shed more light on some aspects of planting out,
but this project deals only with land which has borne cocoa in the past and
is not concerned with new plantings where the problems may be of a
different nature. There is some evidence that microbiological factors may
play a part in the poor performance of replanted seedlings but they appear
to be of minor importance in comparison to damage caused by disease,
insects and inadequate management practices. Much may be learnt from the
work on tea and coffee carried out over many years in India and Africa on
this topic and an appropriate selection of treatments based on those
results would obviate the need for cumbersome multifactorial trials.

Shade

More work is also needed to reconcile the physiological
requirements of the young plants and the practical means of meeting these
requirements in the field. To state that a given cultivar requires a given
percentage of full light intensity for optimum photosynthesis is fine but,
unless it is possible to achieve this with the very limited range of shade
tree species normally available, it may not be of great value. The subject
of shade in cocoa is still controversial and it is important to consider
the practical aspects in some detail. Shade may be defined as 'partial or
relative darkness'. Even the definition causes a problem, i.e. relative to
what? Without an absolute reference quantity the much quoted '20%, 50%
etc. of full daylight' is a meaningless figure and it is virtually
impossible to compare results of shade experiments carried out on cocoa in Ghana, Trinidad, Nigeria, Malaysia, Brazil, Ecuador or the Ivory Coast. This is not to say that the results of an experiment are not perfectly valid for the location in which the work was carried out, but making use of the information poses major difficulties since there is no practical way of achieving the exact shade density or of relating shade density either to absolute light intensity or incoming radiation. As the seedling grows it will be subjected to increased self-shading by upper branches and the light distribution curve changes dramatically until a gradient of from about 1% to 100% of full light is reached. The steepness of the gradient will depend on canopy architecture and this varies greatly among cultivars. Superimposed on this dynamic process is the increasing canopy development of the shade trees which reduces the quantity of light reaching the top of the cocoa canopy.

The spectral composition of the light is also changed due to differential absorption by the shade tree foliage. This oversimplified account indicates some of the complexities of the normal situation in a field of shaded cocoa. To this must be added such factors as root competition, both for water and nutrients between shade trees and cocoa, effects of shade trees on wind speeds, humidity and temperatures, and their interactions. Faced with such problems it is not difficult to understand why so little work has been done on mature cocoa.

**Mature Cocoa**

During the next decade physiological research must be concentrated on detailed investigations of the complex ecological situations existing in mature cocoa if a better understanding of declining yields, failure of replanting and generally unsatisfactory responses to what appear to be improved husbandry practices is to be obtained. The most important requirement is for long term programs, properly staffed and funded, in order that selected problems can be fully investigated. International cooperation in cocoa research exists in the study of some pathological problems and cocoa breeders have an informal international forum but as yet there has not been any similar attempt to bring physiologists together at an international level. The formation of such a forum will not by itself produce any results, but at least joint investigations could be planned and those countries with facilities to carry out research on some aspects of mutually important problems would know that scarce resources were not being wasted by duplication in other countries.

There are many investigations which at present can only be carried out in well equipped universities or research stations in developed countries and a great deal more use could be made of these facilities. A good example is the study of hormones in relation to flushing and flowering. Work has been done on this topic in Africa and Brazil but cannot advance much further than testing the effects of various hormones and hormone type substances on a range of plant responses. The interactions between individual hormones and carbohydrates for example cannot be studied without far more sophisticated equipment than exists in any cocoa growing country at the present time.
An excellent example of the type of work which can be carried out far from cocoa growing areas is that at Liverpool University over the past ten years. The early work on the control of shoot apex activity has led logically to experiments on shoot/root interactions and more recently to the carbohydrate metabolism of the young plant. This will inevitably lead on to a study of mature trees under field conditions provided there are adequate facilities in cocoa growing countries. Ivory Coast and France have collaborated to undertake field work in the tropics and more fundamental studies where adequate facilities exist.

More recently a similar arrangement has been made in Ecuador, where field work has determined the environmental conditions existing in mature cocoa fields and these conditions have been replicated in growth cabinets in UK to determine gas exchange by infra-red gas analysis on cocoa plants of similar genetic types and on leaves of comparable ages to those in the field. Results from these experiments can now be used to improve a proposed simulated model of cocoa growth. This model is one of the more interesting recent developments which, despite its obvious shortcomings, should provide a stimulus to physiologists to both validate the assumptions and fill in the gaps and, more importantly, to use the improved model to indicate the likely effect of management practices on the growth of the cocoa tree.

Disease and Decline

So far only the physiology of healthy trees has been considered and as yet there is not even a rigorous explanation for such a universal phenomenon as cherelle wilt. Indeed the physiology of the diseased plant is almost completely unknown and pathologists and physiologists have rarely collaborated in cocoa research, probably due to a shortage of both in most countries. In South America especially, such collaboration is essential if real progress is to be made. In Ecuador, (and probably in parts of Brazil), meristematic tissue is much more susceptible to Crinipellis, (witches' broom), than mature tissue and therefore young flushes are prime targets during the sporulation period of the fungus. Factors affecting flushing in mature cocoa are not yet well enough known to suggest cultural methods to try and manipulate the tree to produce most of its meristematic tissue outside the infection period and thereby avoid the heavy pod losses caused by witches' broom. The use of the growth retardant PP333 shows some promise in the manipulation of flushing and jorquette formation but it is doubtful if its use will ever be economic on mature trees although it may have a part to play at the nursery or transplanting stage where delay of jorquette formation during the disease period may give the plant a better start in life. Further work on these lines involving physiologists and pathologists could be of enormous benefit to the cocoa industry in the next decade.

The problems of the diseased plant are of relevance to the final physiological topic, declining yields in established cocoa. Although all tree crops show a decline in yield after a given number of years there is a tendency in cocoa for the decline to set in earlier and to be more rapid than was apparent 30-40 years ago if records are correct. There are various possible explanations for this, but few hard facts. In replanted cocoa it may indicate a 'replant disease' such as occurs in citrus and
apple and this is now under investigation, but it also occurs in areas which have not borne cocoa previously and other explanations must be sought. In some cases it is likely that the cocoa was planted without permanent shade trees and fertilisers were applied for a limited time. If the price of cocoa falls it is normal to stop applying fertilisers and this could well cause an irreversible decline in yield. In many other cases the reasons are obscure and once again the physiologist may consider the problem worthy of investigation as the economics of cocoa growing are clearly related to the longevity of the crop.

It is fairly simple to produce a list of physiological problems which remain to be solved but there are very few experienced physiologists actually working on cocoa in producing countries; moreover their number is decreasing. It is sad but true that, as the profitability of a crop declines, it is usually research that is one of the first victims of economy, if not in actual staff, then in the provision of the necessary equipment and facilities. Those research institutes with physiologists on their staff should concentrate their limited resources on the problems associated with establishment in the field, spacing viz a viz shade trees and competition (for water and nutrients), the growth of the tree in relation to disease (with pathologists), and the causes of premature decline in yield. More collaboration with universities and research institutes in advanced countries is essential as is long term planning with adequate funding.

3.4 Shade and Nutrition

Shade Requirements

Young plants need some degree of shade in the nursery and during the first years in the field. Shade is needed because cocoa leaves show a decline in photosynthetic rate when exposed to light intensities greater than 25 - 30% full sunlight. Shade is also needed to reduce air temperature and restrict air movement so that excessive moisture stress in the young plant is avoided. The need for shade decreases when trees grow older and their canopies are sufficiently developed to provide self-shading and later on mutual shading.

Once the canopies have closed, yields are usually higher under conditions of little or no shade. The larger leaf area and the higher photosynthetic activity of unshaded cocoa can only be maintained and result in higher pod production when trees are well provided with nutrients. Therefore fertiliser application is needed in lightly shaded or unshaded cocoa.

Complete removal of shade from a healthy stand of cocoa usually gives a dramatic increase in yield. In general the period of high yields does not last long and is commonly followed by a rapid decline of the plantation. Various factors are involved: excessive transpiration leading to moisture deficiency, lack of nutrients and increased insect damage involving die-back. From a practical point of view, a moderate shade will effectively prevent a premature decline of yields.
The Interrelationship between Light Intensity and Nutrition

The general trend in the yield of unshaded cocoa is illustrated in the no-shade treatments in figure 1 which also illustrates the interrelationship between shade and nutrient requirements. In this experiment with Amelonado cocoa in Ghana the original shade was too heavy for high yields and lack of light prevented full exploitation of the nutrients already present in the soil or added in fertilisers. Following shade removal the supply of soil nutrients became the next limiting factor which was in turn amended by application of fertilisers. Similar results were found in shade and fertiliser experiments in Brazil (see Table III.1).

Table 2. Effects of Shade Removal and Fertiliser Application on Mature Cocoa in Bahia, Brazil. Mean annual yields of 21 sites during the period 1964-73 (kg dry beans per ha).

<table>
<thead>
<tr>
<th></th>
<th>No fertilisers</th>
<th>Fertilisers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shade</td>
<td>907</td>
<td>1,258</td>
</tr>
<tr>
<td>No shade</td>
<td>1,064</td>
<td>1,680</td>
</tr>
</tbody>
</table>

Nutrient Requirements

The nutrient requirements of cocoa can be assessed by chemical analysis of trees at different stages of development and chemical analysis of the crop.

In vigorously growing Amazon hybrids about 200 kg N, 25 kg P, 300 kg K and 140 kg Ca are needed per ha to build up the frame and the canopy of the trees before pod production starts. Large scale immobilisation of nutrients in the vegetative parts continues during the early years of production. The quantities involved decrease later on and when the trees are fully developed they are exceeded by those annually removed in the crops. A crop of 1000 kg dry beans removes about 20 kg N, 4 kg P and 10 kg K. When the pod husks are also taken from the field the amount of K removed is increased more than fivefold.

To arrive at fertiliser recommendations, however, the short and long term nutrient supply in the soil should also be known. Soil analysis can help in this respect especially when soil data are available from sites with fertiliser trials. In that case they can help not only to explain fertiliser effects but also to predict responses elsewhere. Provided that combined results from fertiliser trials and soils are available, soil analysis can be developed as a satisfactory diagnostic method for fertiliser use, but this stage has been reached in only a few cocoa growing countries. Over the years, however, enough data have become available to establish some relationships between soil analysis data and growth and production of cocoa trees. Soil conditions under which responses to N, P and K are likely occur are given in order of importance.

(a) Response to Phosphate: Results from a large number of experiments in West Africa and Brazil indicate that P is the nutrient most frequently limiting production. In Nigeria responses to applied P are likely to occur on soils with less than 13 ppm available P in the top 15 cms of soil. Soils with less than 6 ppm are very deficient and those with 6-12 ppm moderately deficient in P. In Brazil criteria are used of 5 and 15 ppm available P. Table III.2 shows that P levels in the soil are sometimes correlated with the P contents of cocoa leaves.

Table 3. Relationship between the P Content of Cocoa Leaves and Soils, and Response to P Fertilisers in Nigeria

<table>
<thead>
<tr>
<th>%P in Leaves</th>
<th>Older leaves adjacent to the young leaves</th>
<th>Available P in the top soil (ppm)</th>
<th>Linear yield response in kg per ha per kg P₂O₅ applied</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.16</td>
<td>&lt; 0.11</td>
<td>&lt; 6</td>
<td>&gt; 3</td>
</tr>
<tr>
<td>0.17 - 0.20</td>
<td>0.11 - 0.13</td>
<td>6 - 10</td>
<td>1 - 3</td>
</tr>
<tr>
<td>&gt; 0.20</td>
<td>&gt;0.13</td>
<td>&gt; 12</td>
<td>no response</td>
</tr>
</tbody>
</table>

(b) Response to Nitrogen: Responses to applied N greatly depend on shade conditions and P nutrition. In heavily shaded cocoa application of N has either no effect, or it depresses yields. On P deficient soils there is no response unless P is given. Soil N is not useful in predicting N responses, but the N concentrations in the leaves are often helpful.

(c) Response to Potassium: Responses to K have been reported from few countries. In Malaysia response was related to levels of total extractable K below 0.40 - 0.55 m.e. per 100 g soil. K deficient cocoa occurred in Ghana on soils with less than 0.20 m.e. exchangeable K in the top soil (0-15 cm layer). In Brazil soils with 0.11 - 0.30 m.e. exchangeable K are considered deficient and with less than 0.10 m.e. very deficient. Low soil K levels are usually reflected in the K content of the leaves. Concentrations of less than 2.0% are an indication of deficiency.

It appears that Amazon hybrids are more demanding for potassium than the traditional cocoa cultivars.

The above criteria are derived from trials with mature cocoa. It is likely that they also apply to young cocoa but data are lacking to confirm this. The few trials on young cocoa have however given some other information:

- on soils cleared from forest only small amounts of N fertiliser are needed provided the parent material of the soil is not too poor.
- on less fertile soils other fertilisers are needed. Application of fertilisers (and on acid soil also lime) in the planting hole may stimulate growth provided the fertilisers do not contain N.
- fertilisers should be frequently applied in small quantities.
- response to fertilisers, especially N, depends on shade conditions.

Leaf Analysis

In discussing fertiliser responses nutrient concentrations in leaves were mentioned. Leaf analysis is, however, of limited value as a diagnostic aid in cocoa nutrition when it is not combined with soil analysis and fertiliser trials.

The fact that factors other than nutrient supply, especially light intensity and leaf age, affect leaf composition complicates the interpretation of results while there is a fundamental problem that leaf nutrient concentrations in the sufficiency range do not provide information for a quantitative fertiliser program. Therefore leaf analysis can only be used to detect excesses and deficiencies or an imbalance in nutrition.
Fertiliser Recommendations

(a) Young cocoa. As young trees exploit only a small volume of soil, fertiliser recommendations are of a general nature. An example is given in Table 4 which is meant for Amazon cocoa under conditions which are favourable for growth throughout the year.

Table 4. Manuring Program for Young Cocoa in Sarawak

<table>
<thead>
<tr>
<th>Months after</th>
<th>Fertiliser application per point (g.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>field planting</td>
<td>N</td>
</tr>
<tr>
<td>1</td>
<td>6.4</td>
</tr>
<tr>
<td>4</td>
<td>8.5</td>
</tr>
<tr>
<td>8</td>
<td>8.5</td>
</tr>
<tr>
<td>12</td>
<td>12.8</td>
</tr>
<tr>
<td>18</td>
<td>17.0</td>
</tr>
<tr>
<td>24</td>
<td>27.3</td>
</tr>
</tbody>
</table>


(b) Mature cocoa. A number of recommendations have been published which are based on soil and sometimes also on leaf analysis data. In the absence of these criteria, rates of 50-100 kg N, 25 kg P, 85 kg K and 15 kg Mg are proposed as a general guideline in which the highest rate of N is meant for lightly shaded or unshaded cocoa.

Needs for Further Research

The general principles of shade and fertiliser management are well known, but the existing knowledge is rarely applied. This means that the knowledge has not been tested under local conditions and has not been translated into clear recommendations. Following the success of the shade and manurial trial in Ghana large numbers of fertiliser experiments were carried out on farmers' Amelonado cocoa all over the producing areas of Ghana and Nigeria. Now that the more vigorous and earlier maturing Amazon cocoa is replacing Amelonado cocoa, new experiments are needed to investigate the fertiliser requirements of this cocoa under farmers' conditions. During the last two decades Malaysia, and to a lesser extent Indonesia, have become important cocoa growing areas. So far only a few fertiliser trials have been conducted and these did not take shade into account. There is thus a great need for more experiments:
(a) regional, statistically laid out shade and fertiliser experiments which should also have spacing treatments. Tree density is an important factor because of competition between trees for nutrients and light and the aspect of mutual shading.

(b) a network of smaller experiments in the major cocoa growing areas to test results of the regional trials on local farms and plantations.

At all sites nutrient supply from the soil and nutrient uptake should be monitored by soil and leaf analysis. Differential treatments should start during establishment. The trials have to last many years as it may take several years before effects show up and these vary in magnitude with age and development of the crop, external conditions and the length of the treatment period. For accurate measurement of yield it is imperative that throughout that period pests and diseases are properly controlled.

Effective pest control is a prerequisite for maintaining high yields in unshaded cocoa, and it is particularly in this field that further research and development of management practices are needed.

Research should also include the economics of the use of fertilisers and different shade regimes.

3.5 **Pollination**

As the cocoa bean is a product of pollination, it is self-evident that inadequate pollination will diminish the yield. Pollen transfer may be inadequate in two ways; insufficient numbers of flowers may be pollinated or each flower may receive less than the minimum amount of pollen required to fertilize enough ovules to "set" the flower.

Pollination must be considered together with compatibility. A cocoa tree is either self-compatible - fertile with its own pollen and that from any other cocoa tree - or self-incompatible, i.e. sterile with its own pollen and fertile only with pollen from certain other trees. All West African Amelonados, some Criollo and some Trinitario trees are self-compatible, but many Trinitarios and almost all Upper Amazons and their hybrids require cross-pollination. Planting patterns as well as absolute planting density appear to influence the behaviour of pollinating insects.

The large plantings of Amazon hybrids has increased the importance of cross-pollinating insects, although they have always been essential for high yields from Trinitario cocoa. Flower inhabiting insects such as aphids and thrips, and crawling insects, mainly ants, can effect self-pollination although they rarely transfer sufficient pollen from anthers to stigma to cause setting. Flying insects that visit cocoa flowers are essential for cross-pollination and adequate populations of such insects are a prerequisite for high yields from self-incompatible trees.
Ceratopogonid midges have been identified as the main treee-to-tree vectors of cocoa pollen in Brazil, Costa Rica, Ghana, Indonesia, Trinidad and Venezuela but they seem to be rare in Ivory Coast. These midges breed in moist soil, high in organic matter, and in rotting vegetation; the population tends to be high during wet periods and to diminish in the dry season. In Trinidad and Ghana Ceratopogonid midges are rarely found in flowers opening at the end of the dry season and at that time setting does not occur on self-incompatible trees.

Cocoa trees produce many more flowers than are needed for cropping; during the main flowering period less than 5% of flowers set, but when flowers are few 50% or more may be pollinated. When pollinating insects are prevalent and active, the number of developing pods ("Cherelles") that mature is limited by cherelle wilt, a physiological process analogous to fruitlet drop in apples and boll shedding in cotton.

The anatomy of the cocoa flower precludes pollination by any but very small insects which are highly susceptible to contact insecticides. This is an important consideration in pesticide applications during the flowering period. Fortunately the Ceratopogonid midges seem to be resilient species whose populations recover rapidly, either by wind dispersal from unsprayed areas or by replacement by newly emerged generations from breeding sites.

3.6 Replanting and Rehabilitation of Old Cocoa Farms

An individual cocoa tree growing in fertile soil can live for a hundred years or more and may yield well throughout its life. A whole field of cocoa trees will never survive that long, due to losses from pests, diseases or physical damage. The cocoa trees will go out of production at different ages, making it difficult for a farmer to decide when and how to replant or rehabilitate the field. It was observed in Trinidad that only 50% of trees survived 40 years and about 10% survived 60. One might therefore anticipate the economic life of a field to be about 40 years. Recent information from Malaysia indicates that highest cocoa yields are achieved at 15-25 years of age and that a profitable life span may be 50 years, but that from years 26-50 yields decline gradually and production costs rise steadily.

In the mid 1970s it was estimated that in Ghana there were 270,000 ha of cocoa over 30 years old, in Nigeria 290,000 ha of cocoa over 25 years of age and the comparable figures for Ivory Coast and Cameroon were 105,000 ha and 110,000 ha. In Brazil, there were 379,000 ha over 20 years old. Therefore a significant percentage of the world's cocoa trees have reached, or are close to reaching, the end of their useful economic life and techniques of rehabilitation or replanting are needed to enable growers to bring their cocoa fields back to profitability.

In the literature there has been some confusion in the use of the terms 'replanting' and 'rehabilitation'. Here rehabilitation is considered to be 'the process of restoring the yield of existing mature cocoa trees by improved cultivation and managements, whereas replanting is considered to be 'the planting of young cocoa trees where old cocoa trees used to grow'.

Partial Replanting Method

This was the method of rehabilitation recommended for Trinidad conditions in the 1950s. The basic concept was the replacement of the unprofitable trees over a period of years, so that eventually all the poor yielding trees were replaced. It involved at least 10 passages through the plantation spread over a five-year period to mark unprofitable trees, to prune weak trees, to plant temporary shade in the gaps, to clear field drains, to cut down the unprofitable trees marked previously, to plant young cocoa trees, and then fertilise, supply and prune the young trees. In the sixth year farmers were expected to start the exercise again in the same field with a view to replacing those trees which were then unprofitable. An attractive subsidy was offered by the Trinidad Government to growers provided they replaced at least 35% of the trees in any field at any one time. A large number of farmers did carry out such programs, but surveys of the method indicated that, even when properly supervised, partial replanting did little more than maintain the yield of the old field.

Complete Replanting after Clear Felling

Replanting after the removal of all shade and existing cocoa trees was also encouraged in Trinidad in the 1950s. A comparison of complete with partial replanting demonstrated clearly that complete replanting led to much higher yields and surpassed partial replanting in aggregate yield after five years. It is probable that complete replanting with or without the removal of the shade trees is the only appropriate method for areas in West Africa infected with cocoa swollen shoot virus or areas in Papua New Guinea infected with vascular streak dieback. The planting material used for replanting must be as resistant to the disease as possible and other steps should be taken to protect the young trees from re-infection.

Phased Farm Replanting

Under this method a portion of the holding is replanted annually each year until the whole farm has been replanted. This spreads the labour demand and ensures that the farmer is never totally deprived of cocoa revenue from his cocoa. Such a program will be widely adopted on plantations and the larger farms, but there is no intrinsic reason why with an appropriate extension input, such a program cannot be adopted by all cocoa farmers, however small. In Brazil farmers are encouraged to replant annually 10% their farm if the trees are over 40 years of age. The old cocoa trees are cut down and the area replanted within a season.

The "Turrialba" Method or Planting under Old Cocoa Trees

This technique was first described for 45 year old cocoa at La Lola Experimental Farm in Costa Rica. The shade trees in the old cocoa farm were poisoned or felled, banana temporary shade was planted and the farm was lined and holed at 3m x 3m spacing. High yielding cocoa hybrids were planted with fertiliser in the planting hole and permanent shade of *Erythrina* spp. or *Inga* spp. was established at a spacing of 20 m by 30 m. Fertiliser was applied at six monthly intervals and pests and diseases were controlled by regular spraying. The old cocoa trees were pruned about one
year after planting the young cocoa to achieve about 50% shade and are subsequently removed progressively so that all the old cocoa trees and all the temporary shade was cut down by the end of the third year. By this time the hybrids were yielding and the canopy had closed, and the permanent planted shade was then starting to give adequate shade for the young cocoa.

The success of replanting using the Turrialba method will depend on the ability of the labourers, supervisors and managers to adjust the shade correctly, to control weed growth, and to bring the young cocoa into bearing as quickly as possible. The correct regulation of shade will have a major influence on the yield of the planting when young and at maturity and will also be a major determinant in the cost of the operation. Considerable skill is required to estimate the number of shade trees and the numbers of branches of the old cocoa trees which should be removed to give the right shade level for the young cocoa trees. Many fields being replanted by this method have been failures because the farmer had not adjusted the shade correctly. The difficulty of doing this should not be underestimated and in most situations success will be contingent on the availability of a good extension service to assist and advise farmers.

In Ivory Coast this method of replanting has not had the success which it has had in Latin America. The fact that the old cocoa was not planted in lines made replanting difficult and further complicated the shade adjustment and was a major drawback. However, it should be noted that a significant hectarage of old cocoa not planted in rows has been successfully replanted in Brazil by this method.

Rehabilitation of Existing Trees

Rehabilitation may be achieved by the application of good husbandry to cocoa trees or to cocoa farms which have been allowed to degenerate. Some examples of successful rehabilitation by cultural means, including correction of shade, pruning, control of weeds, improving drainage, control of pests and diseases are documented. At Bunso, in Ghana, on 240 hectares of old Amelonado cocoa, yields were raised from 280 kg per hectare to 960 kg per hectare in five years. Similar results have been reported from Ivory Coast, and confirm that good husbandry alone may suffice to bring about very substantial yield increases. However, the majority of the world's cocoa is grown by small farmers, who need a considerable amount of advice and encouragement before they will abandon traditional practices. They must also have ready access to the necessary inputs and an effective marketing system. Any program of rehabilitation must tackle all these aspects at the same time if success is to be achieved. A farmer cannot spray his trees to control pests or diseases if he does not have a sprayer or cannot get the appropriate chemicals when he needs them.

In Brazil much of the older cocoa is over-shaded and therefore the first step in the rehabilitation of a field is often the reduction of shade by poisoning. Many other cocoa growing areas have similar programs and, while it is obviously important to review the shade level of old cocoa farms, care and restraint must always be exercised when reducing shade. Fertiliser must be available for application prior to the reduction of shade; the shade should not be removed all at once; regular treatment for
capsid is necessary as is a careful watch for other pests and diseases as the removal of shade changes the ecosystem dramatically which may cause unexpected problems.

Chupon Regrowth

Farmers have permitted chupon regrowth to fill gaps in the canopy since the earliest days of cocoa cultivation.

The method is used to fill gaps in the existing canopy, to replace branches or trees which have fallen over. If a cocoa tree is damaged it will usually produce a number of chupons, the two most vigorous of these should be selected and the rest removed. Earth should be heaped around the base of these chupons to encourage the formation of an independent root system. If necessary some of the branches of the surrounding cocoa trees can be trimmed back to allow the young chupon sufficient light. Under good conditions, the chupon will bear fruit after two years.

It is easy to explain the technique to labourers and small farmers in a series of simple pictures and no special equipment is needed for its successful adoption. Its use is best restricted to gaps of a few trees where restoration of a complete canopy is important, for instance, to prevent capsid damage. It is not appropriate for the rehabilitation of a complete field which would be better replanted or coppiced.

Coppicing

The removal of the main stem of a cocoa tree in order to permit the canopy to regenerate by chupon growth is known as coppicing. Coppiced trees show rapid regrowth but the fact that improved planting material cannot be utilized is a major drawback to the widespread adoption of this technique. This could be overcome by budding improved material onto the chupons. Early yields will probably exceed those of other methods of rehabilitation but there would be problems in getting smallholders to adopt the technique.

3.7 Priorities for Research

Agronomy

Agronomic research in the future should be orientated toward the cocoa farming system: in particular the use of cover crops and economically beneficial temporary and permanent shade trees. Future advances are dependent upon an understanding of the environmental physiology of the crop. Investigations are needed to determine the relationship between high sustainable yields and the role of water and light in the environment. It is unlikely that, at least in the foreseeable future, intensive orchard systems: dwarf trees, closely spaced with a deliberate short life span will be socially or economically acceptable among small cocoa farmers. However, such systems merit further research in view of their potential under estate management.
Physiology

A considerable amount of fundamental research is required on basic crop physiology; this needs sophisticated controlled environment, instrumentation and other facilities which exist only in advanced laboratories. Priority areas are:

(a) Effect of light and water on growth and flushing;
(b) Effect of light and water on flowering, setting and pod development;
(c) Relationship between vegetative growth and cropping;
(d) Seed physiology in relation to prolonging viability for transport and storage;
(e) Growth analysis – particularly the partition of assimilates and the components of yield. Such knowledge will enable breeders to select for desirable characters and agronomists to develop cultural practices leading to increased yield and quality.
(f) Hormonal control of jorquetting.

Rehabilitation

Much of the world's cocoa is old and declining in yield and research is required to devise appropriate methods of rehabilitation. Whereas the Turrialba method can be used in most of South America, it is not appropriate to West Africa because of capsids and cocoa swollen shoot virus. The potential use of coppicing, partial replanting or infilling needs to be compared with under-planting and complete clearing followed by replanting.

A replant problem has been identified in Ecuador. Current research is adequately funded but might need to be extended in other countries should the problem appear elsewhere. A specific replant disease would be a serious constraint to cocoa rehabilitation and replanting schemes.

Management to sustain yields, particularly of Upper Amazon and other improved material requires research. There is a widespread need to consider the interactions between variety, shade, spacing, thinning and pruning. It is essential that agronomic methods be devised to realize the potential of improved planting material.

The above priorities must be tackled in the cocoa growing areas and require long-term and adequately financed research projects.
IV. SELECTION AND BREEDING

4.1 Perspectives

Most of the main cocoa growing countries now have schemes aimed at producing improved planting material and several of these were started in the 1930s (e.g. Nigeria and Trinidad). The earliest objective was to improve yield while maintaining the commercial quality of the beans. It was soon recognised that most of the seedling progenies of high yielding trees were inferior to their parents and so selections were propagated vegetatively to form clones, of which the Imperial College, Trinidad, selections (ICS) are the best known.

In the late 1940s the hybrid progeny of crosses between different Upper Amazon types and between these and ICS Trinitario types were found in Ghana to be fairly uniform, early bearing and high yielding. Subsequently most breeding programs have aimed at the production of seedling progenies, restricting clonal propagation to the multiplication of parental selections for trials and seed-producing plots ("seed gardens").

In general, disease resistance has not been a primary objective because sources of strong resistance to pests and diseases have been lacking. The one major gene for resistance known in cocoa - the Scavina gene for witches' broom resistance - proved to be ineffective except in Trinidad where it was first identified. Similarly resistance against black pod disease, mediocre at best, was not generally effective, probably because the Phytophthora pathotypes differ from one location to another.

As emphasized in the chapter on diseases the main pathology problems are regionally restricted. Consequently the national cocoa breeding programs tend to have different aims and cannot be of much assistance to each other. The largest scale cocoa breeding project is that in Ghana with resistance to swollen shoot virus as its primary objective; this has continued (with periodic interruptions) for some 30 years. A wide range of genotypes has been introduced and tested without any strong resistance to the virus being identified. Nevertheless seedling progenies can now be produced in which only one third as many plants become infected as in the standard Amelonado type. This degree of resistance should considerably retard the rate of spread of swollen shoot into new cocoa farms, especially if infection pressure is minimised by sensible sanitation and isolation precautions.

One of the side-effects of the Ghana breeding program has been the common use of Upper Amazon types in other countries, resulting in new plantings with greater vigour than the previously used West African Amelonado and Trinitario material. This greater vigour is advantageous when the trees are young, for they bear sooner and more heavily than their predecessors and can be established even on degraded soil; but when mature the "hybrid" trees are too tall for efficient spraying and require more space than they are usually allowed if competition for light is not to diminish yield. Small crops in turn allow more growth and a "podless forest" can result.
There are now two challenges - one for the agronomist to ascertain how to maintain the new, more vigorous trees in high yielding condition, and another for the breeders to combine high cropping with restrained vegetative growth. We may find that the genetic constitution of cocoa precludes this and only the potions of the hormone physiologists can succeed in converting vegetative vigour into continuous heavy cropping by dwarf trees.

4.2 Genetic Resources and Breeding in Cocoa

The centre of diversity of cocoa is thought to be the Eastern equatorial slopes of the Andes in the Colombian, Peruvian and Ecuadorian border area, where a wealth of forms occurs. The centre of cultivation is undoubtedly Central America, where the crop has been grown for more than two millennia. During the long history of evolution and cultivation three broadly recognisable groups of cocoa types emerged. Probably the earliest cultivars were 'Criollo', fine flavoured cocoas which nowadays are cultivated on only a small scale because they tend to be difficult to establish, low yielding, sensitive to environmental stress and susceptible to pest and disease attack. The second major group is the Forasteros, which includes the Brazilian Comum and Para types, the Costa Rican Matina, West African Amelonado and F.J. Pound's Upper Amazon collections. The Forasteros, which are bulk cocoas accounting for about 80% of world cocoa production, are relatively robust in cultivation. The third major group is the Trinitarios, which are either relatively recent hybrids between Criollos and Forasteros or intermediate types. The Trinitarios are a diverse and much studied group which constitutes a valuable source of variability for use in breeding programs. Traditionally, cocoa genotypes have been assigned to one of these three groups on the basis of vegetative, pod and seed characteristics, but many intermediate types are now known and the significance of the classification is declining.

Genetic resources at present available include wild types collected in or near to the centre of diversity, remnants of nineteenth century and earlier cultivations and selections made by breeders. The Trinidadian and Costa Rican germplasm collections are now recognised as universal gene banks accessible to all breeders. The International Cocoa Genebank, Trinidad encompasses both the Cocoa Board and the University collections, including the Imperial College Selections (ICS) from the pre-1930 Trinidad populations, the 'Upper Amazons' collected by Pound in the area of the Headwaters of the Amazon, Pound's Ecuadorian refactario selections, W.S. Chalmer's collection from the Oriente region of Ecuador, wild cocoa from Colombia, cultivated cocoa from throughout the Western hemisphere and selections from half a century of cocoa breeding. Most of the world's cocoa breeding is based on the Trinidad collections, and particularly Pound's Upper Amazons. The Costa Rican collection at Turrialba includes many Criollos obtained throughout Latin America. The International Board for Plant Genetic Resources recognises that there is an urgent need to collect cocoa germplasm because exploitation of the Amazonian forests threatens genetically diverse wild cocoa populations, while remnants of the Latin American Criollo plantings face extinction as they are replaced by Forastero cocoa varieties and other crops. During the last decade extensive collecting work has been carried out in Brazil and Ecuador, but the land areas are so great and communications so poor that
progress has been slow, tedious and expensive. The urgent task of preserving the Latin American Criollos has hardly begun. Systematic collection in NE Peru has a high priority because the indigenous cocoa populations may be particularly variable.

Quarantine

Throughout the world individual breeders have assembled working collections, most of which include remnants of early local cultivation, supplemented by material imported from Trinidad and Costa Rica. While cocoa germplasm can be distributed as seed, most breeders prefer vegetative material because it retains its genetic identity and the elite crosses of one country can be reproduced for testing in another, although there have been several instances of mis-identification arising from confusion of labels. In order to minimise the risk of spreading pests and diseases to new areas, phytosanitary regulations govern movement of both seed and vegetative material; the regulations regarding vegetative material being the more stringent. All vegetative material passing from the Western Hemisphere to Africa or Asia must undergo a period of intermediate quarantine in a temperate climate. The Royal Botanic Gardens, Kew, England and the United States Plant Introduction Station, Miami, Florida, U.S.A., provide quarantine facilities, the latter also maintaining a permanent collection of breeding material at Mayaguez, Puerto Rico. A new quarantine facility has recently been completed in Barbados and is run by the International Cocoa Genebank, Trinidad.

Breeding Objectives and Methods

In most cocoa breeding programs the primary objective is to maximize potential yield; secondary objectives include a low level of economic loss from the locally most damaging pests and diseases. Most breeders seek vegetative vigour in the pre-bearing phase because it leads to ease of establishment, which facilitates rehabilitation programs, and precocity, which is an important economic consideration. The desired quality characters of the finished cocoa depend on the country's traditional product, most commonly beans larger than 1 g with less than 15% shell and of acceptable flavour. Attempts to select fine flavour cocoas, which might command a premium on the world market, have been largely unsuccessful.

Cocoa can be propagated vegetatively, permitting the breeder to select clones for farmers' use as well as facilitating large scale production of single- and multi-cross hybrids and easing the problem of germplasm maintenance. Adoption of clones as planting material would simplify breeding programs because exceptional single plants could be propagated for large scale use. However, vegetative propagation is more expensive than raising seedlings, and the establishment and early maintenance of clonal plots is more difficult and thus costlier. Very few countries now make commercial plantings of clonal material, most encouraging the use of hybrid varieties. The position may change if the recently developed micro-propagation techniques for rapid multiplication of clones, now used for some temperate tree crops, should prove workable with cocoa.
Cocoa is an outbreeding species with flowers adapted to cross-fertilisation by Ceratopogonid midges. In many populations, out-crossing is ensured by a series of incompatibility alleles which show complex dominance and independence relationships and include at least one allele for self-compatibility. The occurrence of heterosis in crosses between unrelated parents was first recorded in the late 1940s and is now the basis of most breeding programs.

Hybrid varieties are obtained in three ways. The first to become available in large quantities, the 'mixed Amazons', were developed in West Africa by rapid multiplication under open-pollination of largely unselected F₁ hybrids between Pound's Upper Amazon populations. They were distributed as F₁ and F₄ seeds. This 'variety' has been variously described as a semi-synthetic or a panmictic population. The parental components were not rigorously tested before the variety was synthesized because it arose from a need to make available vigorous planting material for replanting farms which had been destroyed as a result of swollen shoot disease. F₁ hybrids, the second type of variety, are usually crosses between self-incompatible individuals from Pound's Upper Amazon populations and selections from unrelated populations, either local farmers' varieties, or vegetative introductions from elsewhere, particularly the Trinidad ICS series. A range of selection procedures of varying sophistication have been used to aid selection of parents. F₁ hybrids are described as two-way, if the Upper Amazon is a pure type, or three-way if one of the parents is an inter-population F₁. Seed is produced on a large scale by clonal multiplication of the parents, followed by either natural or manual pollination. The third type of variety, called a polycross, is obtained by vegetatively propagating and interplanting several parents and relying on natural pollination to produce a mixture of hybrids.

Each type of variety has known or theoretical defects. The mixed Amazons show the high level of tree-to-tree variation to be expected in early synthetic generations. Development of synthetics is an approach to cocoa breeding which would generate varieties with a broad genetic base but the time required to grow enough generations for varieties to stabilise militates against their use. Although single F₁ hybrids are quickly and easily produced, there is a danger in that monoculture may express unexpected defects, such as cross-incompatibility restricting cropping or susceptibility to hitherto unimportant pests and diseases. If physical mixing of the output of several seed gardens could be ensured over long periods, random mixtures of several F₁ hybrids of diverse parentage would have the greater stability expected of the multi-line type of variety. Polycross hybrids avoid some of the risks associated with F₁ hybrids but are unlikely to be widely adopted because evaluation of all the individual components would require very large scale breeding trials.

Consideration has been given to generating a mixture of F₁ hybrids based on single female parents chosen from Pound's Upper Amazon material because it gives the greatest heterosis in the widest range of combinations and so is the most likely basis of hybrid varieties for the foreseeable future. Since up to ten years are needed for a seed production plot to reach full production, the quickest way to produce new varieties is to choose and propagate Upper Amazons for use as female parents, simultaneously evaluating candidate pollen parents. The breeder's trials
could be completed by the time the seed production plots were ready. Great care must be taken over the choice of female parents; in order to maximise the genetic base there should be several taken from two or more contrasting populations. The males can be drawn from a broad genetic base and eventually most will be discarded. The final choice should be four or more of different origins which, when crossed on to the chosen female, will give high performance hybrids with trees of similar vegetative vigour, height and habit so that they can be grown in random mixtures. A mixed variety such as this minimises the danger of both cross-incompatibility restricting cropping and of unsuspected susceptibility to pest or disease attack. The seed is produced by manual pollination, so the pollen parents could be changed at will. In this way, breeders can exploit a steadily larger genetic base and suitable elite pollen parents could be considered as the female parents in the next cycle of breeding.

Pound's Upper Amazon populations are valuable sources of disease resistance. Breeders and pathologists have identified resistance to some strains of witches' broom disease (*Crinipellis perniciosa*) and black pod disease (*Phytophthora* spp.) in the Scavinas, resistance to mal de machete (*Ceratocystis fimbriata*) and to cocoa swollen-shoot virus (CSSV) in the Iquitos Mixed Calabacillos (IMCs), and resistance to black pod disease in the Parinaris. There appears to be strain variations in *Crinipellis* and several *Phytophthora* species occur so with both the resistance of individual parents differs between countries. Similarly, progenies which have effective tolerance of infection by the relatively mild Nigerian strains of CSSV are sensitive to the more virulent Ghanaian ones. Disease resistance has been found in other populations; for example some of the Keravat Trinitario selections are resistant to vascular streak dieback disease (*Oncobasidium theobromae*) and there are many reports of *Phytophthora* resistance in Trinitarios. Many of the varieties developed so far can be traced to a narrow genetic base. It can be argued that disease resistance has been found among Pound's Upper Amazons and the Trinitarios because these populations have been most intensively studied. It is at least possible that equally intense examination of other populations would reveal even more variation, not only in disease resistance but in other characters too. The nine Upper Amazon seedlings which have dominated cocoa breeding in West Africa and elsewhere (IMC47, 60 and 76; NA31, 32, 33 and 34; PA7 and 35) were a random selection taken in the first place to demonstrate to students at the former Imperial College of Tropical Agriculture. The narrowness of the genetic base in use can be illustrated in another way by considering experience in Trinidad, with its long history of cocoa breeding and extensive germplasm collections where no more than 40 parents have been fully evaluated.

There are several reasons why cocoa breeders have worked within this narrow genetic base. Firstly, spectacular results were obtained by using Pound's Upper Amazon material as parents in the early 1950s, and for several years breeders were fully occupied in evaluating and exploiting the new hybrids. Secondly, the narrowness of the genetic base has been recognised only slowly perhaps because the plethora of codes used for germplasm has been associated with wide variation in it. Thirdly, expansion of the working germplasm collections has been hindered by the inherent difficulties of mobilising additional germplasm. But a fourth reason is probably the most important: the level and continuity of funding
and resources of personnel devoted to cocoa breeding have rarely been commensurate with the task in hand or with the potential benefits to be gained from a successful breeding program. Few cocoa breeding programs have had unbroken management for fifteen years, sufficient time for two generations, whereas only five years are needed for ten to fifteen generations in a crop like rice.

Variety Evaluation

Cocoa breeding is both long term and expensive; a generation takes up to a decade and evaluation of a single hybrid at one site requires at least 0.1 ha of land. Over ten years a breeder wishing to plant 50 new combinations a year would require over ten years at least 50 ha of trials, an area which should be doubled to allow for germplasm collections, clonal multiplication and ancillary investigations. The large burden of management, recording, data processing and interpretation of such trials is only part of the breeder's task, because he must also assemble and evaluate a germplasm collection, elucidate the inheritance of economic characters and endeavour to understand yield-limiting factors.

The nature of the cocoa crop determines the field technique which must be adopted by breeders and in turn leads to difficulties in estimating the agricultural potential of new varieties. Conventionally, formal experimental designs are used in variety evaluation and a compromise is required between the number of varieties entered on the one hand and the number of trees of each variety tested on the other. In cocoa trials, it is unusual to have more than 200 trees of a variety, often the number is less than 50, divided into small plots. Problems in interpretation of results then arise from interaction between the varieties, which favours those with greater vegetative vigour, as well as masking any effect due to limited cross-compatibility within varieties, because pollinating midges ensure adequate movement of compatible pollen across the relatively short distances involved. A further difficulty arises when the optimal management practices differ between varieties; there have been few comparative experiments testing West African Amelonado and Upper Amazon hybrids where the spacing and shade regimes have been better suited to Amelonado than to the hybrids. The difference in management requirements may explain why cocoa breeders rarely use the most testing control, such as Amelonado in West Africa and Trinitario mixtures in Trinidad.

The multi-harvest nature of the cocoa crop and the fact that wet cocoa beans have to be fermented and dried to become saleable, greatly complicate yield estimation. Depending on the assumptions made, estimates of yield can vary up to two-fold. The best estimate is one based on the area occupied by a plot, with due allowance for interaction between varieties, the actual number of pods harvested (excluding all pods lost from disease and other causes) and an accurate estimate of the wet-to-dry weight conversion ratios. Even so, the estimate may not be a reliable guide to possible yields under farmers' management and it is preferable to take the yield of new varieties relative to those in cultivation, recognising that management procedures may have influenced the conclusion. Only in countries with estate management e.g. Malaysia, is it possible to make a valid comparison between breeders' and farmers' results. In most other countries, including much of West Africa and Latin America, the
assessment of new varieties under traditional smallholder management is beset with difficulties.

In trials there is a natural temptation to optimise the management inputs, including use of the best land. It may be more realistic to follow the practices adopted by the more progressive local farmers, making changes only when there is a demonstrable economic benefit and the additional inputs are readily available over long periods. It is desirable that variety trials should be replicated over sites and that the basic husbandry options should be tested, but resources rarely permit this. When varieties have been tested at different sites the better ones have usually given the largest response to improved conditions.

There are then, real difficulties in assessing cocoa varieties, which are compounded by the pressure put on breeders for early release of promising new varieties for commercial exploitation. Ideally there would be an intermediate stage of variety assessment outside the breeders' control, but this is unlikely to arise because it would be too costly and time consuming. An alternative procedure would be to put experimental plantings of promising new varieties under farmers' management at an early stage in evaluation. It is suggested that plots of up to 1 ha in size could be planted and regularly assessed, without an experimental design or formal recording. This would quickly reveal the characteristics of a new variety, including yield, and possibly make the breeder more aware of farmers' needs.

**Yield-limiting Factors**

Hybrid varieties based on Upper Amazon parents have not always fulfilled their promise of high yield. On some occasions this may have resulted from limited cross-compatibility between trees which did not reveal itself until single varieties were planted in large plots. On others, expectations were too great, because yield projections were based on uncritical evaluation of small scale trials. However, it is now accepted that in some environments Upper Amazon hybrids are liable to grow vegetatively rather than to crop. The Upper Amazon material evolved under conditions favouring trees which compete successfully with neighbours of the same and other species, producing only sufficient seed to ensure survival of the species, and may respond to stress by growing vegetatively rather than producing seed. In otherwise good environments, excessive vegetative growth may be triggered by factors which prevent cropping, for example, diseases such as *Phytophthora* spp. and *Cnipezzis perniciosa*, which destroy flower cushions, or by inadequate cross-pollination. It is also possible that hybrids involving some Upper Amazon material are less fertile than longer established varieties, leading to more frequent failure of fertilisation of individual ovules and greater likelihood that fertilised ovules will abort and flowers will be shed when plants are under stress. In the Trinidad Cocoa Board's breeding program selection for yield components was successful, indicating that a high level of fertility can be attained. The relationship between growth and yield in cocoa is poorly understood and it is important to know whether the vigour induced by crossing unrelated populations is associated with a danger of poor productivity of healthy-looking trees, because if so the effect might be common to all highly vigorous varieties, whatever their parentage. If the
environment is a major factor determining the relationship between growth and crop, then management practices might be used to regulate the balance, implying that there should be close collaboration between breeders and agronomists. Compared to West African Amelonado, vigorous hybrids appear to require wider spacings, less shade and more regular harvesting; without the latter, pests and diseases can build up rapidly. Given sound (not luxurious) management these hybrids undoubtedly outyield Amelonado in poor environments, and in many replantings there is no alternative to using them, because Amelonado and similar varieties would be difficult if not impossible to establish and slow to commence bearing.

Future Prospects

In conventional breeding, availability of resources will determine the attention paid to breeding better parents. It should be possible to fix desirable variation within major populations, either by sib-mating and selection or by use of double-haploids if they can be produced in sufficiently large quantities. Attempts will be made to combine the attributes of different populations by selection among hybrids between them, and success may depend in part on whether multi-way crosses show as much heterosis as two-way crosses, and on whether maximum heterosis is required.

In areas where Upper Amazon hybrids tend to grow vegetatively rather than crop, the breeder's objective may change from maximising potential yield to maximising realisable yield, with more parents drawn from cultivated rather than wild populations. Robust varieties will be of special importance to low income farmers and it is important to maintain establishment ability and precocity. Where high yields can be relied upon and sophisticated management is available breeders will select for characters calculated to reduce production costs, such as large pods which would simplify harvesting and pod breaking, low frequency of harvesting and small tree size. Rapid advances will come with these highly heritable characters if vegetative propagation is adopted. *Theobroma cacao* is a malleable species which responds to selection, so that better varieties can be expected, provided that breeders are given sufficient resources and work towards well-defined objectives.

4.3 Priorities for Research

Several required characters, such as specific disease resistance, have not been found among cultivated types but may occur in wild cocoa which is, however, threatened by forest destruction. Further collection, propagation and distribution of germplasm for evaluation in breeding centres should be given high priority.

Current breeding programs are based on a narrow range of geno-types; this should be broadened by using more of the available material as well as new collections.

Cocoa requires further genetic study to elucidate genotype/environment and growth/yield interactions. A proper evaluation of genetic resources will necessitate a well coordinated, inter-disciplinary approach. An effective team should comprise, in addition to the
geneticist, a pathologist, a physiologist and an agronomist, with perhaps additional backup from manufacturers in assessing bean quality. The inheritance of the characters that influence yield, including growth habit, precocity and disease susceptibility, urgently requires investigation.

Most of the national cocoa research centres employ too few plant breeders for progress to be made on a scale commensurate with the value of the crop. Furthermore, cocoa's protracted generation time operates against continuity of breeding programs. Cocoa breeding should have a higher priority in research programs because improved planting material is a means of raising production without increasing inputs.

An international centre with secure long term funding should be established for the maintenance and distribution of germplasm, development of breeding methods, elucidation of major economic characters and yield-limiting factors and evaluation of combining ability in parental types.
V. PROPAGATION

5.1 Perspectives

Traditionally cocoa has been propagated from seed, but open-pollinated seed from selected trees showed little improvement over unselected seed because of the high variation in Trinitario cocoa, and also because the selected trees were probably cross-pollinated with low yielding neighbours. In the much more homogeneous West African Amelonado, seedling populations are uniformly true to type.

Vegetative propagation for commercial plantings was introduced with the ICS clones in Trinidad in the 1930s. The best of these clones were widely planted not only in Trinidad but also in several South American countries. When it was found that crosses between types from different origins gave a comparatively uniform population of precocious, high yielding seedlings, there was a return to the planting of seedlings in place of cuttings. Vegetative propagation by rooted cuttings is still used for commercial plantings in a few special cases as in Jamaica where ICS 1 is propagated because it shows resistance to black pod disease. Vegetative propagation by cuttings or budtings is essential for the planting of seed gardens. In Malaysia where the techniques of budding are well known, it is the preferred method of vegetative propagation and will increasingly be used in commercial plantations.

In the future, micropropagation will probably play a role, but so far research has not found a way of rapidly propagating cocoa in vitro. When the technique is perfected it should provide a means of quickly multiplying plants of new clones, of transferring germplasm in sterile conditions and of storing a germplasm collection for long periods.

5.2 Seed Production

From the early 1950s, the main breeding programs in Ghana and in Trinidad have been directed towards the production of specific crosses between clonal selections and most of the other major cocoa producing countries have since adopted a similar approach to developing improved varieties. To reproduce these single crosses, it is necessary to propagate their parents vegetatively so that seed-gardens or seed production plots can be developed. Methods of vegetative propagation are well known, and the choice of whether rooted cuttings or budding on to rootstocks, either in the nursery or in the field, are used depends on local convenience and the availability of propagating material.

Most of the earlier seed-gardens were designed to produce seed of one cross from natural crossing between trees of the two parental clones, which were established in mixed plantings using various planting patterns. Such seed-gardens could be used because in the crosses at least one of the two parents was self-incompatible and would not set pods from self-pollinations.

Where hybrids are developed, tested and released from breeders' trials as a series and no differential adaptability of the individual hybrids is detected, the planting of a mixture of these hybrids is usually
recommended in case unsuspected defects occur in some of them. For this purpose a multi-clonal seed-garden can be established to produce a hybrid mixture. With a series of varieties where all parents are self-incompatible and some are common to different individual hybrids, the common parents can be used to link together sections of the garden which each produce a different cross. A layout of this type was used in Sabah to produce a range of \( F_1 \) Amazon hybrids and \( F_0 \) Amazon X ICS Trinitario crosses and is shown below:

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<tr>
<th>Clone</th>
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<table>
<thead>
<tr>
<th>Seed</th>
<th>PA 7 x ICS</th>
<th>Mixture</th>
<th>NA 32 x PA7</th>
<th>Mixture</th>
<th>IMC 60 x NA32</th>
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<tr>
<td>Types</td>
<td>40 and</td>
<td>of PA 7x</td>
<td>and</td>
<td>of NA32 x</td>
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Whatever seed-garden layout is employed, precautions have to be taken to avoid the entry of 'foreign' pollen from nearby cocoa. In the Ghana seed-gardens, where one parent was a self-compatible pollinator this was planted as a perimeter zone eight rows deep around the seed-producing core.

The advantage of seed-gardens which rely on the natural cross-pollination between parental clones is that once established the supervision required is little more than that needed for a similar planting of commercial clonal cocoa. In some countries, Malaysia for example, where the component clones were well balanced for their vegetative and flowering characters, seed-pod production from this type of garden has been satisfactory. In Ghana and Nigeria the gardens planted to produce the Tafo Series II hybrids were not successful. The pairs of clones in these seed-gardens were dissimilar in their characteristics; the Upper Amazon clones were all vigorous and floriferous while the Amelonado and Local Trinitario parent clones were weaker and less free flowering. Imbalances developed quickly such that the growth and flowering of the weaker clones were suppressed. Consequently, cross-pollination was inadequate and pod production low.

A major disadvantage of relying on natural pollination is that production follows the natural cropping cycles and a high proportion of all pods may ripen at times when they cannot be used either for nursery sowings or for direct planting in the field. This problem is particularly marked in West Africa where the peak crop months are from September to mid-December while seeds pods are required either from April to September for direct sowing or from January to April for nursery plantings.
The use of manual rather than natural pollination for seed-
production offers a number of advantages, the most important of which are:

- usually greatly increased pod production at negligible
  additional costs;
- ability to produce seed at the time it is needed;
- greater control over the level of cropping;
- easier control of pod damaging pests and diseases as all the
  pods are of a similar age and concentrated on the lower trunk
  surfaces so that fungicides and insecticides can be applied
  economically and efficiently with hand sprayers; and
- flexibility in the choice of pollen parents.

Experience with hand pollination in several cocoa growing
countries has shown that the necessary skills can be acquired with only a
short period of training. The main requirements are manual dexterity and
good eyesight. Where local customs permit, young females generally achieve
the best results as their hands are smaller and more supple.

When flowers on mature trees are reasonably plentiful,
experienced workers can complete 150–200 pollinations an hour, or some 750
to 1,000 in a five hour working day. The rate of pod recovery to
pollinations made varies in different seasons and with the size and
condition of the trees, but a 50% recovery rate is a reasonable
expectation.

The layout for a seed-garden designed for pod production by
hand-pollination is simple where at least one parent is a self-incompatible
clone, frequently an Upper Amazon selection. This parent, or the more
vigorous and productive if both are self-incompatible, can then be planted
in a mono-clone block from which seed pods will be produced. The other
parent, or parents, is planted in a smaller plot, reasonably adjacent, to
provide the flowers which will be used as a pollen source. The advantages
of using mono-clone blocks over the earlier bi- or multi-clonal
seed-gardens are:

- more economical use of land as perimeter guard trees and
  internal pollinators are not needed;
- smaller units are possible than if bi-clonal gardens are
  planted;
- female parent trees can be used to produce seed-pods at an
  earlier age;
- probably greater purity of seed production;
- propagation and planting of a seed production plot can begin as
  soon as the female parent has been selected and while trials of
  candidate pollen parents are still in progress. This reduces
  the delay in introducing new varieties;
several different pollen parents can be used with the same female and these can be varied when better combinations are found;

- weak, or inbred, clones can be used as male parents as these can be grown in separate plots free from competition from more vigorous neighbours; and fewer natural sets occur in these blocks

5.3 Vegetative Propagation

Budding has the advantages of being a skill that is easy to learn and of making the best use of a limited amount of scion material. It has the disadvantage of not allowing regeneration of the clone from basal chupons, since these will arise from the rootstock, but this can be overcome by budding below the cotyledonary node. The use of pigmented seedlings for green clones and vice versa allow the chupons from each component to be identified. So far only seedling rootstocks have been used and these impart some variation, the amount depending on the parental type. Budding can be used for replacing undesirable trees with improved selections by grafting basal chupons.

Cuttings can be rooted in propagating frames by the method developed in the 1930s for the ICS clones. Careful selection of material, preferably from young, shaded plants is essential. The base of each cutting must be treated with an auxin and the rooting medium must be free-draining. The propagating frame must provide sufficient light for photosynthesis but at the same time high humidity must be maintained. Polythene covers over raised beds have been used successfully instead of frames, as has continuous or intermittent mist application.

Whatever the method adopted for rooting cuttings, a hardening-off period during which humidity is decreased and light intensity increased is crucial for the survival of the plant.

Micro-propagation has recently been investigated at several research centers. This involves the production of rooted plantlets from apical meristem shoot-tips and provides a rapid means of multiplication of clonal material. However a method has not yet been perfected for cocoa. It would be a valuable means of transporting sterile material through quarantine, but because of the capital investment needed in laboratory equipment and the on-cost of growing plantlets to the size when they can be planted in the field, micropropagation is unlikely to provide planting material as cheaply as conventional cuttings.

5.4 Priorities for Research

On seed production more information is needed on:

- the purity of seed. Many normally self-incompatible clones can be induced to set a proportion of selfed seeds when pollinated with a mixture of their own pollen and pollen from another cross-compatible source. Such mixed pollinations can be expected
to occur frequently in seed-gardens which rely on natural cross pollination between parental clones. Mixed pollinations can also occur when hand-pollinations are made on to unprotected flowers, although to a lesser extent. Work undertaken in Ghana some years ago indicated that the level of 'contamination' resulting from unprotected hand-pollinations on freely flowering Upper Amazon clones did not exceed 5%.

- judging the bearing capacity of trees. When a large number of hand-pollinations are made during a short period, the normal crop-limiting mechanism of physiological wilting does not function. Consequently, it is possible to over-crop trees with resultant die-back.

On vegetative propagation we need to know more about stock-scion interactions. The major need is a method of micropropagation, particularly of growth substances that will induce rapid proliferation of plantlets in culture.
VI. DISEASES OF COCOA

6.1 Perspectives

Most of the diseases have markedly different geographic distributions. The history of cocoa production in several of the main producing countries has a similar pattern - introduction, followed by rapid expansion and then a decline caused by either an indigenous or an introduced pathogen. In Colombia, Ecuador, Trinidad, Surinam and Venezuela the fungus *Crinipellis perniciosa* which causes both malformation, "witches broom", of vegetative parts and rotting of the pods, was largely responsible for a decline in production, augmented in the first two countries by *Moniliophthora roreri* attacking only the pods. The latter fungus has spread northwards in Central America and has recently reached Costa Rica. Witches' broom is endemic in the Amazon Basin and its spread to Bahia would be disastrous.

In the region of the world where cocoa planting has expanded most recently, South East Asia, a new disease called vascular streak dieback has caused severe damage, effectively preventing the establishment of the West African Amelonado type. The causal fungus, *Oncobasidium theobromae*, has presumably spread from undetermined indigenous host plants.

Swollen shoot, a virus disease, is a major cause of the decline in cocoa production in Ghana and now threatens Togo. Less virulent strains of the virus occur in Nigeria and the Ivory Coast but have not become epidemic. Although avirulent virus diseases have been reported from Trinidad, Sri Lanka and Malaysia, the only region where a virus disease is of primary concern is West Africa, Ghana in particular.

The one major disease that is not regionally restricted but occurs almost wherever cocoa is grown is black pod. Until recently this was attributed entirely to *Phytophthora palmivora*, a fungus that has attained a very wide distribution within the humid tropics perhaps because of the diversity of its host range. Three other species of *Phytophthora* are now recognised as causing black pod.

The incidence of black pod disease is weather-dependent, being highest when much rain coincides with the later stages of pod development and lowest in that part of the crop that matures in the dry season. Consequently losses differ not only from one country to another but also from year to year depending on the amount and seasonal pattern of rainfall.

In areas where pod infection by witches' broom and *Moniliophthora* is prevalent, the incidence of black pod is partially masked and losses attributed to it would almost certainly increase if either of these other diseases were selectively controlled.

Here we have dealt only with the major diseases of cocoa. Other diseases occur sporadically or locally, notably *Ceratocystis* wilt, outbreaks of which have been serious in Brazil, Trinidad and Venezuela. Certain varieties, e.g. ICS1, are very susceptible while some of the IMC clones from Iquitos island in the Amazon are resistant.
Spread of the pathogen, which is associated with bark-boring beetles (*Xylophagus* spp.) can be diminished if mechanical damage to the bark is avoided during weeding and harvesting. Curative measures are unlikely to be economic; the infection is usually well established before symptoms become conspicuous.

6.2 Phytophthora Disease

Cocoa black pod disease, in which pods rot as a result of infection by species of the fungus *Phytophthora*, is estimated to destroy on average 10% of the world crop annually. However, this average value conceals great variation: the actual percentage in any year differs greatly between different cocoa growing areas, and varies widely with differences in rainfall. Moreover cultivars differ somewhat in susceptibility.

Besides attacking pods, the cocoa *Phytophthoras* can attack leaves and chupons in unusually wet seasons, but the damage seems not to be of economic significance. They can also attack flower cushions, and more importantly, can cause stem canker. In general, stem canker seems to be more damaging on some Trinitario clones and hybrid Amazon material than on West African Amelonado and Bahia Comum and as the two latter types predominated for many years stem canker became the "forgotten" disease. Many years ago canker was considered to be the most important disease of cocoa and there is little doubt that it is more important today than is generally realised. The widespread planting of Amazon hybrid material will result in greater incidence of canker. Cankers can arise from pod infections but other, so far unknown, means of spread probably exist. Cankers may heal spontaneously, or under other conditions may kill the trees. More information is required, both on conditions predisposing to stem canker, and on its control.

Formerly all black pod was attributed to one species, *Phytophthora palmivora*, but it is now clear that although this species is found in all cocoa growing areas, it is much less destructive in Nigeria and Cameroon than a new species which has been named *P. megakarya*. In Cameroon, Brazil and probably elsewhere a third distinct species is also destructive to pods; this has been referred to as a form of *P. capsici*, but it seems likely that on further research it will prove to be another new species. The possibility of a fourth species (*P. citrophthora*) in Brazil now exists. These species are distinct from one another in cytology, morphology, ecology and pathogenicity. It seems likely that some of the reported differences in susceptibility to black pod between different cultivars when tested in different countries may be due to this as the tests were necessarily made with isolates of the pathogen belonging to different *Phytophthora* species. It is not known whether the apparent absence of *P. megakarya* and *P. capsici* from certain areas is due to their non-arrival or to some unfavourable conditions of the environment or of the cocoa tree. Two considerations follow: (i) quarantine precautions are necessary to prevent these black pod *Phytophthoras*, which now have a restricted geographical distribution, from spreading into non-infested areas; and (ii) new cocoa cultivars will have to be tested for resistance to local isolates of the pathogen in each growing area, and in conditions where those cultivars will be grown.
Control by Fungicide Spraying

Numerous experiments show that copper-based fungicides (or organic fungicides such as the dithiocarbamates) can give good control of black pod, although unfortunately in the wetter areas sprays have to be applied so frequently that control by fungicides is often not economic. Details of quantities and frequency of application have to be worked out locally because effectiveness depends on many factors. In Ghana and the drier parts of the Ivory Coast spraying is usually unnecessary; parts of Bahia can achieve reasonable control with two annual applications; whereas for much of West Africa 10-12 applications are required. It seems that field plot experiments to adapt fungicides and techniques of application to local conditions will be needed for a long time to come, depending on amount and timing of rainfall, age and height of trees, even social conditions.

In West Africa trees are commonly too tall to allow adequate spraying and complete harvesting, consequently spores produced on infected pods high in the canopy often infect pods lower down, even if sprayed with fungicide. An urgent problem is for pathologists and agronomists to co-operate to try to find ways of keeping the canopy down to a manageable height so that efficient harvesting and spraying can be achieved.

Protective sprays, although capable of being effective, have drawbacks: cost of fungicide, equipment and labour for numerous spray applications; erosion of deposit by rain. These factors make the possibility of a systemic fungicide very attractive. Hitherto most such fungicides have been inactive against members of the genus *Phytophthora*. However, systemics active against *Phytophthora* are now being produced; one of them metalaxyl (Ridomil) has been very promising in black pod control, but, as with many other highly specific fungicides (in contrast with general poisons like copper) there are signs that variant forms of the pathogen which can tolerate metalaxyl are being selected. (Metalaxyl has already been withdrawn for certain applications with other crops for this reason.) Research may eventually produce systemic anti-fungicides to which the fungus cannot readily develop tolerance.

Meanwhile, systemic fungicides have another drawback in that chocolate manufacturers may look with some suspicion on relatively unknown organic chemicals that are active within the plant tissue, because of possible health risks to consumers, and the risk of effects on flavour in the final product, chocolate. Nevertheless, systemic fungicides active against *Phytophthora* deserve great attention because of their obvious advantages.

For some time to come systemics are unlikely to replace surface protectant fungicides. Meanwhile new fungicides must be tested. There is also a need to develop better methods of application including low volume and more efficient sprayers, to further reduce costs.
Breeding Resistant Cultivars

An ideal solution to the black pod problem would be to breed cultivars resistant to *Phytophthora*. Existing cocoa cultivars differ in their inherent susceptibility. Progress towards this ideal solution may ultimately be expected from the breeding programs now being pursued in various tropical countries, using the increasing range of genetic material that is becoming available from collecting expeditions into forests containing indigenous *Theobroma cacao*.

However, breeding for resistance against a living organism (in this case a *Phytophthora* species) is likely to be slow and fraught with disappointments. When cultivars are bred for properties such as high yield, precocity, or flavour, these characteristics once achieved, are likely to be retained permanently. By contrast the resistance of a cultivar to a variable pathogen with a breeding system of its own, is often found to be transient, because mutants of the pathogen which are able to 'break' the characters of resistance often evolve quite rapidly. This has happened repeatedly with cultivars bred for resistance to cereal rusts, and more relevantly with potatoes bred for resistance to *Phytophthora infestans*. With knowledge of these limitations, techniques can be applied for producing durable resistance but progress is likely to be slow.

As already mentioned, a further complication is that each breeding program can only test progenies against the locally prevalent species of *Phytophthora*, because it is an unacceptable risk to import foreign pathogens for testing in the field or even in the laboratory. Consequently new cultivars will have to be tested where bred, and then re-tested when taken to another area where different species of *Phytophthora* prevail.

Obviously breeding for resistance should be continued, with benefit of the best advice available. Any imported cultivars must be tested against local strains of the pathogen before being introduced on a large scale. Quarantine precautions must attempt to prevent geographical spread of strains. Of all solutions to the cocoa black pod problem breeding for resistance offers the best prospects in the long run.

*Phytophthora* as a Cocoa Root Pathogen

Until recently *Phytophthora* on cocoa roots has received little attention. Mounting evidence indicates that it is also a root pathogen, though still of unknown economic importance.

It has been known for many years that *P. palmivora* can be isolated from soils of cocoa plantations by 'baiting out' with pod material. Some authors even regard it as a soil inhabitant. Some years ago *P. palmivora* was found in roots of cocoa seedlings in plantations in Ghana, and a technique for testing for resistance by root inoculation was developed at Tafo. Studies by the International Cocoa Black Pod Research Team at Gambari, Nigeria, showed that soil is one of the major sources from which *Phytophthora* reaches the pods, either when splashed up by rain, or carried up by 'tent-building' ants. Further it was found that infection of pods near ground level is increased by removing the normal mulch of old fallen leaves which covers the floor of the plantation.
During the International Team's work in Nigeria both *P. megakarya* and *P. palmivora* were isolated from a large proportion of samples of washed and surface sterilized fibrous feeding roots of cocoa trees, but they were both species are pathogens on cocoa roots seems clear (we have no evidence yet on the behaviour of the third or fourth cocoa *Phytophthora* species (*C. 'capsici' or *P. citrophthora*). These facts raise points which need investigating. Are the on roots economically harmful to cocoa trees? Is some of the variability in yield between individual trees in a plantation caused by differences in amount of root infection? Can the amount of root infection (and hence the amount of inoculum reaching the ground surface) be influenced by chemical treatments such as a dry powder copper fungicide applied to the ground? In any case a copper powder at the surface could be active at the crucial soil and litter interface.

These possibilities are worth exploring because making the poor yielding trees in the plantation more productive is the most obvious way of increasing yield.

**Speculative Long Term Projects**

Existing control measures - fungicides, hygiene, resistant cultivars - are all capable of improvement. There are also some more novel possibilities which seem worth exploring: suppression of basal pods (especially on peasant farms in West Africa); and manipulation of the cropping period (more feasible on plantation scale cocoa).

(a) Suppression of basal pods. In West Africa (though less so in South America) pods occur on the trunk right down to ground level. In Nigeria it was noted that a greater proportion of pods became infected below 1 metre than at greater heights on the tree, and it was suggested these pods be eliminated as an aid to control. Experiments by the International Black Pod Research Team at Gambari showed no benefit from removing all basal pods as they developed, whereas copper sprays gave reasonable control of black pod. There remains the possibility that for a smallholder unwilling to spray at all, some way of permanently suppressing flowering at the base of the tree might be useful, provided that the tree as a whole compensated for having fewer pods at the base (in a zone at increased risk from infection by splash from soil) by producing more pods higher up the tree (in a zone of decreased risk). On general grounds such compensation might be expected. The possibility is worth exploring, but would need extensive experimentation, using perhaps chemical destruction of lower flower cushions or their surgical excision.

(b) Manipulation of cropping period. The long period of five or six months during which each pod hangs on the tree exposed to *Phytophthora* infection, and the overlap between generations of pods, means that for many months of each year the trees carry susceptible pod tissue. This characteristic of the cocoa tree aids the spread of *Phytophthora* from older to younger pods, and may render control by fungicides uneconomic due to the large number of applications that are required.
Possibilities exist for intervention to alter the normal flowering cycle. Up to now this has been explored mainly in an attempt to force the tree to mature more of its crop in a drier season when the risk from black pod is less than during rains. There may well be a need to shift the cropping period to other times within the rainy season with the aim of inducing nearly synchronous cropping within a given area. For instance a smallholder may omit to harvest his early light crop if quantities seem insufficient for satisfactory fermentation. Thus a massive inoculum may be left on the tree and the later main crop is put at risk. Eliminating the early crop altogether by clearing trees of pods followed by artificial pollination, could be explored as a way of shortening the period during which pods are at risk, with the advantages of fewer spray applications, and fewer harvesting rounds. Plantings on different parts of a farm might be arranged to mature at different times. This needs co-operation between pathologists, physiologists and agronomists, and possibly breeders, because large scale artificial pollination would be easier on self-fertile trees.

6.3 Witches' Broom and Frosty Pod Rot Diseases

Witches' broom disease is caused by *Crinipellis perniciosa* and frosty pod rot by *Moniliophthora* (*Monilia*) *roreri*. Both diseases cause losses of pods which can be severe, but *C. perniciosa* also causes malformation of vegetative shoots which gives rise to the name - witches' broom. Both these diseases are South American in origin and seriously limit cocoa production in a number of Latin American countries. More attention than ever is being paid to witches' broom disease particularly in Brazil, where the stability of Amazonian colonisation schemes - largely based on cocoa cultivation - is directly threatened, and in Colombia, where recent movement of the pathogen from the Pacific coast into the more important upland cocoa-growing areas is causing alarm. Renewed interest has been generated in *M. roreri* following its discovery in Costa Rica. However, because *M. roreri* does not affect overall tree growth, it must always take second place to *C. perniciosa* in those regions where the two pathogens occur together.

Control of Witches' Broom

The degree of infection by *C. perniciosa* is affected by the amount of shade, heavy shade reducing infection but it may also reduce yield. A balance has to be found. Infection can also be reduced by pruning all the vegetative brooms once or twice a year. However this task is likely to be very laborious in the first place.

Many fungicides have been tested but so far none has proved to be effective and economic.

The ultimate control by means of resistant planting material is more promising. The original search for resistant material in the Amazon basin produced some selections which proved resistant in Trinidad but were not resistant to the disease in Ecuador. This suggested that there might be different races of the fungus and this has been shown to be the case by research carried out at Imperial College, London.
Control of *Moniliophthora*

The removal of mummified diseased pods is essential but will only alleviate the losses to this disease. There are no effective fungicides and little evidence of resistance.

The only known means of reducing losses is to avoid the disease by hand-pollination at the end of the wet season. This is effective in Ecuador where the wet and dry seasons are distinct and prolonged.

The following is a country-by-country review of on-going research.

**Brazil**

Witches' broom disease is not present in the main cocoa area in the State of Bahia but occurs widely in the Amazon Basin. A team of pathologists is being assembled to cope with the present problems and the future threat that the pathogen poses to cocoa cultivation throughout the Amazon basin. *M. roreri* is absent from all cocoa-growing zones.

Research is still at a relatively early stage but some significant findings concerning host-pathogen interactions have recently been reported. This involves a new concept in plant pathology, whereby the host contributes positively to the establishment of the pathogen by producing a metabolite which affects its morphogenetic development. This is of immediate relevance to the breeding program and the feasibility of exploiting the metabolite to develop a rapid method for testing resistance is being investigated.

An international research project to study the epidemiology of the disease has recently been established in Rondonia. The behaviour of the cocoa tree and the development of the disease is being studied in relation to the microclimate.

The discovery of *C. perniciosa* on other hosts, not related to cocoa, in the Brazilian Amazon supports the hypothesis evolved in Ecuador, that specific races or varieties of the fungus exist.

An alternative method of control through the use of fungal hyperparasites or their metabolites is being tested and preliminary results are promising.

**Ecuador**

There are numerous on-going projects involving both *C. perniciosa* and *M. roreri*.

Pichilingue has an important germplasm collection of relevance to disease resistance but only a small part has been evaluated. In this context, a significant development has been the initiation of a project to collect germplasm in the Oriente region and to re-establish the clonal collection.
Most recent research has been concentrated on basic epidemiology. The life cycle of *M. roreri* is now better understood, particularly the methods of inter-crop survival, and it is thought that good crop sanitation will be the main contributing factor to reduced disease losses and increased yields.

Spore-trapping studies have shown that *C. perniciosa* is well adapted to long-distance airborne dispersal and can penetrate any meristematic cocoa tissue including unhardened flushes and cambium exposed during wounding. The ability of the pathogen to remain dormant within cocoa tissues and to sporulate on brooms on the ground has also been investigated in order to revise and improve phytosanitary pruning recommendations.

Conclusions

Due to the general debilitating effect of *C. perniciosa* on cocoa trees and the exploitation for cocoa cultivation of forest areas where the disease is endemic, research on witches' broom disease must take priority and in recent years there have been encouraging advances made in increasing our understanding of how the pathogen functions. This should enable us to tackle the breeding program more logically, and it is felt that long-term control must be through the use of less susceptible or resistant varieties.

Each country should continue with its own epidemiological investigations, preferably in such a way as to permit comparisons between countries. Certain lines of research can only be successfully pursued by co-operation with outside specialist organisations. There is now a need for a more sophisticated approach in order to identify both the host metabolite(s) which promotes parasitism by maintaining the fungus in the Monokaryotic or Biotrophic form and the substances produced by this fungal form which upsets the host's metabolism leading to a hormonal imbalance and broom formation. This will necessitate biochemical investigations which can only be undertaken in a well-equipped and adequately staffed laboratory. The facilities and expertise for such studies can probably be found at present only in countries such as the UK and USA. Moreover, the typification of fungal races or strains must be carried out in non-cocoa-growing areas, since this involves the assembling of geographic isolates of *C. perniciosa* and comparing them under uniform conditions, and again this suggests an American or UK input. The importance of such a study has been highlighted recently by the discovery of *C. perniciosa* on a Solanaceous weed in the Brazilian Amazon. Although the strain is apparently not pathogenic to *THEOBROMA*, it provokes distortion, swelling and cankering of tomato plants and hence the implications extend far beyond the boundaries of cocoa research.

In the USA, the University of Florida has maintained an on-going interest in witches' broom disease and particular emphasis has been placed on the genetics of *C. perniciosa* and factors governing sporulation. Recently, several UK universities have begun projects on witches' broom disease as a direct result of developments in Brazil and Ecuador. The mechanism involved in broom formation is being investigated at Aberystwyth.
where advanced biochemical techniques are available, and these will be further utilised to characterise the toxic metabolites produced by certain fungal hyperparasites of *C. perniciosa*. Several pathogenic races have been identified at Imperial College (London University).

Scientists in various countries have attempted, or are attempting to produce basidiocarps of *C. perniciosa in vitro* but as yet this has not been achieved in a true culture medium. It is essential to continue such work in order to obtain a reliable source of inoculum for resistance studies, and to identify the products released during broom degradation which probably trigger sporulation. This research can be undertaken most successfully in a centralised location where a range of fungal isolates can be tested. Without centralisation there may be a duplication of work and a consequent waste of limited resources.

Very little is known about the biochemistry and physiology of *M. Roreri* and since it may share a common origin with *C. perniciosa*, it is suggested that these studies should be combined with those of *C. perniciosa*.

6.4 Vascular-Streak Dieback Disease

**Historical Background**

Vascular streak dieback was not recognised as a specific disease in Papua New Guinea until 1966 but early reports suggest that it was present in the 1930s. An epidemic broke out in several provinces in the period 1959 - 1961 causing a great deal of damage. The causal fungus, *Oncobasidium theobromae* was identified and described in 1971 at Keravat and placed in the *Tulasnellales*, a group within the Basidiomycotina. The life cycle and infection biology were described in 1972, and since that time the biology of the fungus has been further investigated in Papua New Guinea and Malaysia.

In Malaysia, plantings in Trengganu State were badly damaged in the 1950s. The disease is less severe in the drier western areas of Peninsular Malaysia than in Trengganu, or in Papua New Guinea. Recently it has been causing concern in Sabah and in the Philippines.

**Distribution**

The disease is found throughout Peninsular Malaysia and Sabah. There are confirmed reports that it occurs in Sumatra and Hainan Island and unconfirmed but reliable reports that it occurs in India, Sarawak and the Philippines. It is widespread in Papua New Guinea being found in all the major cocoa-growing areas of the main island and New Britain. The disease does not occur in New Ireland or the North Solomons Province: the latter is the major cocoa-growing area in the country. It has not been reported from the Pacific Islands east of New Britain.
Symptoms

Symptoms of vascular streak dieback have been fully described from Malaysia and Papua New Guinea. In Papua New Guinea the yellow leaves with a characteristic pattern of discrete green spots are a very familiar symptom. In Malaysia they are rather less common but the 'calcium deficiency' symptom of interveinal necrosis on shoots arising from infected branches is more common than in Papua New Guinea. The presence of brown streaks in the xylem of living but diseased branches is probably the most reliable diagnostic symptom. The white sporophores of *O. theobromae* which form on leaf scars are also diagnostic but are only seen in wet weather and are rare in Malaysia.

Life Cycle

The fungus grows only in the xylem of living cocoa except during the production of sporophores and the penetration of young leaves by germinating basidiospores. The fungus cannot survive in dead wood. The whole life cycle is carried out on cocoa though an alternative host must occur. During very wet weather the fungus grows out of scars left by freshly fallen leaves and forms white sporophores on the bark surface. Dew does not provide sufficient free water for sporophore growth. They become fertile in 3-5 days and liberate basidiospores into the night air with peak production at 01.00 hours. Spore production is inhibited by light. Spores have no dormancy and germinate immediately on the surface of young cocoa leaves. Dew provides adequate water for spore germination. The fungus grows into the leaf veins and thence into the stem, where it is present for 3-5 months (6 weeks in very young seedlings) before the first leaf turns yellow and falls. In this time the branch may have put on one or possibly two leaf flushes. Sporophores may be formed as soon as the first leaf falls but are not formed once the leaf scar has hardened (a few days) even if the weather is suitable. Sporophores may form on branches of any age. No other spore types are known.

Epidemiology

Spores of *O. theobromae* are inactivated by sunlight within 30 minutes but under normal conditions the peak production of spores at 01.00 hours ensures that there are about 5 hours of darkness in which spores may be dispersed. The winds which occur at night in lowland cocoa blocks are normally very light and rarely exceed 1 m/sec. Thus the disease spreads slowly within a block of cocoa: a 50% fall-off in percentage infection at a distance of about 10 m from the infection source when young seedlings were planted close to old infected cocoa has been recorded. It has been calculated that the theoretical maximum distance a spore could travel in still air was 182 m but turbulence caused by occasional night storms could increase this figure many times. There are a few records of the disease appearing suddenly in areas many miles from the nearest infected cocoa: such infections could have originated from the unknown alternative host. Despite the recognised presence of the disease in East New Britain for 25 years it has never spread to the west coast of New Ireland, a distance across the sea of 35 km.
Sudden increases in severity followed by a more gradual decline are characteristic of vascular-streak dieback. In a trial where the number of new infections was recorded monthly, up to twenty-fold increases within two months were recorded. These sudden upsurges in disease can be associated with periods of wet weather 3-5 months previously. Attempts have been made to quantify this observation so that upsurges can be predicted from meteorological observations. Advance prediction would be useful to growers in the forward planning of labour allocation for pruning. However, this prediction cannot be made with precision because of the wide variation in the incubation period, which is affected both by the age of the tree and the climatic conditions during incubation. Attempts to correlate peaks in disease incidence with previous infection periods have also failed for this reason.

Control

(a) Chemical. There are no effective chemical controls for vascular-streak dieback. Protectant fungicides are unlikely to be effective because of the need to protect rapidly growing leaves under very wet conditions. Some control was obtained at Keravat by fortnightly applications of copper oxide and in Malaysia by fortnightly applications of bitertanol but such frequent applications would not be commercially feasible. Many other fungicides including some systemics have been tested but all were completely ineffective. The consistent nature of the failure of systemic fungicides to control vascular-streak dieback suggests that they are not being placed in the plant in the right place to inhibit fungal growth. The fungus penetrates through rapidly expanding young leaves and grows directly into the xylem of the stem. Systemic fungicides applied to leaves tend to remain there; if redistribution to other parts does occur it must be via the phloem and this has seldom been demonstrated. It is therefore possible that the fungus and the fungicides never come into contact.

Soil drenching might therefore be more effective because uptake would possibly occur in the xylem, but soil drenches could never be feasible on a commercial scale.

(b) Pruning. In the absence of chemical control, the only way to remove vascular-streak dieback from infected trees is to prune out the infections as soon as they are observed. The Department of Primary Industry in Papua New Guinea recommends that trees should be pruned regularly, at least once a month, from the time of planting until the canopies meet. Pruning is also carried out to control the disease in Malaysia. Infected branches should be split and pruned 30 cm below the last visible brown streak in the wood. Pruning has two beneficial effects, in removing the infection from the tree and also limiting disease spread by removing the spore source. There is no need to remove or burn prunings because the fungus rapidly dies once the severed branch starts to wilt.

(c) Resistance. At the time the epidemic was most severe at Keravat, clonal selections from local Trinitario cocoa were under test for a hybrid breeding program. These trials were badly affected by the disease but large differences in resistance were apparent and emphasis was given to
selecting resistant clones. These were then used for distribution to growers. In an early field assessment of resistance the most susceptible clone sustained fifteen times as many infections as the most resistant one. The susceptible clone was subsequently completely obliterated by the disease and third generation open-pollinated progeny from it which survive are also very susceptible. The most resistant clones are still resistant twenty years after they were selected.

Trinitario and Upper Amazon selections at Keravat have shown a wide range of susceptibility but good resistance is readily found. Amelonado cocoa introduced to Keravat in 1963 was susceptible in its early years but the performance of surviving trees has been quite good. In Malaysia, Amazon hybrids are more resistant than Amelonado. This has been partly attributed to the greater vigour of Amazon hybrid material.

Resistance to vascular-streak dieback appears to be stable, which is probably a result of the contribution made by many mechanisms to the overall effect. Field testing remains the only available method for assessing resistance in clones or progeny. An inoculation technique has been developed using basidiospores but its use has been frustrated by the erratic availability of spores from naturally occurring sporophores. The recent discovery of a way of inducing dual cultures to sporulate should lead to a more regular availability of spores and the consequent application of the inoculation technique to screening for resistance.

Quarantine

Within Papua New Guinea there is a total ban on the movement of planting material (including seed) into the areas free of vascular-streak dieback. An unfortunate consequence of the ban has been that these areas have not benefitted from the superior planting material developed at Keravat. This is critically important now that much cocoa has reached replanting age and should be replaced by improved planting material. In 1974 a very elaborate quarantine scheme was devised to introduce clonal material into the disease-free area. This scheme involved microscopic screening and two separate isolation periods, one on a small off-shore island.

It became clear in 1980 that this scheme, although successful, was not going to provide sufficient material in time to meet the demand. A quarantine station was therefore built on Bougainville island in the North Solomons Province and screened budwood was flown to it. The scheme is slightly less safe because the intermediate quarantine is within the disease-free area itself rather than on an isolated island.

To date, several hundred budsticks have been screened microscopically at Keravat before transfer to intermediate quarantine at one of these two sites. No vascular-streak dieback has been detected in any of the sticks and no infection has ever occurred in the preliminary quarantine shadehouse. There are four separate points in the process where the disease could be detected:
(a) In the nursery where the plants are selected for preliminary quarantine.
(b) By inspection during preliminary quarantine.
(c) By microscopic examination.
(d) By inspection during intermediate quarantine.

This scheme is very elaborate and could probably be simplified without introducing any significant risk. Microscopic screening is very tedious but is a very safe and thorough check where only small amounts of material are involved.

The possibility that vascular-streak dieback could be transmitted by seed has often been discussed. A number of considerations suggest that the disease would not be seed transmitted. The fungus only grows naturally in the living xylem so hyphae would have to be in the xylem of the testa, embryo or cotyledons at the time of planting. Such an infected seed would probably not germinate and even if it did it is unlikely that the fungus would be able to sporulate from such a small amount of mycelium before the seedling died. However, this is all speculation and the only indisputable fact is that hyphae of *O. theobromae* have been found once in the placenta of a pod taken from an infected branch but they were not found within the seeds. Therefore the transfer of pods cannot be allowed at present. The pod stalks can be screened microscopically for hyphae and over a half million seeds had been sent to disease-free areas by December 1983 after microscopic screening.

It should be easy to prevent the introduction of vascular-streak dieback into other cocoa-growing countries. There should be a total ban on the movement of rooted planting material or seed. The only transfer that should be allowed is of budwood, taken either from disease-free areas (all the improved planting material in Papua New Guinea is, or will be, available from the North Solomons Province), or from quarantine houses after microscopic checking.

**Current Research**

Active research on vascular-streak dieback is being carried out in Papua New Guinea and Malaysia. At Keravat, three aspects are under investigation:

(a) Systemic fungicides for disease control in young plants.
(b) Growth of the causal fungus in culture.
(c) Field screening of young plants as an alternative to screening by controlled inoculation.

In Malaysia, research is being carried out on the growth of the fungus under Malaysian conditions. They are also investigating fungicides for disease control.
6.5 Virus Diseases of Cocoa

Virus infection of cocoa trees is widespread in West Africa having been found in Sierra Leone, Ivory Coast, Ghana, Togo and Nigeria. It is rare elsewhere and localised where it occurs in Trinidad, Indonesia, Sabah and Sri Lanka. As no virus disease has been found in cocoa in South America where the species originated, the viruses have probably spread to cocoa from indigenous plants where infection occurs. There is no evidence of spread by man moving infected cocoa plants from one country to another and this seems improbable because the viruses are not seed-borne; a possible exception is the disease in Sabah, which may have been introduced in clones imported as plants or budwood.

The Viruses

Economically the most important is the swollen shoot virus (CSSV) that occurs only in West Africa. CSSV is highly variable in its virulence to cocoa, occurring in numerous strains which differ in the leaf symptoms, the size of the swellings, if any, that they cause, and the rate at which infected trees are debilitated or killed. All strains of CSSV are transmitted by mealybugs, Planococcoides njalenesis and P. citri being the main vectors.

Two viruses certainly unrelated to CSSV have been described. Cocoa necrosis virus occurs in a few isolated outbreaks in Nigeria and Ghana. It is probably transmitted by nematodes, as it is serologically related to other non-cocoa viruses that are, but the vector is unknown. Cocoa yellow mosaic virus is known from one, or possibly two, outbreaks in Sierra Leone.

A relationship of the cocoa virus in Trinidad to CSSV is indicated by their having mealybug vectors in common. Until serological tests have been carried out it is premature to regard them as related. No infected trees have been found in Trinidad for many years.

Swollen Shoot Disease

The disease occurs in most areas where cocoa is grown in Ghana and Togo where its effects have been most severe but it is not prevalent in Ivory Coast and is localised in Nigeria. Attempts at eradication by removing infected trees have succeeded where discrete outbreaks have been treated, regularly re-inspected by trained observers, and re-treated until no further infection was found. The efficiency of treatment was greatly improved by removing apparently healthy trees which might have been recently infected. Eradication campaigns probably prevented swollen shoot from becoming epidemic in Ashanti. In the Eastern Region of Ghana, however, the disease had already become epidemic when eradication was first attempted, and in the most intensely affected area (between Suhum, Koforidua and Tafo) infection was widespread 40 years ago and continues to be so in replanted cocoa farms. Some 186 million infected trees had been cut down by 1982 and probably as many remain, although the official figure a few years ago was only 40 million.
The main impediment to improving the control measures, apart from the enormous size of the operation, is the small area of each individual farm within more or less continuous cocoa plantings. As treatment by cutting out infected trees is not now compulsory, small, irregularly shaped areas of infected cocoa are removed and the land replanted close to or adjoining untreated farms with many diseased trees as sources of reinfection. Only by removing all infected trees (preferably all cocoa trees) from much larger areas and replanting in blocks preferably of several hundred hectares could re-infection be kept within manageable limits.

**Ecological Aspects**

Intensive studies of the mealybug vectors have revealed the complexity of their association with many ant species and wild host plants. Introduced predators and parasites have failed to become established, and chemical control did not diminish vector numbers sufficiently to reduce the rate of virus spread.

The known natural host plants of the virus are tree species some of which are common where cocoa is grown. There are, however, marked regional differences in distribution, providing evidence for different origins for groups of virus strains. The two most clearly defined groups are those in the extreme west of Ghana that probably spread to cocoa from *Cola chlamydantha* trees, a species which grows only in that high rainfall area; and those in the extreme east of Ghana and also in Togo that probably originated in *Adansonia digitata*, the baobab tree commonly found in savannah vegetation.

The most virulent group of CSSV strains prevalent in the Eastern Region of Ghana (and occasionally in Ivory Coast, Togo and Nigeria) may have spread to cocoa from one of several forest tree species known to be susceptible, such as *Ceiba pentandra* (kapok), *Cola gigantea* and *Sterculia* spp., but the evidence is too scanty to determine now whether trees of these species became infected from cocoa or were sources themselves.

Wild hosts seem the most probable source from which isolated outbreaks start in cocoa. These primary infections are relatively rare, and most cocoa trees become infected from others. Tree-to-tree spread among contiguous trees is the predominant mode of progression; but spread over distances measured in hundred of meters by wind-carried insects probably accounts for the development of "satellite" outbreaks, each of which enlarges so that farms are destroyed much more rapidly than would be expected from the observed slow rate of spread at the periphery of discrete patches of infected trees.

Because cocoa pods are favoured feeding sites of the vectors, man has probably aided the dissemination of the virus. New infections were often found at pod-husk sites where pods were taken to be opened. Lorry loads of pods were transported from infected farms to provide seed for new plantings which would often be close to existing cocoa farms.
Virus Resistant Cocoa

A search for sources of resistance began as soon as the virus cause of swollen shoot was established. A cross-section of the genetic variation assembled in collections in Trinidad was introduced as seed to Ghana, including types originating from South and Central American countries. Among these were some from the Iquitos region of Peru that were more difficult to infect and less severely affected by the virus than any other cocoa so far tested. The degree of resistance is inadequate to prevent trees becoming infected when grown among diseased trees in trial plots, but the rate of infection is usually proportional to the susceptibility as calibrated in laboratory tests. Combined with tolerance, which varies with environmental factors so far undefined, this resistance can be expected to diminish the virulence of the disease and the speed at which it destroys new plantings.

The multiplication and distribution of resistant planting material presents no intrinsic difficulties as the use of seed gardens to produce hand-pollinated seed is well established in Ghana. Agronomically the resistant types are more easily established and can be selected so as to be no more susceptible to fungus diseases than Amelonado cocoa. The remaining problems are logistic - and of course the search for more highly resistant types must continue.

In recent years many introductions to Ghana have been made via quarantine at Kew and this continues as new accessions become available from the Upper Amazon tributaries where much wild cocoa remains. Many of these recent introductions have been tested for virus resistance, but so far none has proved more resistant than the types from near Iquitos. As this resistance occurs in the absence of virus disease, there is no reason why it should be unique; further exploration should reveal other sources with a different genetic basis. The Iquitos resistance is highly polygenic or "horizontal" and could be expected to be durable. Its mechanism is obscure but seems to be linked to impediments to virus multiplication; it is not related to vector feeding behaviour.

Future Policy

(a) Control measures. There is ample evidence that swollen shoot outbreaks can be controlled by a rigorously applied policy of cutting-out infected trees if sufficient neighboring symptomless trees are also removed to eradicate latent infection. In practice this implies careful re-inspection at frequent intervals and prompt removal of new infections. Where swollen shoot is rife the task becomes impossible to perform efficiently, partly because of man-power costs and partly because the proportion of trees with symptomless (latent) infection rises to a high level as scattered outbreaks tend to merge into large areas with more infected than healthy trees. Complete replanting in large blocks would be the logical policy, but there are political considerations involving compulsory measures and changes in land tenure. Certainly piecemeal treatment is ineffectual, expensive and discourages cocoa farmers. (Future control measures are examined in more detail in section 6.6).
(b) Plant breeding. Resistant varieties that are virtually immune in the field would provide an ideal solution, although to be readily accepted by the farmer they should also be no more susceptible to black pod than Amelonado and as easy to establish on partially degraded soil as the Amazon hybrids. While the search for strong resistance continues, the breeders' objective should be to combine the Iquitos resistance with other desirable characters that would encourage the farmer to plant the new types despite doubting the efficacy of their resistance. Early bearing and high yield could make cocoa growing as profitable as food crops even though swollen shoot necessitates replanting at 12 year intervals.

(c) Mild strain protection. The use of mild strain protection is less controversial now than 30 years ago when it was advocated for the worst affected areas in Ghana. It has been used in citrus and tomatoes to good effect.

Research on mild strains of swollen shoot on the protection they provide against the effect of virulent strains and their effect on yield of the new hybrids would require at least five years. It would be prudent to do this in order to have mild strains suitable for use, if only in special cases. If, for example, an exceptionally high yielding and black pod resistant variety of cocoa proved to be highly sensitive to swollen shoot it could not be planted extensively in Ghana and Togo unless it could be protected by a mild strain of the virus.

6.6 The Swollen Shoot Eradication Campaign in Ghana

Various approaches have been considered for controlling swollen shoot disease in West Africa, but all have involved eradication measures. These have been used for over 40 years in Ghana where the "cutting-out" campaign has been the largest and costliest of its type ever undertaken against a plant disease.

The evolution of the campaign, the procedures adopted and the progress made have been described in detailed reports presented at successive conferences of The Cocoa, Chocolate and Confectionery Alliance (1948 - 1961), and at subsequent international gatherings (1965 - 1983). The reports provide a wealth of information and show how the methods used have been little changed over the 40 years since they were first introduced, although there have been great fluctuations in the vigour and effectiveness with which they have been implemented.

At the outset there was opposition from farmers and problems due to the immense scale of the undertaking, to inadequate maps and access roads, and to the difficult terrain. Nevertheless, activities increased to a peak in the late 1950s, when about 80% of total government expenditure on cocoa was being spent on swollen shoot control and up to 1 million trees a month were being cut out. However, the official campaign was discontinued between 1962 and 1964 and it has since been operated on a limited scale. After a second peak of activity in 1976 operations declined even further and currently only about 1 million trees a year are being removed. This represents only a small fraction of the number known to be infected from
the most recent comprehensive survey of the entire cocoa area begun in 1970 and completed in 1979. It was then estimated that there were 37.1 million infected trees in the Eastern Region and a further 0.8 million elsewhere. The validity of these estimates has been challenged but many of the figures must be gross underestimates because of the spread that has occurred since the inspections were completed and because many outbreaks were completely overlooked. There is also evidence that the total number of infected trees is on average five times greater than the number found with symptoms after allowing for latent and missed infections.

Swollen shoot is now more prevalent than ever before and the disease is spreading almost unchecked because of the limited and ineffective measures being employed. Treatments are currently operated on an individual farm basis and cutting-out operations are often suspended at times when the trees are bearing pods. In many instances farms are being cut out and replanted with cocoa even though numerous untreated sources of infection occur nearby or even around the perimeter. There is rapid reinfection and the cycle of infection is maintained with devastating and demoralising consequences for the farmers concerned.

**Future Policy**

The current situation is highly unsatisfactory and a complete reappraisal of the entire cutting-out campaign is essential if the available manpower and resources are to be deployed more effectively. An immediate requirement is to resume compulsory cutting-out in the least affected districts - the west and north-west parts of the cocoa growing area - where outbreaks are widely scattered and amenable to control. The immediate aim should be to treat all such outbreaks without delay and to reintroduce a system of regular monthly reinspections and retreatments. There are also cogent arguments for resuming monetary grants to farmers as an inducement for them to replant and so relieve the authorities of this expensive and labour-intensive liability. Another requirement is to resume regular comprehensive surveys of the scattered outbreak areas and these should be done more frequently than hitherto to detect outbreaks whilst they are still small and relatively easy to control. These innovations are likely to lead to a big increase in the effectiveness of the cutting-out campaign and further improvements are possible by introducing more drastic procedures for dealing with large outbreaks (see suggestions for further studies).

The situation in the worst-affected "areas of mass infection" in Eastern and Central Regions is far less tractable and there is no agreement on the most appropriate policy. One view is that swollen shoot is now so prevalent that the use of current procedures for treating and retreatting outbreaks is not justified because it would take years, would be excessively expensive in manpower and resources and may ultimately be ineffective. The counter-argument is that an intensified effort at control is justified because of the large areas that are particularly well-suited for cocoa production, with all the roads, buying stations, infrastructure and local expertise required to restore output.
A possible compromise policy would be to select groups of farms or even whole districts for treatment and to encourage replanting with resistant varieties after removing all known sources of infection from within and immediately around the designated areas. Thus a series of expanding 'enclaves' could be established and brought under regular surveillance, even though no attempt is made to control swollen shoot elsewhere. Such a concentration of effort will make better use of the available resources than the present policy of indiscriminate treatment and replanting of small, scattered individual farms. However, there is currently only limited evidence on the feasibility and techniques of block planting (see suggestions for further studies).

Conclusions

Swollen shoot disease has caused incalculable damage to the Ghana cocoa industry and to the economy of the whole country by killing or debilitating vast numbers of trees and by making it difficult or impossible to grow cocoa economically in what would otherwise be some of the most productive areas. Moreover, the disease has diverted manpower and resources from other means of stimulating cocoa production and from elsewhere in the agricultural sector.

This situation is unsatisfactory yet there is no immediate prospect of any improvement and there is a continuing need for control measures to prevent or restrict the spread of swollen shoot to new plantings and to hitherto unaffected areas. Otherwise even greater losses are inevitable and the performance of major rehabilitation and replanting projects will be seriously undermined due to reinfection as has occurred already in the Eastern Region Suhum project. Thus it is essential to implement a policy for controlling swollen shoot that is adequate in relation to the problems and costs involved and to the value of the crop being protected. Unfortunately there is still insufficient information available on many aspects of swollen shoot spread and control and some of the main areas for study are now considered.

Further Study

A critical appraisal of the cutting-out campaign is long overdue. An essential requirement of the undertaking is that it should consider the cost-effectiveness of the different options available in relation to the prevalence of infection in each area and to current cocoa production and future prospects after remedial measures have been introduced. This could lead to improved procedures that bring outbreaks under control more readily and less expensively. However, there is only limited evidence available on the rate, pattern and sequence of virus spread and on the effectiveness of eradication procedures, isolation and barrier crops in decreasing rates of reinfection. Such information is required urgently to facilitate treatment and replanting and to define the minimum size of unit to be adopted in implementing cutting-out measures and rehabilitation projects and for virus resistant varieties to be deployed most effectively.
It has long been recommended that replanting should be done in large compact blocks away from sources of infection, yet the minimum size of block and degree of isolation have not been determined. The results of the various block plantings and treatments in the Eastern Region could provide invaluable information and should be analysed as a matter of priority. It is also essential to continue monitoring the pattern and sequence of reinfection in the various experimental plantings of different size, shape and variety established in Eastern Region in the 1970s. The minimum size and isolation requirements may be less than in generally assumed and there are good prospects of developing procedures for use locally on groups of adjoining farms.

Additional studies are also required on symptom expression in different types of cocoa and on the effectiveness of routine inspections. There have been suggestions that symptoms have become more difficult to assess in recent years and this may be due to the widespread use of Upper Amazon or hybrid material. It is also uncertain why so many infected trees are missed during routine surveys. Undoubtedly some are overlooked, whereas others will not have shown symptoms or will have ceased to do so and the relative proportion in each category is unknown. Considerable information could be obtained by means of the enzyme-linked immunosorbent assay (ELISA) technique to monitor virus spread within and between trees.

The current procedures for controlling swollen shoot were developed when growing conditions and mealybug populations were very different and when the disease was far less prevalent than it is now. Further studies are required and may show that the standard recommendation to remove only visibly infected trees and their immediate contacts irrespective of outbreak size is no longer appropriate. Cutting-out measures are particularly ineffective in dealing with the many very large outbreaks now being found. These are seldom controlled without repeated reinspections and retreatments, which are expensive, inconvenient and may ultimately lead to the removal of whole plantings. It may prove to be more effective to clear entire farms at the outset if more than say a third of the trees are found to be infected during the initial inspection. This possibility should be considered and also the applicability of the Nigeria finding that cutting-out procedures should depend on outbreak size.

In attempts to improve current procedures it is essential to consider changes in land use and the way in which large contiguous areas of cocoa have been disrupted by bush fires and increased plantings of food or other crops. This could facilitate swollen shoot control by increasing the separation between different cocoa farms, but only if all abandoned or neglected cocoa is removed and is not allowed to remain as sources of infection. In co-operative farm projects or subsidised rehabilitation schemes there is scope for developing rational systems of land use and the value of barrier crops or mixed cropping systems should also be considered. Their use has long been advocated as a means of decreasing spread into or within plantings, but they have never been fully evaluated. Such methods of decreasing the 'infection pressure' on plantings have an important role to play in 'learning to live' with swollen shoot and in making the best possible use of resistant varieties.
6.7 Priorities for Research

**Phytophthora**

(a) The geographical distribution of the three species of the fungus involved in *Phytophthora* pod rot and *Phytophthora* canker infections must be established with urgency. Their relative virulence in each cocoa area must then be established.

(b) Very recently another species (*P. citrophthora*) has been identified as an important pathogen of cocoa in Bahia, Brazil. Work is now required to establish its importance in other cocoa areas.

(c) It is probable that the *Phytophthora* species will attack the various plant organs with differing severity i.e. one species may predominantly cause cankers while another may only infect pods. It is also possible that the vigour of cocoa roots could be seriously impaired by *Phytophthora* infection. These aspects require study.

(d) When the geographical distribution, relative virulence and epidemiology of the relevant species have been determined for a particular location, then field trials on the dosage of fungicides, frequency and method of application must be carried out to give a cost effective control method. The climate, type of planting material, size of holding, level of losses and socio-economic factors as well as the species involved will all influence the control method adopted.

(e) The incorporation of durable resistance to each of the pathogens offers the best chance of a permanent method of control. Progress will of necessity be slow, but research should be undertaken at a number of centres

**Witches' Broom**

(a) Differentiation of pathotypes of the witches' broom fungus is in progress and should explain apparent differences in cultivar susceptibility or resistance between different growing regions.

(b) The epidemiology of the disease is poorly understood. Detailed work in every country where the disease occurs is needed at once and should be carried out in a comparative way. Initial work on development of techniques has just started in Rondonia, Brazil.

(c) Screening of candidate fungicides should be given high priority.

(d) Fundamental work on the host/pathogen interaction, which in this disease is particularly complex, is needed so that the trigger mechanisms which turn the saprophyte into a parasite can be identified. An understanding of this mechanism may lead to novel methods of control.

(e) Fungal isolates from different regions should be compared to see whether variation exists in pathogenicity.

(f) The epidemiology is poorly understood and requires study so that control methods can be devised. This disease has been neglected far too long in the cocoa growing areas where it is important.
Vascular-Streak Dieback

(a) It may be that the failure to achieve control by systemic fungicides is due to inability of the plant vascular system to transport the chemical. This should be studied urgently and this might involve the use of radio-active labelled fungicides.

(b) Alternate hosts of the fungus should be sought; they are probably important in the epidemiology of the disease.

(c) A more effective test for the screening of promising cultivars for resistance should be developed urgently.

(d) Breeding for resistance offers good prospects for success and must continue.

(e) The only recommendation for control has been the removal of an infected branch. Successive severe prunings of this nature can easily reduce a once healthy cocoa tree to a bare pole. The study of this practice in both immature and mature cocoa should be continued.

(f) It is possible that different races of the fungus exist in West Malaysia, Sabah and Papua New Guinea and this would account for apparent differences in symptom expression; this requires confirmation.

Virus Diseases

Resistance to swollen shoot virus has been found in cocoa types from the Iquitos/Nanay region of the upper Amazon where no virus disease of cocoa is known. This resistance is only partial and can be expected only to diminish the rate at which swollen shoot destroys cocoa farms. Clearly it is important that new sources of resistance should be found and used by the breeders in Ghana to augment that already being included in the latest planting material. The Amazonian forest seems the most likely area in which new genotypes untested by virus infection could be found. New accessions should therefore be sent through quarantine to Ghana and tested for resistance and tolerance with as little delay as possible.

Much of the new cocoa planted after infected trees have been removed becomes infected by spread from neighboring farms or from trees with latent infection that were not cut out. There is evidence that the relative abundance of vector species of mealybugs has changed over the past 25 years and this may have altered the pattern of virus spread. Up-to-date information on the epidemiology of swollen shoot disease is required so that rational decisions can be taken on control measures, especially in relation to replanting farms in areas where the virus is endemic.

Swollen Shoot Disease

The campaign to control swollen shoot disease has been ineffective in recent years. Compulsory cutting-out should be resumed and the methods used in the campaign re-assessed; further studies of the way the disease spreads should be undertaken.
VII. INSECTS AND OTHER PESTS OF COCOA

7.1 Perspectives

Over 1,500 different insects are known to feed on cocoa but only 1-2 per cent of these can be regarded as of considerable economic importance; most are regional in occurrence. Insect pests of cocoa can be considered in three categories: those which cause direct and very serious damage, those which are important because they increase the incidence of cocoa diseases and those which though normally minor pests may attain serious pest status following the misuse of insecticides. These categories are used in the brief assessments of individual pests and pest groups in this introduction.

Direct Pests

Mirids (capsids). These occur in all cocoa areas except the Antilles and the smaller Melanesian and Pacific Islands. Attack is very definitely at its worst in those areas where the tendency to feed on stems in addition to pods is strong. This is especially so in West Africa, where damaged stems also become catastrophically infected by die-back fungi, but less so in the Americas. Nevertheless it is worth noting that in both South and Central America, mirids are considered the most serious of cocoa pests. The mirid control situation in West Africa is very far from satisfactory, for though resistance to gamma-HCH has been known for twenty years, only one acceptable substitute insecticide has so far been developed. Resistance is now widespread in the Ivory Coast, Ghana and Nigeria. The current status and conduct of resistance surveys is also inadequate and requires regularisation, especially in Ghana and standardising throughout the whole West African area.

Leaf cutting and enxerto ants. The former (species of Atta and Acromyrmex) strip leaves often leading to tree death and the latter (Azteca spp) fosters sap-sucking insects on cocoa and damages shoot apices. Both groups are restricted to the Americas where they probably constitute the most serious pest problem after mirids.

Cocoa pod borer. A single species, Acrocercops cramerella, has been the limiting factor to cocoa production in the Philippines and parts of Indonesia and has very recently become firmly established in Sabah and Sarawak. Apart from mealybugs it is probably more difficult to control than any other cocoa pest.

Pantorphytes weevils. Infestations of these wood-boring beetles, at present restricted to Papua New Guinea and the Solomons, are extremely difficult to eradicate. They are strongly associated with the current epidemic of Phytophthora bark canker in Papua New Guinea. Cocoa entomological research in Papua New Guinea is currently at its lowest ebb for the last twenty years and it seems doubtful if work on Pantorphytes is likely to be adequate. Spread of this pest could have very serious consequences.

Cocoa 'bollworm'. This moth, Earias bipaga, is the single most serious pest of establishing cocoa in West Africa. Its management will be an essential part of any cocoa rehabilitation or development scheme.
Current research in the Ivory Coast on genetically based resistance is encouraging, but more short-term answers are required. A cocoa armyworm, *Tiracola plagiata* in Papua New Guinea is also a very serious establishment pest. The circumstances leading to its attack are largely understood and again must be taken into account in making new plantings.

Vertebrates. Damage is mainly directly to ripe and ripening pods by rats, squirrels, parrots etc. and is universal. Losses are very variable but a world level might well be 5-10% or 80,000-160,000 metric tons, and thus on a global scale vertebrate damage may be second only to that caused by mirids. Research seems generally quite inadequate.

**Disease Associated Insects**

**Mealybugs.** Cocoa virus diseases occur in West Africa, Trinidad and Sri Lanka and have been found more recently in Sumatra and Sabah; they are transmitted solely by mealybugs of which several species are involved in each area.

**Antiteuchus (Mecistorhinus).** Shield bugs of this genus have been strongly implicated in the increase of frosty pod rot, caused by the fungus *Moniliophthora roreri*, in Western parts of South America, especially Ecuador. The relationship of this bug and of other insects, to disease incidence requires more precise definition.

**Xyleborus ferrugineus.** This is the single most important species of wood boring scolytid beetles associated with epidemics of wilt disease caused by the fungus *Ceratocystis fimbriata* in South and Central America. Though the beetle is known to effect a great increase in the quantity of airborne fungal spores, its role in disease transmission requires further definition. Studies on its control also require to be extended since at present only one moderately satisfactory insecticidal system seems to be available.

**Insecticide Promoted Pests**

A number of insects, normally of minor importance, can be elevated to major pest status by the misuse of insecticides. The majority of such insects bore in cocoa tissues in the larval stage. When insecticides affect them less than their parasites upsurges result. Examples are the wood borers *Eulophonotus myrmeloon*, species of Tragocephala and *Metarbeza* and the pod epidermis miner *Marmara/Spulerina* in West Africa and the wood boring *Zeuzera* and leaf eating bag worms (Psychidae) in Sabah. The insecticidal regimes which have resulted in such status changes have either involved very persistent chemicals (dieldrin, endrin, DDT) or over-frequent and large applications of a more volatile substance (gamma-HCH). Once appreciated, such situations are easily avoided but more alarming has been the fairly recent indication that in West Africa the shield bug *Bathycoelia thalassina* has developed as a widespread pest, firstly because it is favoured by the relatively aperiodic cropping pattern of the newer Amazon Hybrid cocoas and secondly by suppression of its parasites by the use of gamma-HCH against mirids. *Bathycoelia* is not itself particularly sensitive to gamma-HCH. An acceptable control method for *Bathycoelia* is required, more accurate assessment of its status as a pest and a delineation of the environmental conditions under which it attains injurious levels.
Regional Assessments.

The impact of insect pests varies greatly from region to region and though, because of lack of adequate assessments of crop losses, it is impossible to be precise, some generalisations can be made. Firstly, the cocoa in South and Central America (35% of world production) appears to be freer from major pest depredations than in any other producing area. Apart from occasional destructive epidemics of *Ceratocystis* wilt disease associated with *Xyleborus ferrugineus* and other scolytid beetles, there seem to be no areas of devastation. By contrast the cocoa of West Africa (56% of world production) is especially under pressure from insect pests, notably mirids but also the mealybug - vectored virus diseases. Going further east, Asia and Oceania (only 9 per cent of world production) suffer a number of very serious problems; Indonesia and Sabah with their very difficult cocoa pod borer, Papua New Guinea with *Pantorhytes* weevils, whilst mirid attack occurs in all areas except the smaller and more remote islands (e.g. Samoa).

Thus, areas producing around 65% of the world's cocoa currently suffer the worst pest problems.

7.2 Cocoa Mirids (Capsids)

The names mirid and capsid are synonymous, the former being the more strictly correct. Mirids are a West African problem: in the presence of severe attack half the world's cocoa is produced. Losses are difficult to determine but are probably not less than 20%.

Damage mainly results from feeding on stems and pods. Mirids have sucking mouth parts which they insert into plant tissues destroying an area of cells and causing dark, oval lesions; these are large enough for just a few to effectively girdle a living stem. Lesions on stems are especially prone to infection by pathogenic fungi. Stems so affected may die back considerable distances and this is an especially serious feature in West Africa. Extensive tree canopy deterioration follows. The pattern of this effect is that groups of trees are especially degraded to form 'capsid pockets'. If neglected these pockets expand disastrously.

The chlorinated hydrocarbon insecticides were extensively tested on cocoa in the 1950s and the gamma isomer of benzene hexachloride (gamma-HCH, lindane, Gammalin, etc.), gave good control and was widely used. However mirid resistance to gamma-HCH, and with it to a group of chemically related compounds, was noted in Ghana in 1961 and Nigeria in 1962, since when it has also been found in the Ivory Coast. This alarming situation greatly accelerated the pace of mirid research in a general way but especially in the search for alternative chemical pesticides and new control strategies.

Mirid Diversity and Occurrence

The thirty or more species of the family Miridae attacking cocoa all belong to one subfamily, the Bryocorinae. Within this subfamily two tribes only are involved. In the Monalonini lie all the New World cocoa
mirids, these all falling in the one genus, *Monalopsian*. The very widely distributed Old World genus *Helopeltis* also belongs here. A larger group of genera belong to the second tribe, the *Odoniellini*. The most notable of these are the very important West African *Sahlbergella Singularis* and *Distantiella theobromae*. Of less widespread importance are *Boxiopsis madagascariensis* (Madagascar), *Platyngomiriodes apiformis* (Sabah) and several species of *Pseudodoniella* (Papua New Guinea).

**Mirid Biology, Ecology and Crop Damage**

The fecundity of mirids is low, about 30–40 eggs being laid. However, rapid population increases may occur because development is swift: the time from egg to adult averages 30–40 days and populations may easily change by a factor of 10 within a period of six months. Population densities of cocoa mirids may peak at around 7,000/hectare and this may seem low compared with the densities at which many other insects exceed the economic threshold. However, mirid feeding *per se* is extremely damaging and the distribution of mirids is never random but tends strongly to aggregation so that at any one time the local intensity of attack may be more severe than mere numbers suggest.

The interactions of mirids with cocoa trees are complex and, in some areas, fraught with uncertainty. Briefly, 'capsid pockets' are most frequent in shaded cocoa and the canopy breaks tend to precede mirid invasion and not to be its direct result. *S. singularis* is the main early exploiter of pockets probably because it prefers fan tissue. As trees deteriorate more chupons are produced and these favour invasion by *D. theobroma* which becomes dominant as the canopy is gradually lost. Ultimately trees may degenerate to branchless trunks. By contrast mirid attack on unshaded cocoa tends to result more in a general blast though ultimately pockets form. The decline of plantations is a consequence of the wilt induced by mirid feeding, invasion of lesions by *Calonectria* and, as the canopy deteriorates, a growing competition with weeds. Increasing water stress probably occurs and accelerates the *Calonectria* induced die back.

**The Control of Cocoa Mirids**

Gamma - HCH proved an ideally effective insecticide because of its innately high toxicity to mirids and also because its high volatility gave it strong fumigant action so that even comparatively inefficient spraying tended to give satisfactory results. In addition it presents a low hazard to spray operators and does not leave unacceptable taint or residues in the dried beans.

The use of HCH was developed in Ghana in the early 1950s and it was soon generally accepted throughout West Africa and other cocoa growing regions of the world. The usual recommendations call for double applications at about 28 days apart. The first spray is to kill adults and juveniles whilst the second destroys mirids which have hatched from eggs present at the first spray before they are reproductively mature. In Ghana two such double applications are employed in June–July and November–December, the first sprayings covering the beginning of the
population increase whilst the second covers the main period of infestation. In Nigeria the recommendation has been that three overall applications be made at 28 day intervals beginning in August and that thereafter spot treatments should be used to deal with residual foci of infestation. The 'traditional' dosage rate is 4 ozs of active ingredient/acre (circa 300 g/ha) but it has been suggested that after the first application the rate could be reduced to a half or even a quarter of this.

A useful approach to mirid (*Helopeltis*) management developed in Indonesia is based on regular damage surveys. A sample of the trees (20% in ordinary plantations, 50% at the lesser cocoa tree densities associated with coconut shade) is surveyed. Spot spraying is carried out when less than 10% of trees have new damage but overall spraying when more are damaged. Post-spray surveys are made followed by appropriate insecticidal treatment. Gaps in the canopy are repaired, especially if large, by planting seedlings under shade, e.g. banana, which can later be thinned and then removed. A very similar system was shown to provide effective regulation of *Sahlbergella singularis* in the Lukolela Plantations in Zaire.

The use of gamma-HCH has been remarkably free from the catastrophic consequences which are known to follow the employment of more persistent insecticides. In both West Africa and Sabah (Malaysia) the use of the very persistent compound dieldrin has resulted in extremely serious problems with wood boring insects and some others. The extent of such a reaction can be truly remarkable. In Ghana heavy infestations of the moth *Metarbela* sp. occurred though previously this insect had never been recorded from cocoa locally. Though the consequences of gamma-HCH are clearly milder, it is nevertheless implicated in some increases of two 'non-target' insects. *Marmara* is the lesser of these. Its larvae burrow superficially beneath pod epidermis and may be sufficiently common to make the determination of pod ripeness difficult. More serious is the cocoa shield bug, *Bathycoelia thalassina*, which is dealt with later.

**Insecticidal Resistance**

In West Africa the first instance of mirid resistance occurred in Ghana in 1961 when *D. theobromae* at Pankese was found to be resistant to HCH. Similar resistance in this species was detected in the Ivory Coast in 1964 but in Nigeria not until 1972. However, in Nigeria the dominant cocoa mirid *S. singularis* showed resistance by 1962 though curiously enough in other West African countries it seems to have retained its susceptibility. In both these mirids resistance to HCH carries with it resistance to other cyclodiene compounds (dieldrin, aldrin, endrin, heptachlor) but not to DDT or other groups of pesticides such as organophosphates or carbamates. Thus it is not multiple resistance.

Since these first discoveries the areas in which resistant mirids occur have expanded greatly. In Western Nigeria resistant *S. singularis* appeared to occupy 1,100 - 1,200 square miles by 1976.

Data from Ghana suggest that between 1965 and 1971 resistance became nationally widespread with nearly all the *D. theobromae* samples tested from Eastern and Central Regions, Brong Ahafo and Ashanti being in the highest resistance category.
The Future of Mirid Control

The initial response of research organizations to the resistance problem was swift and consisted essentially of two components. The first was testing of a range of chemically unrelated insecticides in an endeavour to find satisfactory alternatives to HCH. The second was an in-depth inspection of the behaviour and ecology of mirids to provide a wider base of understanding from which it might be possible to devise other control stratagems. Now, fifteen years or more after the emergence of resistance, much information has been accumulated and the mirid problem is undoubtedly better understood than ever before, but it cannot be said that much has been learned that is of immediate value in alleviating the present serious situation.

(a) Insecticides: coping chemically with the resistance problem. In the search for alternative insecticides three groups of compounds have been extensively tested: the organophosphates, the carbamates and, more recently, the synthetic pyrethroids. Among many tested the following have been found, by 1984, to be acceptable by the U.K. Cocoa, Chocolate and Confectionery Alliance on grounds of their failure to cause taint in the finished product.

<table>
<thead>
<tr>
<th>Chemical Group</th>
<th>Common Name</th>
<th>Trade Name</th>
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<tbody>
<tr>
<td>Organochlorine</td>
<td>Gamma-benzine</td>
<td>Gammalin</td>
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<tr>
<td>hexachloride</td>
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<tr>
<td>Carbamates</td>
<td>Dioxacarb</td>
<td>Elocron</td>
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<td>Bufencarb</td>
<td>Orthobux</td>
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<tr>
<td>Propoxur</td>
<td>Aprocarb, Baygon, Uniden</td>
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<tr>
<td>Carbaryl</td>
<td>Sevin</td>
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<tr>
<td>Promecarb</td>
<td>Carbamult</td>
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<tr>
<td>Organophosphates</td>
<td>Acephate</td>
<td>Orthene</td>
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<tr>
<td>Fenitrothion</td>
<td>Sumithion</td>
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Of those with suitable action against mirids two, dioxacarb and bufencarb, are now considered too irritant to spray operators to be acceptable for general use. Hence only one alternative to HCH is currently available. This is propoxur, a carbamate with a strong fumigant action, but it is appreciably more expensive.

(b) Biological Control. The agencies of natural biological control consist of insect parasitoids (mainly parasitic Hymenoptera), predators and pathogenic micro-organisms.

Whilst the possibility of control of cocoa mirids by the introduction of parasite species from one geographical area to another, in the manner of classical biological control, has often been discussed, no actual studies seem ever to have been made. The main reason for this has
been the feeling that adequate regulation of what was considered to be a fundamentally low density insect is unlikely to be achievable. This view was understandable in the days before the availability of quick knock-down insecticides permitting the spraying of whole trees and collection of complete tree faunas on ground sheets. Analysis of such collections showed that mirid populations had consistently been underestimated. In any event the concept of inefficient parasitism of lower density insects is of doubtful validity since it denies the possibility of evolution of parasites to cope with just such a host distribution.

(c) The use of ants to regulate cocoa mirids. Analysis of the complex ant mosaics, especially in Ghana, Nigeria and Papua New Guinea, led to the very general conclusion that some ant species are inimical to some mirids and other insect pests but that their potential beneficial influence may be suppressed or limited by inter-ant species competition and also by environmental conditions. The main leads of economic portent to emerge may be summarised as follows:

(i) In West Africa the native ant *Oecophylla longinoda* is inimical to *D. theobroma* but not to *S. singularis*. Its territories are restricted by other ants, notably species of *Crematogaster*, and by restricting *Crematogaster* nesting sites and avoiding spraying as much as possible *Oecophylla*-infested trees, the level of *D. theobroma* regulation can be increased.

(ii) The ant *Wasmannia auropunctata*, a South and Central American species, has been present in Cameroon for some years where it is known to be inimical to *S. singularis*. Because it readily occupies artificial nests it is said to be easy to spread thereby extending protection against mirids to new areas.

(iii) In Papua New Guinea the 'tramp' ant species *Anoplolepis longipes* is not only inimical to cocoa mirids but also to the local but extremely serious wood boring *Pantarhytes* weevils. There is an on-going research investigation into the practical possibilities of the use of this ant in cocoa plantations. As in the case of *W. auropunctata* artificial nests are readily colonised and can be moved to new situations. Provision of a suitable source of food seems necessary for ant maintenance and it is likely that interplanting cocoa with *Gliricidia sepium* will provide this through its infestations of honey dew producing scale insects.

(d) Cultural Control. The main implements of cultural control are barrier crops, shade management, pruning of infested tissue, removal of alternative host plants and attention to the water and nutrient status of the crop. Whilst it is unlikely that manipulation of such factors will reduce the mirid problem to a subeconomic level, nevertheless it is very important. The maintenance of a continuous uninterrupted cocoa canopy and a level of overhead shade appropriate to local conditions and the maturity of the cocoa may be singled out for special mention. Shade manipulation is of significance in relation to other insect pests and generally speaking the presence of shade confers some protection from insect pests.
The influence of shade type on pest problems has received some attention in Papua New Guinea. It has been found that the incidence of the major pests—mirids, *Amblypelta* bugs (see later section) and *Pantorhytes* weevils (also see later section) — is greatly reduced by high shade such as rubber, tall forest trees and coconuts. Indeed a current PNG recommendation for avoidance of *Pantorhytes* attack is to plant cocoa beneath hybrid coconuts of not less than four years of age. More severe problems are encountered on cocoa under lower shade such as *Leucaena leucocephala* and *Gliricidia sepium* particularly because of higher densities of the pests mentioned and also because *Leucaena* in particular supports various pests which can attack cocoa.

(e) Integrated Control. The need for a comprehensive approach to mirid control was recognised long before the invention of the term 'integrated control'. Indeed before the advent of the modern synthetic insecticides it was the mainstay of the control philosophy. However, even within West Africa, the most seriously affected cocoa region, the degree of success achieved by such methods is so variable that no generally applicable advice can be offered. Certainly there is a case for integrated control at its very simplest when it would consist of attention to the factors noted above under cultural control plus the minimal insecticidal regime necessary to keep mirid populations at an acceptably low level. The concept of an economic threshold has been used with many insect pests to determine the population densities above which spraying is necessary. Because mirid feeding can result in structural damage to trees and can have a fairly long term effect on yields the economic threshold system is not applicable to cocoa. So long as mirids pose a threat, one pair of prophylactic sprays early in the season of likely increase will be necessary. The need for further spraying should be determined by the results of routine inspections for fresh damage and live mirids. Persistent pesticides are best avoided since in the long run they will be extremely likely to result in very serious pest problems.

Fully integrated control systems take into consideration the management of all pest, disease and nutritional problems of the crop. Much remains to be done in this vast area but there is no doubt that productivity in most areas could be significantly increased by the proper application of existing knowledge. There is an immediate need for greater attention to the mirid problem and a very great deal of benefit can be obtained simply by correct application of the right insecticide and maintaining the cocoa tree canopy in good condition.

7.3 Other Pests of Mature Cocoa Trees

Whilst mirids are the main large sap-sucking bugs seriously damaging cocoa on a regional basis three other genera are involved.

The Cocoa Shield Bug (*Bathycoelia* spp.)

Members of this genus of large flat shield-like bugs (family *Pentatomidae*) attack cocoa from the Ivory Coast to Central Africa. The main species concerned is *Bathycoelia thalassina*, the adult is about two centimetres long, i.e. about twice the length of *Distantiella* or *Sahlbergella*. 
**B. thalassina** appears to feed exclusively on pods and with its long stylets it can penetrate the pod wall and suck out the contents of the beans. When young pods are attacked they tend to be distorted and yields can be greatly reduced. Infestations are associated particularly with Amazon and hybrid cocoas because, unlike Amelonado, these types bear pods throughout the year and so provide a continuous supply of food.

Under normal conditions natural parasites and predators achieve more than 90% control but there is strong evidence to show that in areas where gamma-HCH is sprayed regularly this is greatly reduced. **B. thalassina** is tolerant of HCH, at the rates currently employed (there is no evidence for acquired resistance) and no adequate insecticidal regime has been devised.

Some control approaches are possible. Local eradication of alternative host plants (*Citrus* spp. and *Kigelia africana*) and hand collection of bugs should be practiced. Minimal anti-mirid spraying will be beneficial in giving least disturbance of natural enemies. The possibility of control by 'rampasan' which until recently was the only real means of minimising attacks by the cocoa pod borer *Acrocerops cramerella* in the Far East, should be investigated. This consists of the removal of all pods from the trees once a year, so breaking the breeding sequence of the pest.

**Antiteuchus (=Mecistorhinus)**

These shield bugs, especially *Antiteuchus tripterus*, are common in South and Central American cocoa. Their economic importance stems from a reported association between their feeding on pod stalks and *Mondiplomthora* pod rot caused by the fungus *Mondiplomthora roreri*. More work may be needed to confirm the connection but meanwhile it may be noted that whilst *M. roreri* seems restricted to the western parts of tropical America (Peru, Ecuador, Colombia, Venezuela and Panama) *Antiteuchus* species are known on cocoa through to the cocoa growing regions of Brazil. Hence should *M. roreri* spread eastwards its effects could well be exacerbated by local species of *Antiteuchus*.

**Amblypelta cocophaga**

These large elongated coreid bugs attack cocoa in Papua New Guinea and the Solomons. The damage they cause is not unlike that inflicted by mirids though the lesions tend to be larger. Insecticides adequate for mirid control are also satisfactory against *Amblypelta*. Just as the ant *Oecophylla longinoda* is inimical to *D. theobroma* in West Africa, trees infected with *O. smaragdina* in Papua New Guinea tend to be little attacked by the main species.

**Thrips**; (*Selenothrips rubrocinatus*)

In many countries this insect can cause damage to foliage, especially young leaves and seems to be particularly important in areas where trees are unshaded. A severe infestation can cause significant loss
of yield and even death of a tree if not treated. A brown coloration is often observed on the pods which makes it difficult to assess the maturity of the pod but does not cause an economic loss. In Brazil the recommended control is 1.5% HCH in powder at the rate of 15-17 kg/ha though this is not always effective. This supports the theory that thrips is not a primary pest and that attack indicates stress, especially drought stress, in cocoa trees.

Cocoa beetle *(Steirastoma Breve)*

The adult beetle causes damage to cocoa trees in the West Indies and several South American countries. Eggs are deposited in slits in the bark. The larvae form spiral galleries in the cambial layers of the branches and can be noted by external symptoms of frass and a sticky exudate. An attack can result in the death of a young tree or in the loss of individual branches on older trees. Recommended control is to burn dead branches or trees and remove larvae with a knife from surviving branches, with chemical treatment by injection of Aldrin 40% in the trunk and damaged branches or Acephate at the rate of 150 g/100 l with the addition of a sticker. The physical damage to the cocoa tree by cutting out the larvae can be considerable, and therefore, the method can only be recommended for dealing with isolated cases.

Weevils *(Pantorhytes spp.)*

These insects are singled out for consideration because, although they are largely restricted to Papua New Guinea and some of its associated islands, their status as pests is extremely high. A dozen species are involved but the two most important are *Pantorhyodes szentivanyi* in the Northern District of Papua and *Pantorhyodes plutus* in New Britain and New Ireland. *Pantorhyodes biliagiatius* is a cocoa pest in the Solomon Islands. Adult *Pantorhyodes* are flightless and very long lived (up to 15 months in the field). Eggs are laid at jorquettes and other branch unions and the larvae burrow in the stems one or two centimetres deep and more or less parallel with the surface. They take 5-9 months to mature. Heavily bearing branches often will split from the main trunk at the jorquette or be killed by ring-barking. Channelling of the bark permits entry of *Phytophthora* causing canker and repeated weevil attack kills the trees.

Though over thirty possible parasites and predators exist biological control is totally inadequate. Insecticidal control is very difficult but is said to be achievable by repeated applications of the stomach poison, trichlorphon. Prevention is easier than cure. In uninfested blocks of cocoa or in new plantings all alternative host trees must be removed and barrier crops (*Pueraria phaseoloides* or *Mimosa invisa* with *Imperata cylinrica*) planted in a 15 m wide strip. If possible new blocks should be planted under hybrid coconuts at least four years old. Where cocoa is planted alone, introduction of the ant *Anoplolepis logipes* has been recommended together with the tree *Gliricidia sepium* to provide it with a food source. Adult *Pantorhyotes* should be collected and destroyed and in all situations beetle galleries should be treated with insecticides. The current recommendations are for either 1.5% fenthion or dichlorvos in 25% white oil, however, dichlorvos has not yet been cleared with respect to taint and residue levels in the dried beans.
It would probably be unwise to introduce the ant *Anoplolepis longipes* when cocoa is grown beneath coconuts until such time as its effects on the coconut insect fauna have been adequately investigated.

7.4 The Cocoa Pod Borer (Cocoa Moth)

The cocoa pod borer is potentially the most serious insect pest of cocoa in South-East Asia and the Pacific. It is a small moth of the family Gracillariidae, the larva of which bores into the cocoa pod and by feeding in the placental tissues reduces or prevents normal bean development. Because of very limited knowledge of the insect, and the fact that during most of its life it is, by its habits, hidden or protected within the pod, it has proved very difficult to control.

**Historical Development**

The moth (*Acrocercops cramerella*) apparently existed in the Malay Archipelago prior to the introduction of cocoa by the Spanish. It is reported to have host plants among several wild and cultivated members of the families Sapindaceae and Leguminoseae, the most common being various species of *Nephelium* (e.g. rambutan). The species adapted to cocoa in Sulawesi and spread within the region. However, it has not been reported on cocoa outside Indonesia, East Malaysia and the Philippines. Pest status was achieved in Sulawesi probably by the 1850s, Java in the 1890s, Mindanao by the 1930s, Sumatra in the 1970s, Sabah in 1980 and Sarawak in 1983. At present the cocoa pod borer infests most of the cocoa regions of Sabah and eastern Sarawak, about 2,000 ha in Indonesia (almost entirely in Sulawesi and other islands east of Java), and possibly 1,000 ha in Mindanao. The earlier infestations in Sumatra and Java have been eliminated by uprooting all cocoa trees in the vicinity of attacks, a policy made possible only by the widely scattered and discrete plantings there. This method does not offer a practical means for elimination of the insect in other circumstances.

The development of infestations over the past century strongly suggests that the movement of infested cocoa pods for new planting stock has been responsible for the spread. It is also possible that the movement of infested *Nephelium* fruits may have contributed to the transfer in some areas. Active migration over even quite short distances appears unlikely due to the moths' poor flying ability.

This insect has been considered by many authorities as a major limiting factor to cocoa production in Indonesia and the Philippines up to the present. Heavy infestations of larvae, (up to 40 per pod have been seen) can reduce bean size, and in extreme cases renders the pods completely unusable. Very serious economic losses have been reported as a result. In light infestations, however, with very few larvae per pod, there is little actual loss, and the infestation may even go unnoticed until numbers build up over several seasons.

Control has been attempted by a number of means, biological, chemical, and cultural. Several species of parasites were promoted in Java in the early 1900s, but hyperparasitism and lack of specificity limited
their effectiveness. Work is currently in progress by the Sabah Department of Agriculture on mass rearing of trichogrammatid egg parasites for release, and some estate companies in Sabah and Mindanao are trying this. Various pesticides have been tried since the 1950s without success, due largely to inefficient application and products and considerable resurgence problems in some areas. New research has resulted in a technique applying pyrethroid or carbamate insecticides specifically to the resting sites of adult moths under lower canopy branches. This has given very promising results with minimal environmental upset. An artificial sex pheromone has been produced by the Tropical Development and Research Institute, London in cooperation with Imperial College. This is being tested in Sabah for development of a mass trapping or confusion control technique. There are indications of considerable partial resistance in some of the varieties of cocoa planted in Sabah. Some preliminary screening is underway to identify resistance factors, and hopefully a greater degree of resistance can be incorporated in future plantings in South-East Asia.

An early cultural control was pod stripping (called 'rampasan') to break the life cycle by eliminating oviposition sites. Practical problems in removing all pods in an area have made this method unsuccessful. Sleeves of cloth, paper or plastic have been placed over individual pods early in their development to prevent egg laying. This method is effective but expensive and only suitable for lower pods. Another cultural method, still under investigation, involves early and frequent harvesting into closed bags and with subsequent destruction of husks, to try and prevent pupation by borers leaving the ripe fruit. This method has achieved some measure of success in Sabah but requires good organisation of labour.

Current Research

Currently, the three principal places of research activity are in Sabah, Mindanao and Java. In Sabah, a research project is being carried out by Imperial College, London, sponsored by the East Malaysia Planters' Association, in cooperation with the Sabah Department of Agriculture. These are wide ranging programs examining the biology and behaviour of A. cramerella, searching for natural enemies, and testing cultural and chemical control methods. It is anticipated that the Commonwealth Institute of Biological Control will begin a search for exotic natural enemies. Most of this work has come about through the initiative of private firms involved in cocoa production, supplementing the State research effort.

In Mindanao, research is conducted by several private cocoa growing firms in the Davao area and is directed mainly at pest monitoring and chemical control. In Indonesia, research is centred at the government's Research Institute for Estate Crops in Java. The work there is aimed primarily at eradication of the insect from small and isolated areas of cocoa by removing trees or imposing intensive regimes of cultural and chemical control.
It is only since 1980 that serious research on *A. cramerella*, has been resumed. Most of the literature on the biology and control of the cocoa pod borer comes from Dutch entomologists stationed in Java prior to the First World War. Little interest was shown for the next 60 years because of commercial disinterest in cocoa in South-East Asia (partially, but not entirely, due to poor returns because of the cocoa pod borer). A revitalization of interest in cocoa in Indonesia and the Philippines due to higher prices in the late 1970s and the advent of the pest in the vigorous cocoa industry in Sabah, has caused renewed activity against the moth.

Main Information Requirements from Research

Despite the difficulties in control caused by the insect's life cycle and behaviour, lack of basic information on its biology and habits has undoubtedly contributed greatly to the century of unsuccessful control that this pest has enjoyed. The following points are the most important, and the fundamental nature of some highlights the fact that previous control efforts have been based on inadequate knowledge of the pest.

(a) Taxonomic clarification;
(b) Host plant identification, and the ability to transfer from alternate hosts to cocoa;
(c) Accurate damage assessment to relate infestation levels to loss;
(d) Dispersal behaviour;
(e) Causes of natural population fluctuations, mortality, and reproductive capacity;
(f) Mating behaviour;
(g) Oviposition site finding and selection;
(h) Cultural control techniques;
(i) Natural enemies;
(j) Insecticide application techniques to give effective, but selective, control, without resurgence, etc;
(k) Relationship to other pests/natural enemies in control programs; and
(l) Potential resistance mechanisms in cocoa.

Research is already underway on all of these topics, but most studies are in the early stages. Considerable advances have, however, been made concerning the moth's basic biology and damage relationships. Novel control techniques arising from biological observations are being tested, and it may soon be possible to make use of further information to achieve
an inexpensive and effective control of this serious pest. Knowledge gained already has considerably reduced the potential of the cocoa pod borer to cause the level of destruction to the South-East Asian cocoa industry that it did 50 years ago.

7.5 Pests of Cocoa during Establishment

Quite a variety of insect pests attack young cocoa following planting out and pose problems in its establishment. The most serious of these tend to be mainly regional in their distribution and none is of general occurrence. For instance in Ecuador and Malaysia damage by adults of scarabaeid beetles (cockchafers) may be considerable and not easy to control because of the diffuse nature of their breeding sites. In Papua New Guinea larvae of the moth *Tiracola plagiata*, the cocoa army worm, can cause considerable delay in jorquette formation and general deformation of young plants largely by damage to buds. This highly polyphagous insect often breeds on weeds and the commonly used cocoa shade tree *Leucaena glauca* which thus constitute reservoirs of infestation. The collapse of over 3000 ha of cocoa in agricultural settlement blocks between 1960 and 1967 in the region of Popondetta was strongly associated with this insect.

However, by far the most serious pest of establishment is the so-called cocoa 'bollworm', *Earias bipagla*, better known as a bollworm of cotton occurring south of the Sahara. This moth, which attacks cocoa throughout West and Central Africa, merits considerable attention in relation to cocoa establishment and rehabilitation schemes.

The eggs are laid near the tops of young plants mainly after planting out and the larvae first burrow into and destroy the apical bud. Vertical growth is retarded and the formation of the jorquette delayed or entirely prevented.

There are over ten generations in a year and the adult lays in excess of 400 eggs so that there is a very great capacity for rapid increase. The highest populations occur in dry seasons largely because of the prior effect of rainfall on the very delicate egg parasite, *Trichogrammatioidea lutea*. The heaviest attack is on unshaded or poorly shaded plants. Premature removal of nurse shade may also have serious consequences.

The essence of *Earias* control lies in avoidance of the circumstances of attack and depends upon the provision of adequate shade for plants during at least the first three years after planting out. Without this, cocoa cannot be grown satisfactorily in West Africa. The establishment of cocoa should always (in West Africa) be beneath pre-existing shade, either thinned forest or pre-planted nurse shade. Nevertheless, since in strong dry seasons attack may reach unacceptable levels even on shaded trees, a means of direct control is required. At present there are two avenues of approach. One is by mass production and release of the parasite *T. lutea*, an attractive concept because it does not involve the use of chemicals. However, it requires further investigation to establish its practicability. Its most suitable role might be in the
context of large centrally organized cocoa establishment schemes. The second approach is the more generally practicable, but currently rather unrewarding, use of chemical pesticides. Good control of *Earias* can probably be obtained only by persistent compounds, the use of which is undesirable due to the secondary pest effects which usually follow, or by systemics. Thus the use of monocrotophos and possibly aldicarb and other compounds with similar systemic action should be further investigated.

In the somewhat longer term it is important to continue the search for cocoa types on which *Earias* attack has less impact and to evaluate promising candidates in relation to vigour, yield, disease resistance and other qualities.

### 7.6 Vertebrate Pests

Much damage is caused to cocoa by vertebrates, mainly rats, squirrels and monkeys, directly attacking the ripe or nearly ripe pods. Beans are not generally eaten but the surrounding sweet mucilage is sucked off. Abortive attempts to enter pods may still cause serious losses because of subsequent infection by the fungal wound parasites *Botryodiplodia theobroma* ('brown pod' - not to be confused with 'black pod' which is a consequence of infection by *Phytophthora* spp.) and *Trachysphaera fructigena* ('mealy pod').

Pod losses vary greatly from place to place. A world average might be 5-10%, or 80,000 to 160,000 metric tons in terms of the 1980/81 production forecast.

Damage also occurs on seed and young seedlings in the nursery and the field. Control is by clearing barriers and overhanging trees around plantations, by poison baiting and by trapping (the use of hedges is being investigated in the Ivory Coast). Rats are fairly easily baited but squirrels less so; both may be trapped, squirrels especially by drop door traps placed in trees.

Anti-coagulants, such as Warfarin, are effective at very low dosages, e.g., 1 mg/kg body weight for five days against rats. The tendency of baits to decay in hot, wet climates can be minimized by incorporating them in wax blocks. General applications of products having very high mammalian toxicity, are too hazardous and are objectionable on environmental grounds. Growers may gain some protection by restraint in the destruction of snakes and other beneficial predators, which often feed on rodents.

### 7.7 Priorities for Research

Economically important pests are not yet controlled or managed adequately in cocoa, though many of them are now understood biologically and ecologically. Insect pests are generally more important in Africa than elsewhere. Recent information on mealybugs as vectors of cocoa swollen shoot virus indicates that successful vector control is unlikely to be achieved.
Priority must now be given to the following problems:

**Mirids in West Africa**

(a) With only one acceptable insecticide as an alternative to gamma-HCH, the testing of alternatives must be intensified.

(b) Field tests of insecticides should be carried out on an area which is large enough for possible pests arising to be observed.

(c) A survey of the current status of resistance to gamma-HCH should be carried out using a standardised method.

(d) The use of parasites should be reconsidered.

(e) The possible contribution of ants to mirid control should be studied further.

**Cocoa Pod-Borer**

Excellent work is in progress on the biology and control of this pest but the research effort must be strengthened and sustained.

**Pantorhytes Weevils**

More research is required to determine economic control of *Pantarhytes* weevils in Papua New Guinea and the Pacific area. The relation between weevil damage and the bud-destroying moth, *Tiracola plagiata* and *Phytophthora* bark canker must be investigated.

**Cocoa "Bollworm"**

Management of the cocoa "bollworm", *Earias biplaga* and other pests affecting cocoa establishment in West Africa and elsewhere is essential. Although genetic resistance is a long-term possibility, biological control, cultural control and the use of systemic insecticides require immediate research.

**Thrips**

Work is required on thrips damage in Brazil: particularly the relationship between thrips and soil water deficits.

**Cockchafers**

Cockchafers are now believed to be a serious factor hampering cocoa re-establishment in Ecuador. Present research should be followed up with research into control of the beetles.

**Vertebrates**

Crop loss studies of vertebrate pest damage believed to be significant in many areas, are needed - followed by the development of poisoning or other control methods.
8.1 **Perspectives**

The history of application of sprays to cocoa has been one of trials of available machinery with little critical analysis and consequently little understanding of the nature of the sprays generated or the ultimate fate of the individual droplets—whether these hit and stick to the target, bounce off, drift through the canopy or simply evaporate prematurely. Only recently has it proved possible to exercise any real control over the size and numbers of droplets generated by spraying machinery. Hand in hand with this a greater understanding of the behaviour of spray droplets has developed so that there is now a real possibility of analysing the spraying needs of specific pest and disease situations and of matching these with a choice of appropriate machinery.

The real problems of cocoa spraying have been masked by the use of very volatile and hence fumigant chemicals which yielded good results even when inefficiently applied. Following the appearance of resistance to gamma-HCH it has become apparent how rare are volatile insecticides which are acceptable in all other respects. Improvement of spray technique would widen the possible choice by permitting the use of some chemicals which are less volatile.

8.2 **Application Equipment and Techniques**

**Equipment in Current Use**

Cocoa farmers in West Africa adopted spraying with enthusiasm during the 1950s and 1960s. This started in Nigeria during the 1950s in order to combat black pod. The farmers used knapsack sprayers of two basic types:

(a) Side-lever operated sprayer

(b) Compression sprayer

Both types have a capacity of about 10 litres, are relatively inexpensive, robust and reliable. Many are still in use.

In Ghana cocoa farmers took up spraying against capsids from 1960 using knapsack mistblowers. Several models were sold to farmers, all were very light in weight and used engines of 26 or 35 cc. Such machines could project spray to a vertical height of 5.5 metres, which is not high enough for farmers' cocoa in Ghana but would be quite suitable for capsid control with shorter trees.

In the francophone countries fogging equipment has been used to control capsids. This equipment has several disadvantages even where conditions are most suitable. Where the canopy is low and dense, these machines can be used advantageously and the effect is increased when used very early in the morning when temperatures are low. Where the canopy is
broken and open, the fog can ascend through the breaks and escape to the atmosphere and this is increased when ground temperatures are rising. Thus only in limited areas can the application of pesticides by thermal fog be recommended.

The machines most used for this type of application can be carried and operated by one man. As high temperatures are involved care is needed in handling, otherwise severe burns are possible. It also requires skill to set the machine to produce a wet fog that will stick to any surface. Although particles or droplets emerge with some velocity at the nozzle, air movement is desirable to drift the fog into the trees and in particular up into the canopy.

Application Techniques

The effective application of pesticides to cocoa pods to control black pod demands considerable care. Every part of the surface of the pod must be covered with the fungicide, including the stalk of the pod and the area where the pod touches the trunk. The farmer has to apply the fungicide to every cocoa pod on every tree. It may also be necessary to spray the ground and the canopy as the inoculum also occurs there.

For capsid control, using the motorized knapsack mistblower, considerable preparatory work is needed. The average mistblower weighs in the region of 20 to 25 kg when fully charged so it is necessary to ensure that the farm is weeded, so that undergrowth and obstacles are cleared or marked to avoid accidents when the farmer is walking and spraying while looking up into the canopy. The basic method developed in West Africa and now widely adopted is to divide the farm into plots of 100 trees. In early methods of application in Ghana the farmer walked through the plot pointing the nozzle into the canopy and moving it from side to side, continuing until all the 100 trees had been sprayed. With Gammalin as the insecticide, this was known as the G method and relied mainly on the fumigant action. Further trials proved this method inadequate and another method known as the T1 method was developed in which the farmer would direct the spray to the base of the tree, up the trunk and along the branches on one side and then across the branches on the other side ensuring that the canopy received an adequate dose. Whilst this method was an improvement on the G method, it still did not give the effectiveness that was required. The next improvement was for the farmer to retrace his steps, spraying the opposite side of the trees to that previously treated. This used double the amount of spray liquid but gave better control.

Research and Development on Pesticide Application Equipment

There have been no significant advances in equipment that will lead to more effective control of capsids. Both manual and motorized sprayers are still using the basic principles of the original machines and machines purchased in the mid 1950s are still being used today. Engine capacities of the newer machines have been increased, but this makes the machines slightly heavier.
It is possible to install adaptors in the liquid feed system of knapsack mistblowers for ultra low volume application. In the past five years, two manufacturers have developed and marketed knapsack mistblowers designed specifically for the application of pesticides at ultra low volume rates. A normal low volume application requires about 50 litres per ha but, using ULV equipment, this is reduced to only 2.5 litres of oil-based spray per ha. This means a considerable saving in time and labour as the fetching and carrying of water will no longer be necessary and with a full tank of 12 litres, it becomes possible to cover nearly 5 ha.

Other machines utilizing centrifugal energy, i.e. spinning discs, and employing a motorised fan to produce an airstream, have been tried on cocoa but have never proved successful. However, the latest development, employing an electrostatic force to induce all liquid leaving the nozzle to receive an electrical impulse of the same polarity as the nozzle electrodes, is showing definite promise. This machine known as the Electrodyne is still in the development stage and has not been tested on cocoa. The pesticides for use with this machine are prepacked in special containers which combine a nozzle. This might prove expensive. However, this type of machine has great potential as there are no moving parts to wear out and no water to be carried.

There have been no new developments in thermal fog generating equipment although some work has been carried out and one or two machines are on trial in Malaysia. For the majority of cocoa growing areas, this method of pesticide application would not be successful unless a wet fog could be applied to give a residual deposit.

8.3 Priorities for Research

(a) In view of the current concerns about environmental pollution, and the difficulty of applying pesticides on targets high in the cocoa canopy, priority must be given to adapting new spraying technology to the cocoa crop. Recent advances in low volume, ultra-low volume and electrostatic charging of spray particles should be evaluated for cocoa. A spray physicist and a spray machinery expert should be engaged to work in West Africa on the problem of spraying to control mirids and black pod. The results will be applicable to other spray situations.

(b) Much of the spraying presently done is ineffective and research is needed on the techniques of application, as well as the most effective organisation of the spray team.

(c) The organization and economics of spraying programs are location-specific. In each situation appropriate programs need to be developed to ensure the best possible coverage in time and space, and to evaluate the role of spraying as part of integrated pest management programs.

(d) Ways should be found of mobilizing the practical experience that is available at the international level in developing and managing spraying by farmers and making this available on a country basis.
9.1 Quality and Flavour

Cocoa quality is of paramount importance to the chocolate manufacturer and his experience of the quality of the cocoa from a particular origin will determine how much of a premium or a discount he is prepared to pay for a particular shipment. Obviously there is variation between seasons and between individual shipments, nevertheless broad generalisations about expected quality from the major sources can be made based on experience over the years.

Various off-flavours can arise from poor methods of harvesting, fermentation and drying on the farm or poor storage at a later stage. Most of these off-flavours cannot be removed during manufacture.

Off-flavours

(a) Mouldy off-flavours. These are due to the presence of internally mouldy beans which may arise from:

(i) Prolonged fermentation, or

(ii) Slow or inadequate drying (If the moisture content exceeds 8.0% the beans are liable to turn mouldy.)

(b) Smoky off-flavours. Contamination by smoke gives rise to a characteristic off-flavour, sometimes called 'hammy'. Such contamination may be due to:

(i) Bad design, faulty operation or poor maintenance of a wood-fired dryer.

(ii) Poor conditions of storage

(c) Acidic off-flavours. These arise in certain sources due to differences in the beans or to faulty methods of fermentation or drying. Recent research is helping to reduce this defect.

(d) Excessive bitterness and astringency. This is due to inadequate fermentation and may be detected by the presence of slaty beans in the cut test.

9.2 Country Situations

In the following section the methods of fermentation and drying and the quality of beans from the major producing countries are briefly reviewed together with notes on the current situation on local processing factories.
Ghana

The standards of fermentation and drying are generally good. The grading system is well established and still operates fairly effectively. However, recent difficulties have put the Produce Inspection Service under enormous strain, with much regrading and rebagging of cocoa at port. Buyers are now much more wary of the quality of Ghana cocoa and many feel that each parcel must be checked carefully. However, buyers will probably be prepared to pay a premium for Ghana cocoa if its reputation for consistent quality can be restored. Planting material used to be very uniform and was all Amelonado. To-day about 20% of the Ghana crop comes from Amazon hybrid material. The nature of the Ghana flavour may change over the next decades as the proportion of Amazon hybrids increases, but it is expected that the Cocoa Research Institute will continue to consider manufacturers' requirements when determining what new varieties should be made available to farmers.

Almost all cocoa in Ghana is fermented in heaps by small farmers and then dried on mats in the sun. The farmer usually carries his dried beans to a Licensed Buying Agent. These buyers have, as a result of many years' experience, acquired much knowledge about cocoa quality and understand the requirements of the manufacturer. The Ghana farmer, in common with his Nigerian counterpart, is usually penalised for delivery of Grade II cocoa.

The cocoa processing factories in Ghana processed about 8,000 tons of beans in 1983 into powder, cake and butter though their capacity is nearer 50,000 tons.

Nigeria.

The methods of fermentation and drying are essentially the same as in Ghana though cocoa is frequently dried on concrete platforms adjacent to the farmer's house. The marketing system and system of controls by the Produce Inspection Service operating in Nigeria is very similar to that in Ghana, both having been developed at a time when chocolate manufacturers were involved in cocoa purchasing in the field. The agricultural sector, and thus the cocoa industry, has suffered from a serious labour shortage for a number of years because of the pace of government investment in infrastructure. The domestic price has been above the world market price for some years and so cocoa growing should be an attractive proposition, but there has in fact been a steady decline in cocoa production. The cocoa processing factories used 22,000 tons of beans in 1983 but the tonnage allocated to the local processing factories is likely to increase as there are plans for at least three new factories. These projects have run into difficulties but the projected capacity equals current production.

Ivory Coast.

Fermentation and drying are essentially the same as in Ghana though the management and control by the farmer is not as effective. There are a few large estates where cocoa is fermented in boxes and dried artificially on a semi-industrial scale. Labour is short in Ivory Coast
and so experiments are being carried out with a view to designing a semi-industrial fermentary and drying unit for use on a co-operative basis. A small number of experimental units have been constructed and the work is continuing. The need for such units in Ivory Coast is urgent but the quality implications to the chocolate manufacturer have to be kept constantly in mind. The marketing and grading systems in francophone West Africa have developed in a different way from those in anglophone Africa. In francophone Africa many more entrepreneurs are involved at all stages of the buying process but there is no regular inspection and grading of the produce by a government organisation. Although the marketing system is highly regulated, grading has never been imposed at the level of the first seller i.e. the farmer.

Ivory Coast cocoa is widely considered by chocolate manufacturers to be of poorer quality than that produced in Ghana and Nigeria and is usually purchased at a discount to them. Steps are currently being taken to improve the reputation of Ivory Coast cocoa but it will take several years for such a program to achieve success. The particular problems are high mould percentage, very high bacterial counts and wide variation between and even within parcels.

The three cocoa processing factories in Ivory Coast processed about 65,000 tonnes in 1983 and their capacity is over 70,000 tons. Liquor, cake, powder and butter are produced.

Cameroon.

Cameroon cocoa has a poor reputation for quality because it is inconsistent and often suffers from mouldy off-flavours, insufficient fermentation, high percentage 'black pod' damaged beans and generally poor standard of preparation. The current marketing system in Cameroon is very similar to the system in Ivory Coast. As the farmer is paid the same price for Grade I and Grade II cocoa there is inadequate incentive to improve quality. Many intermediate buyers are involved and cocoa is rarely graded more than once. For improved quality it will be necessary to change the marketing system so that:

(a) cocoa is graded at least twice to ensure that the grading is correct;

(b) a differential price based on quality is paid at the farm gate.

There are several factors which influence the value of Cameroon cocoa to a buyer. The high fat yield and ability to give a very desirable colour to the powder make Cameroon cocoa much sought after by butter and powder pressers - especially in Holland and Germany. However, the mouldy off-flavours are a major drawback and fat softness can cause difficulties for the chocolate manufacturer and reduce the value of Cameroon cocoa to them. Fat yield, softness and powder colour cannot be influenced by the farmer and are probably a function of the cocoa growing environment, but the other aspects of quality are a direct function of the farmer's activities. Experience in Cameroon has shown that the farmer responds to a premium for good quality when payment is fairly controlled by Produce Inspectors operating to well publicized standards.
Cocoa in Cameroon is nearly all grown by smallholders though there is one estate and a few large farms. Production has remained relatively stable for many years and though there are substantial development projects, these are probably only balancing the production lost by the older plantings going out of production.

There are three cocoa processing factories in Cameroon with a capacity of 30,000 tons beans though none of them has been operating at anything near capacity recently. Historically the factories have been allocated poorer quality, often sub-standard beans.

Brazil.

Smoke contamination during drying has for many decades given Brazilian cocoa a reputation for having a smoky/hammy off-flavour. In moderation this flavour is considered acceptable by some chocolate manufacturers in the United States and Eastern Europe, but is considered to be totally unacceptable to nearly all West European chocolate manufacturers. Brazilian cocoa is therefore nearly all exported to USA, Eastern Europe and other parts of Latin America with a small tonnage going to the butter pressers in Holland and Germany. This presented no problem when Brazilian cocoa production approximately matched the demand of these countries, but as Brazil's share of world production has increased dramatically in recent years so has the quantity of cocoa available for sale to other markets. There is therefore a risk that this cocoa can only be disposed of at a substantial discount unless the characteristic off-flavour is controlled at the farm level.

The cause of this off-flavour has been identified and steps are being taken to reduce it but it requires a long-term program of farmer education and in many cases modification of the artificial dryers on the farms. Such modification can be expensive and farmers have so far been somewhat reluctant to carry it out, as they have historically received no premium for sales of smoke-free cocoa. This is now gradually changing and farmers are having deductions made for delivery of cocoa seriously contaminated by smoke. Artificial drying is often needed in June/July/August at the time of the major cocoa harvest when heavy rains and high humidity prevail. Smoky flavour can be prevented by effective maintenance of the wood fired dryers thus ensuring that there is no leakage of smoke into the drying chamber. It is also necessary to prevent farm workers building wood fires close to the sun dryers. At the moment smoke contamination is not a problem with cocoa from the newer plantings in the Amazon Basin.

Brazilian cocoa from the States of Bahia and Espirito Santo produces a soft butter which has a low melting point and this too can be a problem in chocolate manufacture. The reason for this is not understood, but it is likely to be an environmental influence because the same planting material, grown in the Amazon Basin, produces a much harder butter. The softness of the butter is also a factor limiting the demand for Brazilian cocoa.
There are some very large cocoa farmers and companies with large holdings of cocoa land in Brazil but also a substantial number of small farmers in the traditional cocoa growing areas in the States of Bahia and Espirito Santo. Cocoa is now being encouraged in a number of areas in the Brazilian Amazon with the participation of both large and small farmers and companies.

There are some seven modern cocoa processing factories in Brazil constructed at a time when investors were offered substantial fiscal incentives by the Brazilian Government. These incentives were withdrawn during 1981 since when factories have been experiencing difficulty. The factories which are still operating are taking steps to become more efficient. There is sufficient capacity to handle over 300,000 tons of beans, and it is forecast that 200,000 tons of beans will be processed in 1984.

**Ecuador.**

The quality of Ecuadorian beans and products is extremely variable and is confused by substantial flavour variation. This may be due to the planting material, environmental conditions or the fermentation/drying methods employed. Ecuador used to be a producer of fine flavour cocoa (Arriba) which usually attracted a premium on world markets. The tonnage of this cocoa now demanded by world chocolate manufacturers is insignificant and the premium is almost non-existent, so no new plantings of pure Arriba cultivars are being made.

The cocoa processing industry in Ecuador has the capacity to process almost twice the national cocoa crop. Faced with this enormous overcapacity, coupled with static local production of beans and lower world market prices, the Ecuador cocoa processing industry is struggling to survive and indeed some factories have already gone into liquidation. This overcapacity resulted from a government program of incentives to agro-industrial projects in the late 1970s and there are currently some 12 cocoa processing factories in and around Guayaquil. The industry is seeking further government support to see it through these difficult market conditions.

**Malaysia.**

The major part of Malaysian cocoa production is on efficient plantations. The Malaysian Government has forecast that production will rise to 150,000 tons by 1985. This may be optimistic, but it could make Malaysia the fifth largest cocoa producer. There are five processing factories in operation which expect to use 39,000 tons of beans in 1984. The bean quality tends to be very variable, often with a very acidic taste. This is thought to be due to fermentation and drying methods and research is in hand to find the cause and propose new methods. There is wide variation in bean size and shell content depending on season, and the bean count per 100 g is generally high as is shell percentage. In some seasons beans are very small and shell percentage very high. This is probably a climate effect.
Cocoa beans produced by smallholders is variable in quality and an effective grading system and rigorous quality standards are now urgently needed. Progress is being made in the establishment of an agreed national standard.

9.3 Quality Control at Farmer Level

From the above it can be seen that there is a need for more effective quality control in many producing countries. There is no one way to achieve this, but experience in many countries suggests that a number of aspects are important. These include:-

(a) An open marketing system where the farmer is paid a well publicised price in cash for his cocoa by licenced commodity brokers, i.e. he is not selling to general traders in exchange for goods;

(b) there should be buying points in or as near as possible to every village;

(c) the published price for cocoa should only be paid for cocoa that meets FAO grade 1 standard. There should be a significant discount for poorer quality (10-20%);

(d) there needs to be considerably more publicity about the grade 1 cocoa standard and the recommended methods of harvesting, fermenting and drying to achieve this standard;

(e) all cocoa should be graded twice, once at the point of first purchase and once immediately prior to shipment;

(f) the produce inspection and grading service should be in the hands of a government department independent of licensed buying agents, commercial shippers etc.;

(g) grading staff need to be well trained, well paid and respected;

(h) the individual grader and buyer, (or the buying point), of any sack of cocoa needs to be identifiable from the bag or seal so that in the event of the cocoa subsequently being found to be below standard it can be traced back to the grader and the first buyer or buying point and the responsible person can be penalized;

(i) grading certificates should be valid for a specific limited period - say six months;

(j) there should be no long distance movement (over Departmental boundaries?) of ungraded cocoa, or even worse, wet cocoa (more than 7.5% moisture);
(k) the selling organisation, whether governmental or commercial, should be responsible for the quality of the cocoa that it is shipping and for meeting any claims. They should be encouraged to visit their customers in consuming countries to discuss quality matters so that they understand their customers' problems.
In order to provide some guidance as to labour requirements for mature cocoa two tables have been drawn up, one for plantations in Malaysia, the other for smallholders in Ghana. The first is derived from plantation data collected in 1982, the second comes from well known studies which were published in the 1940s but the data have been substantiated by more recent field work.

The plantations in Malaysia from which the data were obtained are efficient and would have an average yield of 1,000 kg dry beans per hectare. While the annual total of labour usage varied between 63 and 84 man-days per hectare, the individual tasks varied to a greater extent, as a result of different soils, shade and pests and diseases. There would be even greater variation between countries due largely to different pests and diseases.

The data for smallholdings in Ghana, which do not include the labour required for fermentation and drying, are very similar in total to those of the Malaysian plantations. However, the labour cost per ton of dry beans is much higher on the smallholdings than on plantations in Malaysia as the yield in Ghana was less than 400 kg dry beans per hectare.

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<tr>
<th>Table 5. Labour Usage for Mature Cocoa on Plantations in Malaysia</th>
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<td>Task</td>
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<tr>
<td>Weed control</td>
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<td>Pest control</td>
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<td>Disease control</td>
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<td>Shade management</td>
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<td>Fertiliser application</td>
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<td>Road and drain maintenance;</td>
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<td>water conservation</td>
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<td>Pruning</td>
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<td>Road, paths, bridges</td>
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<tr>
<td>Harvesting, pod opening</td>
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<td>Fermentation, drying, bagging</td>
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<th>Table 6. Labour Usage on Small Holdings in West Africa</th>
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<td>Task</td>
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<tr>
<td>Weed control</td>
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<tr>
<td>Other maintenance</td>
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<tr>
<td>Harvesting, pod opening and carrying</td>
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</tbody>
</table>
ANNEX I
NOTES ON THE CONTRIBUTORS

J.E. Clayphon

Worked for many years in West Africa on cocoa production and storage problems. Subsequently spent 12 years as Senior Research Officer at the Overseas Spraying Machinery Centre, now called the Silwood Centre for Pest Management of the Imperial College of Science and Technology, London. Duties included teaching, demonstrating and researching pesticide application equipment for overseas territories and developing specialised machines for the World Health Organisation. Now a part-time consultant.

D.F. Edwards, B.Sc., D.T.A.

Took a degree in agriculture at Reading University, followed by the post-graduate course at Cambridge and D.T.A. course at I.C.T.A., Trinidad. Held various posts in the Department of Agriculture, Ghana, from 1952 - 62, initially as Agricultural Officer, finally as Deputy Chief Cocoa Officer. Joined Department of Agriculture, Sabah, in 1962 as plant breeder working on cocoa and oil palm. Left Sabah in 1968. Worked for Ministry of Overseas Development at Tafo, Ghana as member of cocoa swollen shoot project 1969 - 72 and at Pichilingue, Ecuador 1972 - 77. Cocoa breeder at Cocoa Research Unit, University of West Indies, Trinidad 1978 - 80. Consultant to World Bank.

P.F. Entwistle, B.Sc., ARCS, FRES

Graduated from the Royal College of Science, London, in 1953. On joining the Colonial Research Service spent from 1955 to 1959 as entomologist at the West African Cocoa Institute, Ghana, and from 1960-64 at its sub-station in Nigeria (now Nigerian Cocoa Research Institute). In 1964 joined the Unit of Insect Pathology, now Natural Environment Research Council, Institute of Virology, Oxford. In 1972 published "Pests of Cocoa" (Longman), and in 1975 and 1984 revised the insect pest chapter in successive editions of "Cocoa" (Longman), and is still involved in consultancy work on cocoa pest problems. Main current preoccupations are the interrelated areas of insect virus disease ecology and the development of viruses as insect pest control agents. Recent work has led to the first insect virus, that of Pine sawfly, to be commercialised in the U.K.

H.C. Evans, B.Sc., M.Sc., Ph.D.

Studied botany and plant pathology at London, Exeter and Keele. cocoa mycologist, Tafo, Ghana, 1969 - 73, cocoa pathologist, Pichilingue, Ecuador, 1973-77; cocoa pathologist, Belem, Brazil, 1977-80. All the above posts were financed by ODA under technical cooperation schemes with CRIG, (Ghana, Black pod disease); INIAP (Ecuador, Witches' broom and 'Monilia' diseases); and CEPLAC (Brazil, Witches' broom disease).

From April 1980 to present working as Forest Mycologist at Commonwealth Mycological Institute, Kew, England, on diseases of Central American pines.
P.H. Gregory, B.Sc., Ph.D., D.Sc., FRS.

Received Ph.D. at Imperial College 1931. Mycologist, Canada 1931 - 34; Seale Hayne Agricultural College, Devon 1935 - 40; plant pathologist Rothamsted Experimental Station 1940 - 54; professor of botany, Imperial College 1954 - 58; head plant pathology Rothamsted 1958 - 68. F.R.S. Pres. British Mycological Soc. 1951. Author of 'Microbiology of the Atmosphere' and many papers on behavioural studies on pathogenic microbes especially airborne fungi. From 1968 - 1979 was consultant to the Cocoa, Chocolate and Confectionery Alliance on black pod and other diseases. Editor of "Phytophthora disease of Cocoa" published by Longman in 1974 and with A.C. Maddison of "Epidemiology of Phytophthora on Cocoa in Nigeria", published by CMI in 1981.

W. Hadfield, B.Sc.

Took a degree in botany at Liverpool University in 1957. Worked in Assam for Indian Team Association 1957-74 as botanist/physiologist studying shade and nutrition interactions. Appointed physiologist to INIAP Ecuador working on cocoa at Pichilingue and became leader of the Overseas Development Administration's cocoa project in 1980. This project was set up to study some of the problems of growing cocoa under the unusual climatic conditions existing in Ecuador.

R.A. Lass, B.Sc., (Agric.), D.T.A.

Read Agriculture at Nottingham University and after further training at University of West Indies for Diploma of Tropical Agriculture, took up employment with Cadbury Schweppes Ltd. in the field of tropical agriculture. Currently Agricultural Manager with particular responsibility for the Cadbury Schweppes involvement in cocoa research, extension and quality improvement. Visits all major cocoa producing countries on a regular basis and is currently involved in many international cocoa projects. Joint author of 4th Edition of "Cocoa" in Longman's Tropical Agriculture Series, with G.A.R. Wood.

G. Lockwood, B.Sc., M.Sc., Ph.D.

Received B.Sc. (Horticulture) from Wye College, London University in 1967, M.Sc. from Wye in 1968 and Ph.D. from London University in 1982. Joined the Overseas Development Administration in 1967 and was cocoa breeder with the British Research Team at the Cocoa Research Institute of Ghana from 1969 to 1978. Now breeding field beans at the Plant Breeding Institute, Cambridge, but maintains an interest in cocoa through consultancy work for the Commonwealth Development Corporation, the International Board for Plant Genetic Resources and the Overseas Development Administration.
J.D. Mumford, B.Sc., Ph.D., D.I.C.

Studied entomology at Purdue University, Indiana, and received Ph.D. 1978 and D.I.C. 1980 from Imperial College, London. Since 1979 has been lecturer with the Environmental Management Unit of the Pure and Applied Biology Department of Imperial College and is concerned with the economics of pest control. Director of the research program on integrated control of cocoa pod borer in Malaysia.

A.F. Posnette, C.B.E., Ph.D., D.Sc., V.M.H., F.R.S.


C. Prior, B.A., Ph.D.

Studied Botany and plant pathology at Cambridge. From December 1973 to the present, employed as a research fellow by the University of Papua New Guinea on a collaborative program of cocoa research with the Papua New Guinea Government, based at the Lowlands Agricultural Experimental Station (L.A.E.S.), Keravat, East New Britain. Worked initially on vascular streak dieback disease, but now also working on Phytophthora problems of cocoa, particularly canker. Funded by the Confectionery Manufacturers of Australia Ltd., and the Cocoa Industry Board of Papua New Guinea.

R.W. Smith, B.Sc.

Studied botany at Bangor and had further training at East Malling Research Station, England before taking post as Agronomist at West African Cocoa Research Institute (now C.R.I.G.), in Ghana for five years. Agronomist/Crop Physiologist for 10 years with Research Dept. of the Coconut Industry Board, Jamaica. For the past 10 years has been Assistant Advisor and later, Agricultural Research Advisor with the U.K. Ministry of Oversease Development (now ODA). In the latter post has been involved in cocoa research in most cocoa growing countries.

J.M. Thresh, Ph.D., ARCS

J.M. Thresh is Deputy Head of the Plant Pathology Department at East Malling Research Station, U.K. and is founder-Chairman of the Plant Virus Epidemiology Committee of the International Society for Plant Pathology. He studied the epidemiology and control of cocoa swollen shoot virus at the West African Cocoa Research Institute 1953-1960 and has since 1981 been adviser to the Cocoa Research Institute of Ghana.
M. Wessel

Worked from 1960-70 as soil scientist at the Cocoa Research Institute of Nigeria and in subsequent years in agricultural research and development projects in various countries, especially in Indonesia. Joined the Department of Tropical Crops of Wageningen University in 1977. At present Director of the International Course for development oriented Research in Agriculture (ICRA). Member of an international advisory group for cocoa development in Indonesia.

G.A.R. Wood B.A., D.T.A.

Graduated Cambridge in 1948 and studied at Imperial College of Tropical Agriculture 1951-52. Subsequently employed by Cadbury Limited as advisor on cocoa production and research. Editor of Cocoa Growers' Bulletin until retirement in 1981. Author of "Cocoa" 3rd edition the standard English Language text on cocoa cultivation and co-author with R.A. Lass of the 4th edition which will be published shortly.
World Bank Publications of Related Interest

Adoption of Agricultural Innovations in Developing Countries: A Survey
Gershom Feder, Richard Just, and David Silberman


Agrarian Reform as Unfinished Business—the Selected Papers of Wolf Ladejinsky
Louis J. Walinsky, editor


Agrarian Reforms in Developing Rural Economies Characterized by Interlinked Credit and Tenancy Markets
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William Cuddihy

*Staff Working Paper No. 388. 1980. 174 pages (including annex, bibliography).*
Stock No. WP-0388. $5.
Agricultural Price Policies and the Developing Countries
George Tolley, Vinod Thomas, and Chung Ming Wong

This book first considers price policies in Korea, Bangladesh, Thailand, and Venezuela, bringing out the consequences for government cost and revenue, farm income, and producer and consumer welfare. Other effects, including those on agricultural diversification, inflation, economic growth, and the balance of payments are also discussed. The second part of the book provides a methodology for estimating these effects in any country. Operational tools for measuring the effects on producers, consumers, and government are developed and applied.


NEW

Agricultural Prices in China
Nicholas R. Lardy

Analyzes recent adjustments to China's agricultural pricing systems and its effects on urban consumers and overall production patterns. Defines price ratios from key inputs and outputs and examines price/cost relations in view of the institutional setting for price policy.


Agricultural Research

Points out that developing countries must invest more in agricultural research if they are to meet the needs of their growing populations. Notes that studies in Brazil, India, Japan, Mexico, and the United States show that agricultural research yields a rate of return that is more than two to three times greater than returns from most alternative investments and cites some of the successes of the high-yielding varieties of rice and wheat that were developed in the mid-1960s. Discusses the World Bank's plans to expand its lending for agricultural research and extension, particularly for the production of food and other commodities that are of importance to low-income consumers, small farmers, and resource poor areas.


Agroindustrial Project Analysis
James E. Austin

Provides and illustrates a framework for analyzing and designing agroindustrial projects.


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Alternative Agricultural Pricing Policies in the Republic of Korea: Their Implications for Government Deficits, Income Distribution, and Balance of Payments
Avishay Braverman, Choong Yong Ahn, Jeffrey S. Hammer

Develops a two-sector multimarket model to evaluate agricultural pricing policies, replacing insufficient standard operational methods. Measures the impact of alternative pricing policies on production and consumption of rice and barley, real income distribution, import levels of rice, self-sufficiency in rice, and public budget. Provides a valuable synthesis of the work that has been done to date on agricultural household models. Helps economists evaluate the impact of alternative pricing policies aimed at reducing deficits. Based on the experience of the Grain Management Fund and the Fertilizer Fund in Korea.


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The Johns Hopkins University Press, 1983. 624 pages (including maps, bibliographies, index).


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Edited by Roger D. Norton and Leopoldo Solis M.

The principal tool of analysis is the sector model CHAC, named after the Mayan rain god. This model can be used throughout the sector to cover short-cycle crops, their inputs, and their markets. It can also be broken down into submodels for particular localities if more detailed analysis is required. The model helps planners weigh the costs among policy goals, which can vary from region to region. This volume reports the experience of using the CHAC model and also presents purely methodological material.

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The Common Agricultural Policy of the European Community: A Blessing or a Curse for Developing Countries? Ulrich Koester and Malcolm D. Bale
Examine the importance of the European Community (EC) in global agricultural trade. Points out that the EC is the leading importer of agricultural goods and is the dominant exporter of a number of agricultural products. Emphasizes that policymakers in developing countries must understand the implications of the EC’s common agricultural policy. Spells out how this policy operates and categorizes important commodities. Staff Working Paper No. 630. 1984. 64 pages. Stock No. WP 0630. $3.

The Design of Rural Development: Lessons from Africa Uma Lele

Economic Analysis of Agricultural Projects Second edition, completely revised and expanded J. Price Gittering
Sets out a careful and practical methodology for analyzing agricultural development projects and for using these analyses to compare proposed investments. It covers what constitutes a "project," what must be considered to identify possible agricultural projects, the life cycle of a project, the strengths and pitfalls of project analysis, and the calculations required to obtain financial and economic project accounts. The methodology reflects the best of contemporary practice in government agencies and international development institutions concerned with investing in agriculture and is accessible to a broad readership of agricultural planners, engineers, and analysts. This revision adds a wealth of recent project data; expanded treatment of farm budgets and the efficiency prices to be used to calculate the effects of an investment on national income; a glossary of technical terms; expanded appendices on preparing an agricultural project report and using discounting tables; and an expanded, completely annotated bibliography. EDI Series in Economic Development. The Johns Hopkins University Press, 1980. 154 pages. LC 79-3704. ISBN 0-8018-2386-2, Stock No. JH 2386. $15 hardcover; ISBN 0-8018-2387-0, Stock No. JH 2387. $6.50 paperback. Spanish: Presupuestos de fincas. Editorial Tecnos, 1982. ISBN 84-309-0886-2, Stock No. IB 0522. $6.50 paperback.

Fishery
Highlights the importance of fisheries to the economies of developing countries and recommends that the World Bank provide assistance to those countries that have the fishery resources and are willing to develop them further. Sector Policy Paper, 1982. ISBN 0-8213-0138-1. Stock No. BK 0138. $5 paperback.

Forestry
Graham Donaldson, coordinating author
Examines the significance of forests in economic development and concludes that the World Bank should greatly increase its role in forestry development, both as a lender and adviser to governments. Sector Policy Paper, 1978. 63 pages (including 7 annexes). English, French, and Spanish. Stock Nos. BK 9063 (English), BK 9064 (French), BKL 9065 (Spanish). $5 paperback.

The Design of Organizations for Rural Development. Projects: A Progress Report William E. Smith, Francis J. Lethem, and Ben A. Thoelen
Forestry Terms—Terminologie forestiere
English—French; Francais—Anglais.
Prepresents terminology related to forest development and erosion control in arid and semiarid lands. Since fuel-wood problems and desertification have become serious, particularly in Western Africa, the World Bank has become increasingly involved in wood-based energy and erosion-control and in forest-management projects. Assists translators and researchers who work in this field.
A World Bank Glossary—Glossaire de la Banque mondiale
1984. 48 pages.

Improving Irrigated Agriculture: Institutional Reform and the Small Farmer
Daniel W. Bromley

India: Demand and Supply Prospects for Agriculture
James Q. Harrison, Jon A. Hitchings, and John W. Wall
Stock No. WP-0500. $5.

Irrigation Management in China: A Review of the Literature
James E. Nickum
Analyzes irrigation management in the People's Republic of China. Major topics covered are the institutional environment, the organizational structure, water fees and funding, and water allocation. The report is based on Chinese-language materials published in China and now available in the United States.

Land Reform
Examines the characteristics of land reform, its implications for the economies of developing countries, and the major policy options open to the World Bank in this field.
Stock No. BK 9042. $5 paperback.

Land Tenure Systems and Social Implications of Forestry Development Programs
Michael M. Cernea
Stock No. WP-0452. $3.

Managing Elephant Depredation in Agricultural and Forestry Projects
John Seidensticker
Outlines procedures for managing elephants in and around project areas as part of the project design. Helps project designers plan activities that will protect wildlife and prevent financial loss from damage by animals. Illustrates methods used to investigate elephant behavior and ecology. Notes that careful scheduling of project activities is required to ensure that elephants are not isolated in production areas.
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Managing Information for Rural Development: Lessons from Eastern Africa
Guido Deboeck and Bill Kinsey
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Measuring Project Impact: Monitoring and Evaluation in the PIDER Rural Development Project—Mexico
Michael M. Cernea
Stock No. WP-0332. $5.

Monitoring and Evaluation of Agriculture and Rural Development Projects
Dennis J. Casley and Denis A. Lury
This book provides a how-to tool for the design and implementation of monitoring and evaluation systems in rural development projects. Because rural development projects are complex, they seek to benefit large numbers of people in remote rural areas, and they involve a variety of investments. The need for monitoring and evaluating them during implementation has been accepted in principle, but effective systems have not heretofore been formulated. The concepts of monitoring and evaluation are differentiated and issues that need to be considered in designing systems to monitor and evaluate specific projects are outlined, emphasizing the timeliness of the monitoring functions for effective management. Elaborates on such technical issues as selection of indicators, selection of survey methodology data analysis, and presentation. It is directed primarily to those working with specific projects and will be useful to project appraisal teams, designers of monitoring and evaluation systems, and to project staff who work with these systems.

Monitoring Rural Development in East Asia
Guido Deboeck and Ronald Ng
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Monitoring Systems and Irrigation Management: An Experience from the Philippines
Agricultural economists, planners, and field workers will find this 1983 case study report a practical guide for designing efficient monitoring and evaluation systems for irrigation and similar projects. It illustrates the practical application of the principles covered in the 1982 publication Monitoring and Evaluation of Agriculture and Rural Development Projects. Highlights the problems as well as the successes.
Opportunities for Biological Control of Agricultural Pests in Developing Countries
D. J. Greathead and J. K. Waage
Describes how to use living organisms as pest control agents, either alone or as one component of pest management. Biological control offers hope of long-term—permanent—results, causes no pollution, poses no risk to human health and is often cheaper than chemical controls. Gives methods and costs. Specifies controls for specific crops found in developing countries.

Prices, Taxes, and Subsidies in Pakistan Agriculture, 1960-1976
Carl Gotsch and Gilbert Brown

Rural Development in China
Dwight H. Perkins and Shahid Yusuf
Looks at China’s rural development experience as a whole since 1949. Analyzes China’s agricultural performance and traces it back to the technology and other sources that made that performance possible. Goes beyond the conventional sources of growth analysis to examine the political and organizational means that enabled the Chinese to mobilize so much labor for development purposes.
Describes the successes and failures of China’s rural development policy. Helps clarify both the strengths and weaknesses of a self-reliant strategy of rural development.

NEW

Project Evaluation in Regional Perspective: A Study of an Irrigation Project in Northwest Malaysia
Clive Bell, Peter Hazell, and Roger Slade
This innovative study develops quantitative methods for measuring the direct and indirect effects of agricultural projects on their surrounding regional and national economies. These methods are then applied to a study of the Muda irrigation project in northwest Malaysia. A linear programming model is used to analyze how a project changes the farm economy, and a social accounting matrix of the regional economy is then estimated. This provides the basis for a semi-input-output model, which is used to estimate the indirect effects of the project on its region. Thereafter, a similar methodology is used to estimate the project’s effects on key national variables, thus permitting a full social cost-benefit analysis of the project.
The Johns Hopkins University Press. 1982. 336 pages (including maps and index).

Rethinking Artisanal Fisheries Development: Western Concepts, Asian Experiences
Stock No. WP-0423. $5.

Rural Development
Discusses strategy designed to extend the benefits of development to the rural poor and outlines the World Bank’s plans for increasing its assistance in this sector.
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NEW

Rural Financial Markets in Developing Countries
J. D. Von Pischke, Dale W. Adams, and Gordon Donald
Selected readings highlight facets of rural financial markets often neglected in discussions of agricultural credit in developing countries. Considers the performance of rural financial markets and ways to improve the quality and range of financial services for low-income farmers. Also reflects new thinking on the design, administration, evaluation, and policy framework of rural finance and credit programs in developing countries.

Rural Poverty Unperceived: Problems and Remedies
Robert Chambers
Staff Working Paper No. 400. 1980. 51 pages (including references).
Stock No. WP-0400. $3.

Rural Projects through Urban Eyes: An Interpretation of the World Bank’s New-Style Rural Development Projects
Judith Tendler
most important determinant of overall economic growth, has been sluggish in Sub-Saharan African countries during the past two decades. This overview takes a three-pronged approach to understanding the problems of agricultural production in the 47 countries that make up the region. It outlines domestic and global constraints; summarizes price, trade, and consumption forecasts for major agricultural exports; and project trends.

Staff Working Paper No. 608. 1983. 172 pages (including more than 75 tables and charts).

A System of Monitoring and Evaluating Agricultural Extension Projects
Michael M. Cernea and Benjamin J. Tepping
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Thailand: Case Study of Agricultural Input and Output Pricing
Trent Bertrand
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Traditional Land Tenure and Land Use Systems in the Design of Agricultural Projects
Raymond Noronha and Francis J. Lethem
The feasibility of agricultural projects and their intended impact are often determined by traditional patterns of tenure and land use. This paper provides agricultural project designers with an analytical basis and rationale for examining systems and suggests how to use such information in designing projects.

Women and the Subsistence Sector: Economic Participation and Household Decisionmaking In Nepal
Meena Acharya and Lynn Bennett
Fascinating analysis of the complex social, demographic, and economic factors that affect women's decision-making role in the subsistence sector. Data collected from seven villages show women play a major role in agricultural production, both as laborers and managers. Bringing women into the market economy would make better use of local resources and improve their status and economic security in Nepal.
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