ESTUDIO SOBRE CACAO

Ing.Agronomo Alejandro Angeleri

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CACAO MANUAL

(ENGLISH EDITION)

COMPILED AND EDITED BY

FREDERICK HARDY

INTER-AMERICAN INSTITUTE OF AGRICULTURAL SCIENCES
TURRIALBA, COSTA RICA
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FREDERICK HARDY,

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FOREWORD

This manual has been compiled for the specific use of students of the Cacao Course that is held annually at the Inter-American Institute of Agricultural Sciences, Turrialba, Costa Rica, Central América. It is based mainly on teaching materials provided by the course lecturers comprising cyclostyled notes used during or in conjunction with the lectures. The Cacao Course lasts approximately three months, and is generally held during the early part of the year. Lecturers are drawn from the staff of the Institute or, in special cases, they are recruited from outside sources such as the Imperial College of Tropical Agriculture in Trinidad, West Indies, or I. C. A. organisations in Latin America. The Manual is issued in English and in Spanish.

Although it does not purport to be an exhaustive textbook on cacao, it is hoped that the Manual may interest and help readers who are concerned in any way with the cacao industry. The Manual is technological in aspect and mostly consists of information dealing with the planting, growing, reaping and curing of the cacao crop. The subject matter is arranged in sections and chapters which logically follow the establishment, planting, rehabilitation, management, control of disases and pests, reaping and curing, as carried out on the cacao plantation, and the manufacture of cacao products as carried out in factories overseas. Attention is mainly given to the scientific principles that form the basis of the processes of growth and production of the cacao tree, viewed from an ecological and plant physiological standpoint. Special attention is given to horticultural practices employed in the preparation of planting material, to diseases and pests and to genetics involved in the breeding of improved planting material, as well as to the botany of the cacao plant.

The Manual has been produced under the special contract agreement, signed in February, 1955, between the International Cooperation Administration (ICA) and the Inter-American Institute of Agricultural Sciences (IAIAS) to supply regional services in coffee and cacao to the United States Operation Missions (USOM) in Latin America. The first short course was given in March to June, 1956; the second in January to March, 1957, the third during the corresponding months in 1958, and the fourth and fifth during the same months in 1959 and 1960.

The Manual was compiled and edited by Professor Frederick Hardy, Soil Scientist on the ICA/Turrialba Contract Staff, who is Professor-Emeritus and late head of the Department of Soil Science and Chemistry of the Imperial College of Tropical Agriculture, Trinidad, West Indies. It is partly based *on material used in preparing the first (Spanish) edition of the Cacao Manual of which the editor was Mr. A. L. Erickson, formerly under ICA contract at the Institute. Acknowledgement is accordingly made to the contributors to the first Spanish edition, namely, Dr. P. de T. Alvim, Mr. A. L. Erickson, Dr. L. R. Holdridge, Dr. J. R. Hunter, Dr. A. L. Jolly, Dr. J. León, Ing. M. Machicado, Mr. E. Martin, Dr. J. R. Orsenigo and Dr. F. R. Wellman.*

References to papers and articles consulted in the preparation of the text are set out at the ends of the chapters. Authors names are rarely included in the text so as not to disturb the continuity and to aid in easy reading. The narrative method has been adopted in the writing. A brief summary is given of the main subject matter at the end of each chapter. Special mention is made in foot notes at the beginning of each chapter to course lecturers whose notes and articles have been especially used and abstracted in preparing some of the chapters. They include the following: (Ecology) *Dr. P. de T. Alvim, Prof. F. Hardy, Mr. G. Havord:* (Pedology) *Prof. F. Hardy,* (Horticulture) *Mr. A. L. Erickson, Mr. E. Camacho, Mr. L. de Verteuil, Mr. L. A. Montoya:* (Management) *Dr. A. L. Jolly:* (Diseases and Pests) *Dr. R. Desrosiers, Dr. L. M. Hutchins, Dr. E. Dresner, Dr. G. Berg:* (Botany) *Dr. J. Soria, Dr. J. León:* (Curing and Marketing) *Prof. F. Hardy, Mr. A. Helfenberger.*

The compiler's special thanks are expressed to Dr. J. R. Hunter for advice and encouragement, to Ing. E. Camacho, for helpful suggestions, and to Sra. María de Orbegoso, Sra. Aída Villalobos de Gutiérrez and Miss Gretchen Cahusac for undertaking the typing of the preliminary drafts of the various chapters.

INTRODUCTION

PLAN OF THE CACAO COURSE

The sequence of subjects taught in the Cacao Course purposely conforms to the order of events involved in the establishment, maintenance and management of a cacao plantation. The various aspects of these major developmental stages are the concern, not only of the planter, but also of specialists in many different branches of applied science, notably, economics, pedology, plant ecology and physiology, horticulture, entomology, plant pathology, taxonomy and plant breeding. Whilst it is not essential, nor is it advocated, that cacao growers should be well versed in these different disciplines, it is at least essential that their technical advisers and those responsible for extension work among cacao planters and cacao farmers should be familiar with the general principles of these subjects in their relation to cacao production and especially in relation to the main trends and results of scientific researches now being conducted at various institutes situated in cacao-growing areas. This implies that cacao technologists should have access to central libraries, or that they be enabled to participate in some scheme of literature distribution whereby copies or summaries of current articles describing recent research are regularly made available to them.

The Cacao Course was originally designed to cater chiefly for estate managers, technical advisers, extension workers and nursery technicians living and working in Latin America, and not primarily for cacao planters or plantation owners. The subject matter of the actual Course is taught by a number of specialist who are called upon each year in which the Course is given to deal with their own special subjects.

The plan of the Cacao Course is indicated by the Table of Contents in which the subject matter is classified, as follows.

(I) *Establishment:* The various factors that determine the selection of a suitable place to establish a cacao plantation are partly ecological (or environmental) depending on the prevailing climate, topography and soil, and partly economic, depending on access to lines of communication, nearness to markets and availability of labor. Among the ecological factors, the nature of the incident vegetation is in itself important, since it partly decides the planting procedure. The original vegetation may be either virgin forest, second-growth bush, old cacao or agricultural crops other than cacao, including pasture. The suitability of the soil for the satisfactory growth of the cacao crop can be gauged by "reading the soil-profile", paying special attention to the color, structure, texture and consistency of the soil comprising the different horizons or layers that are displayed in the section.

Since the procedure involved in the establishment of the cacao plantation depends largely on the nature of the vegetation that is covering the ground, several alternative cases have separately to be considered. It is not yet a customary practice to cultivate, by hand or by machinery, land on which it is intended to plant cacao, although it might be necessary to do so in future when the rehabilitation of worn-out plantations by complete replanting is being undertaken. Hence little attention is given in the Course to the construction and use of agriculture implements.

(II) _Cacao ecology:_ The successful growth of the cacao tree depends primarily on the temperature relations of the environment which are particularly exacting in the case of cacao. Next in importance are the water and air relations of the tree which are complementary in that both water and air occupy the pore spaces of a soil at the same time. The cacao root system is especially sensitive to oxygen deficiency and it cannot develop satisfactorily unless the root room of the soil is adequate and aeration is unrestricted. When the temperature relations and the water and air relations are suitable, then growth depends on the supply of available nutrients which can artificially be increased or augmented by the use of manures and fertilisers. The light relations of cacao are complex, since the incident radiant energy from the sun comprises both light and heat. Each of these agencies is important, not only for the manufacture of carbohydrate by photosynthesis, but also for transpiration whereby nutrients in solution are brought up from the soil and transferred to the leaves. Thus nutrient supply and light intensity are inter-related and both are involved in the problem of shade provision in the cacao field. When the nutrition of the cacao tree is limited by one or other of the environmental growth factors operative in the soil, only a restricted number of cacao pods can be brought to maturity and a large proportion of fruits that set cease to grow and then shrivel. Cherelle wilt is thus explained as the result of general mal-nutrition and nutrient imbalance.

(III) _Cacao pedology:_ Having learnt how closely the successful growth and production of the cacao tree is controlled, not only by factors of the climate, but also by factors operating in the soil, the cacao student should learn to recognise a good cacao soil and to distinguish it from a bad soil, and to appreciate the circumstances that give rise to each. These objectives belong to the science of pedology which stresses the interplay between the chief soil-forming factors which determine the features and properties of a soil, namely, parent rock, climate, organisms, relief and time.

(IV) *Horticulture:* All those who are in any way concerned in the actual growing of cacao should be conversant with the techniques, equipment and installations employed in the preparation of planting material comprising seedlings, cuttings, buddings, grafts and marcots, and in the management of the cacao nursery. They should also be familiar with modern methods of weed control which is particularly important during the establishment phase of the cacao plantation. In the Cacao Course, opportunity is afforded to students to observe these techniques in operation, and to practice them themselves under the guidance of experienced teachers of horticulture. The practices of pruning and weed control in the cacao plantation are also studied, actually on a part-commercial part-experimental cacao plantation ("La Lola") situated on the Atlantic coastal plain of Costa Rica.

(V) *Decline and rehabilitation:* The causes of decline in yield of cacao plantation are many. They include the ravages of diseases and pests, accidental damage caused by the cutlass or machete or by falling shade trees, soil deterioration due to several causes such as erosion, reduction in litter supply, nitrogen accretion, over-exposure to sunlight and exhaustion of nutrients through continuous cropping, as well as old age, unsuitable cacao varieties and bad management. Rehabilitation becomes necessary when production is no longer profitable. Experience has shown that merely replacing unprofitable trees by planting new material is generally unrewarding and it is advisable to replant derelict fields completely, using the best planting material available. The application of fertilisers when re-establishing cacao fields is recommended, but it is advisable first to ascertain which fertilisers are best to use, in what quantity, at what time and in what manner. These questions can only by adequately answered by first carrying out chemical soil analysis, pot tests and field experiments.

(VI). *Management:* Of all the factors that ensure the success of a cacao plantation and determine the magnitude of the profits, good management without doubt is one of the most important, for without good management, the advantages to be gained by the application of the proper scientific techniques involved in growing cacao cannot be realised. The progress and results of cacao research should be understood, followed and where possible, applied by the efficient manager. Future developments in the research field are likely to be of considerable importance and value to the progressive cacao planter.

(VII) *Diseases and pests:* In order to appreciate the possibilities of increasing the cacao crop by the economic control of diseases and insect and animal pests, the plantation manager must be conversant with the life histories and pathological features of the specific fungi, algae, bacteria, viruses, insects and animals that are parasitic on the cacao plant. He should be ever ready to try new fungicides and insecticides and new kinds of spraying apparatus and techniques. He should always be on the lookout for possible deleterious effects of fungicides and insecticides on the particular insects that pollinate cacao flowers and on the predators and parasites that might be exerting biological control of the insect pests.

(VIII) *Botany:* Whilst the botanical features and relationships of *Theobroma cacao* and the classification of its different cacao varieties might be regarded merely as a subject of academic interest, it is important for the cacao planter or manager to be aware of the economic possibilities of intercrossing different varieties, species and genera of cacao from the points of view of the resistance of the crosses to diseases and pests, higher production potential and improved bean quality. To this end, the planter or manager should have some knowledge of the principles of plant genetics and plant breeding and of the methods used by the geneticist and breeder for producing new strains of cacao.

(IX) *Curing and manufacture:* In order fully to appreciate the need for great care in the curing of cacao beans on the plantation or peasant holding, and in order to understand the importance of proper processing in determining the quality of the final chocolate and cocoa powder, the planter or manager and the cacao advisor ought to know something about the biochemistry of cacao and of the changes that occur during curing, as well as the broad outlines of the manufacture of cocoa products and by-products and their uses. Instruction in these matters is provided in the Cacao Course in the lecture room and model fermentary and by actual visits to commercial cacao curing plants and chocolate factories in Costa Rica. Finally, the problems of marketing should be appreciated, for it is only by close and sympathetic co-operation between producer, buyer and manufacturer that the cacao industry can be expected to progress and to flourish.

PREFACE

ETYMOLOGY AND HISTORY OF CACAO

Origin of the words "cacao" "cocoa" and "chocolate": The word "cacao" was apparently derived from two Mayan words, "kaj" and "kab", which mean "bitter" and "juice" respectively (1). Their combination, "kajkab", became "kahkah" in Spanish. The suffix, "atl", meaning "water" or "liquid", when added to kajkab, that is the word "kajkabatl", became "kajkabhuatl" by the conventional insertion of the diphthong "hu". This, in Spanish, became "kakahuatl" or "cacahuatl", which later was changed to "cacauatl" and to "*cacaoatl*". Finally the last three letters were dropped, giving "cacao".

The origin of the word "chocolate" seems to have been different, the term having been derived from the word "chacau" which means "anything warm", according to the Maya-Spanish Dictionary of Motue, a document which links the language of Yukatan with the 16th century. From "chacau" comes "chacau-haa", which means "warm beverage" (2). Confusion with the word "cacaoatl" for cacao, presumably resulted in the term "chacau-atl" which was changed to "chocolatl" and finally, in Spanish, to "chocolate", which was later adopted into English.

Early history of the uses of cacao (or cocoa) and chocolate: The Mayan's "cacahuatl" was a cold beverage prepared without either sugar or milk, but the Spaniards preferred it hot and sweet and mixed with milk. Cacao beans were used as a medium of monetary exchange (4). Samples of cacao beans were taken by Columbus to Europe as a curiosity (3) but it was Cortes who earliest realised the possible commercial value of cacao. Spain was the first European country to use cacao and it monopolised its use for many years. Cacao beverage became popular in Italy and France in the early part of the 17th century and soon afterwards in Holland, Germany and England. Cacao cost about $ 3.00 a pound and its consumption was limited to the wealthier classes. "Chocolate houses" became famous as clubs in England, for example, White's Chocolate House and the Cocoa Tree Club of Piccadilly in London. As the demand increased, the cultivation of cacao rapidly extended throughout the western tropics from whence it spread to the East Indies in 1560 and later to Fernando Po and Principe off the coast of West Africa, to Madagascar and, in 1950, to Ceylon. It was introduced in 1870 into the Gold Coast (now Ghana) probably as a single Amelonado pod from Fernando Po which accounts for the great uniformity of the cacao tree population of that country.

Definition of the terms "cacao" and "cocoa": Many authorities restrict the term "*cacao*" to the tree and its parts and to the materials produced on the plantation, for example, cured cacao beans, but use the term "*cocoa*" for the products of manufacture and for materials undergoing fabrication, for example, cocoa nib, cocoa butter, cocoa powder.

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PART I

ESTABLISHMENT OF THE PLANTATION

PART I:

ESTABLISHMENT OF THE PLANTATION

CHAPTER 1

SELECTION OF SITE AND LAND

The original home of the cacao tree is the densely forested lowlands of Central America and northern South America. In this region the climate is hot and wet all the year round. Consequently it would be expected that, in selecting a suitable site for establishing a cacao plantation, *temperature* and *rainfall* must be the chief considerations. It is indeed known that the temperature and water relations of cacao are particularly exacting.

TEMPERATURE

As will be fully explained in Chapter 3, the "cold limit" for the permanent and profitable production of cacao has been set at 21°C (70°F) for the average annual temperature, with mean daily minimum temperature in the coldest months not lower than 15°C (60°F) and the absolute minimum 10°C (50°F) *(4)*. The main reason for this is that flower formation is apparently inhibited when the temperature falls below 22°C (72°F) *(1)* and proceeds normally only at temperatures above 25.5°C (78°F). Moreover, the growth in girth of the trunk of the cacao tree is greatly restricted when the average air temperature is low *(2)*. Finally, the incidence and spread of Black Pod disease *(Phytophthora palmivora)* are markedly enhanced by fall of air temperature *(7)*. Besides being extremely susceptible to low temperature, the cacao tree does not grow satisfactorily when the *range* of daily temperature exceeds 9°C (16°F) *(3)* because bud bursting and leaf flushing then become too frequent, and the tree may eventually suffer debilitation or even death. The continual production of leaf flushes also greatly increases the susceptibility of the cacao tree to attack by diseases such as Witches' Broom disease *(Marasmius perniciosus)* and pests such as Thrips.

The "hot limit" for cacao is difficult to decide. The considerations discussed above suggest that it should be about 30°C (86°F) (equals 21° + 9°C or 70° + 16°F) though temperatures above 32°C (90°F) are often reached and maintained for long periods of time in certain cacao producing countries. High temperatures, however, enhance the rate of decomposition of plant residues that collect on the soil surface. Thus it has been shown that, in Java, the rate of loss of organic matter exceeds its rate of accumulation on the forest floor when the air temperature exceeds 25ºC (77ºF) *(8)*. Finally, high temperatures are not conducive to human endeavour and labour efficiency is diminished when the temperature of the air exceeds 30ºC (85ºF).

Factors controlling temperature: The chief factors that determine the temperature of the air at any locality upon the earth's surface are *latitude* and *altitude*. The particular humid zone within which the average yearly temperature lies above 21ºC (70ºF) (the "cold limit") and does not vary greatly throughout the year, extends between latitudes 15º north and 15º south of the equator at sea level. Within this zone the difference in mean temperature between the hottest and the coldest months is less than 1.5ºC (3ºF). This zone closely coincides with the cacao belt.*

Temperatures diminish regularly with rise in altitude by about 2ºC (3.6ºF) for every 308 m. (1000 ft.) of elevation. Thus, on ascending a mountain whose base is at sea level at a place where the average yearly temperature is 27ºC (80ºF), the critical value is reached at about 924 m. (3000 ft.) elevation. It is commonly stated that cacao cannot be grown successfully at altitudes greater than 620 m. (2000 ft.) although it is admitted that there are some exceptions to this rule, for example, the Cauca Valley in Colombia where the altitude is 1000 m. (3250 ft.) and the Chama Valley in the Venezuelan Andes where the altitude is 1250 m. (4000 ft.). At each of these places, however, the average temperature is only just above 21ºC (70ºF) *(4)*.

RAINFALL

Within the cacao belt, rainfall ranges from 40 to more than 200 ins. (1000 - 5000 mm) a year. Its effect on the cacao tree does not solely depend, however, on the total amount of rain but rather on its distribution over the year. Its effect also depends on the physical properties and the depth of the soil, as will be discussed later. In order to maintain an adequate water supply within the rooting zone so as to ensure the continued rapid growth of the cacao tree, the amount of rain that falls must be at least equal to the amount of water that is lost by evaporation from the soil and by transpiration from the leaves. This depends on the temperature, humidity and movement of the air and is thus a function of climate. Measurements of evapotranspiration, made in countries where cacao is grown, notably Trinidad, Colombia and Nigeria, show that the amount of water lost by evapotranspiration

* Actually, cacao is grown commercially in many countries whose latitudes are greater than 15º N or S, for example, Southern Mexico, Cuba and the Greater Antilles islands of the Caribbean. Nevertheless, it is considered that, except for local abnormalities, the temperature relations of these places are marginal for cacao and that, in some instances, temperature may constitute the limiting growth factor for really high production.

lies between 4 and 5 ins. (100 - 125 mm.) a month. This implies that a monthly rainfall of at least 4 ins. (100 mm.) is needed to satisfy the water requirements of the cacao tree.

It may be noted here that this critical value, 4 ins. (100 mm.) is identical with that suggested by Dr. E. C. J. Mohr to denote "wet" months in Java *(5)*. In Mohr's scheme, "dry" months in which evaporation greatly exceeds the rainfall, are denoted by rainfalls less than 2.4 ins. (60 mm.). A "weak" dry season is defined as one in which there is one dry month and 4 to 11 wet months, the remaining 7 to 0 months being "intermediate". A "marked" dry season is likewise defined as one in which there are 2 to 3 dry months, 6 to 0 intermediate, and 4 to 9 wet months, and an "intense" dry season as one having 4 to 5 dry months, 5 to 1 intermediate, and 3 to 6 wet months.

The "dry limit" for cacao is mainly decided by the length of the dry season. In the extreme, this is 3 to 4 months in duration and coincides with Mohr's "marked" to "intense" dry season. The total rainfall corresponding with a 4 months 'dry season lies between 40 and 50 ins. (1000 - 1250 mm.) a year. At sites where the annual rainfall is exceptionally high, say over 100 ins. (2500 mm.) the soil must be deep and both soil and subsoil must be highly permeable to water, otherwise surface erosion will ensue or water-logging will occur and the cacao tree will suffer accordingly.

Factors controlling rainfall: As for temperature, *latitude* and *altitude* mainly determine the amount and distribution of rainfall. At the equator, rain falls at all times of the year. Within the zone 3º to 10º north or south of the equator there are two wet and two dry seasons, while still further from the equator there is a single wet and a single dry season. This variation in seasonal distribution with latitude depends on the annual passages of the sun overhead. When the sun is in the zenith, the rainfall is heaviest.

The variation of rainfall with altitude in the tropics is not well marked but, in general, the mountains receive more rain than the lowlands and the amount of rainfall increases with altitude up to about 2000 m. (6500 ft.) above which it decreases because of reduced humidity.

CONCLUSIONS

Air temperature and rainfall are the two most important climatic factors controlling the growth of the cacao tree; their limits for commercial cacao production are known with some degree of accuracy and should be employed when selecting a cacao site. Both temperature and rainfall can readily be measured and information regarding them is generally easy to obtain. In undeveloped areas where meteorological stations have not been established, or where they are too far distant for the records to be relevant, much can be learnt by a consideration of the natural vegetation.

NATURAL VEGETATION AS CLIMATIC INDEX

The features of the vegetation which occupies an area of land integrate the various environmental factors that operate, particularly temperature and rainfall. The kind of plant formation of which cacao is a component, is the *Tropical Moist Forest*. This consists of 3 or 4 storeys of trees, the highest being over 100 ft. (30 m.) tall. Cacao belongs to the lowest storey. The forest is evergreen and comprises a large number of tree species. Many of the taller trees are buttressed. Lianes and epiphytes are common. Where the climate is less rainy and a dry season occurs, the forest is either semi-evergreen or deciduous. In the *Semi Evergreen Forest,* there are only two storeys, the taller up to 80 ft. (25 m.). Few of the trees are buttressed; epiphytes are scarce but lianes are abundant. In the *Deciduous Forest,* there are also two storeys but the upper one is completely deciduous. Buttresses are absent, lianes are rare, and epiphytes are scarce. These various distinguishing features are mainly the expression of differences in rainfall.

In Trinidad, the three kinds of forest occur where the rainfall characteristics are as follows:

		Total annual rainfall	*Dry periods* (Mohr's scheme)
(i)	Evergreen Forest	Over 80 ins. (2000 mm.)	Continuously moist
(ii)	Semi-Evergreen Forest	80-60 ins. (2000-1500 mm.)	Weak dry season
(iii)	Deciduous Forest	60-40 ins. (1500-1000 mm.)	Marked dry season

Cacao is grown commercially in Trinidad where the original vegetation was either Evergreen or Semi-Evergreen Forest.

OTHER GROWTH FACTORS

Air temperature and soil moisture are examples of environmental factors that affect the growth of the cacao tree *directly,* whereas latitude and altitude affect it *indirectly* through their influence on temperature and on rainfall which mainly determines soil moisture. Temperature and rainfall are climatic factors whilst latitude and altitude are geographic factors. Other direct climatic factors, already alluded to, are humidity and air movement or winds, which, together with temperature, directly affect the growth of the cacao tree because they control evapotranspiration. Another important direct climatic factor is light, both in regard to its intensity and its daily duration or photoperiodicity. Light intensity and duration are greatly reduced by cloudiness which, in some places, constitutes the main limiting factor to the growth of cacao.

Among the indirect geographic factors, besides latitude and altitude, must be mentioned land relief which includes degree of slope and also direction of slope or aspect. This is important because it partly decides the amount of insolation and its converse, degree of shade, afforded by natural land features such as hills and ridges. Undulating land promotes good drainage but flat land is often swampy, necessitating the provision of drains and the cambering of the beds that lie between them and upon which the cacao trees are planted.

Besides all these different climatic and geographic factors which directly or indirectly control the growth of cacao, there are others of great importance which may be grouped under *Soil Factors* and *Economic Factors*.

SOIL FACTORS

The most valuable part of a forest soil is the thin surface humic layer of crumb soil with its covering of organic detritus consisting chiefly of leaf-litter, flowers and twigs in various stages of decomposition. This layer is rapidly lost when the soil surface becomes exposed to sun, wind and beating rain. It is much more difficult, and generally impossible without expensive treatment, to establish a cacao plantation on land whose forest vegetation has been removed by felling and burning, particularly if some food-crop, such as maize or rice, has been grown, or the land has been allowed to go down to grass after the felling. It is often difficult to establish a satisfactory cacao plantation even on land which is in second-growth forest or bush, though much depends in this case on the duration of the transition period between the destruction of the original forest and the development of the second growths, as well on the nature of the soil and whether or not the forest was burnt after felling.

The particular features to be examined when attemping to assess a soil in regard to its suitability for cacao are: (i) the quanity of litter and crumb soil that form the surface layer (ii) the thickness of the humic layer (iii) the thickness, porosity and degree of aggregation of the soil below, and (iv) the porosity and mineral composition of the parent rock. These features will be discussed in detail in a later chapter.

ECONOMIC FACTORS

There are numerous economic factors having varying degrees of importance that should be considered in selecting a place wherein to establish a cacao plantation. Among the more significant of these are *(6)*.

(1) The kind of indigenous population available as labor to run the plantation, and its abundance.
(2) The general health conditions of the area.
(3) The existence of good communications and of easy accessibility of the area.
(4) Nearness to markets and to towns and villages.
(5) Other less-important considerations.

These factors will briefly be considered in turn.

(1) *Population:* The nature, abundance and occupation of the local population are extremely important economic factors. The people should be willing to work regularly for wages. They must not depend for subsistence entirely on the products of the forest which will be destroyed by the establishment of the cacao plantation. They must be skilled in agricultural operations but they should not be fully employed in farming. They should preferably be organised on a community basis to facilitate negotiations for labor. If

labor has to be imported, the legal obligations involved should be reasonable. Labor laws that are exceptionally favorable to labor may render the interprise uneconomic for cacao production.

(2) *Health:* The prevalence of malaria, yellow fever, and other infectious diseases of man, or of trypanosomiasis of draft animals may render an area unsuitable for growing cacao when their effective control is expensive.

(3) *Communications:* These are perhaps not so important in the case of cacao planting as with most other agricultural ventures, because the final product is not perishable when properly treated and stored, and its value is high. Highly-organised markets, although desirable, are not essential. It is an advantage, however, if the area is easily accessible and supplied by good, all-weather roads. Basic amenities, such as fuel, food and water, should be available to meet the needs of a contented labor force.

(4) *Nearness to markets:* This is obviously an important factor in large countries which are only partly developed and where the markets are overseas, necessitating transportation of the product to the places of export. For example, the successful development of cacao plantations on the eastern side of the Andes mountains which divide longitudinally the cacao-growing countries of South America (Colombia, Ecuador and Peru) involve haulage over difficult mountain roads to the main centers of commerce.

(5) *Other considerations:* The price of land should nominally amount to only a small proportion of the cost of development of a new cacao plantation, but any price comparable with that of developed agricultural land of over 50 dollars (U. S. currency) per acre would disqualify an area for cacao development. Planting material in most cases will have to be produced at nurseries situated within the area, should it be decided to use cuttings or buddings for the new plantings.

SUMMARY

When selecting land suitable for the establishment of a cacao plantation, consideration should be given firstly to *geographic* factors, namely, latitude, altitude and relief, secondly to *climatic* factors, especially temperature and rainfall, thirdly to the main features and past treatment of the *soil,* and lastly to certain *economic* factors concerning labor supply, communications and markets.

The requisite *temperature* conditions are:

(1) Average annual temperature above 21°C (70°F).
(2) Mean daily minimum temperature in the coldest months above 15.5°C (60°F).
(3) Daily range less than 9°C (16°F).
(4) Average annual temperature below 30°C (86°F).

The mean optimum temperature for cacao is therefore 25.5ºC (78ºF) with a range of 4.5ºC (8ºF) on either side of this mean, i. e.: 25.5º $\pm$ 4.5ºC (78º $\pm$ 8ºF) or 30º to 21ºC (86º to 70ºF) daily range.

The requisite *rainfall* conditions are:

(1) Total annual rainfall above 50 ins. (1250 mm.).
(2) Rainfall well distributed between the months.
(3) Monthly rainfall for each month of the year 4 ins. (100 mm.) or over.
(4) Absence of a marked or intense dry season comprising months having rainfall less than 2.4 ins. (60 mm.).

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CHAPTER 2

PREPARATION AND PLANTING OF THE LAND

Having selected the right kind of site and the right kind of land in relation to the environmental growth factors controlled by climate and soil in accordance with the principles enunciated in the last chapter, and having ascertained that the economic factors are suitable, the next step is to prepare the land for cacao planting. The chosen area might be occupied by one or other of the following types of vegetation: (i) virgin forest; (ii) second growth forest in various stages of development following felling of virgin forest, with or without burning; (iii) abandoned cultivations; (iv) pasture. Land previously planted in cacao is not included; it will be considered under the heading "Rehabilitation" in a later chapter.

(1) VIRGIN FOREST

Until recent years, the only kind of land that was normally utilized for cacao planting was virgin forest land which undoubtedly presents the best possible conditions for the successful growth of cacao, assuming that other circumstances are favourable. Virgin forest soil generally contains abundant organic matter which has penetrated to considerable depth, and which consists partly of organic detritus (leaf litter, twigs, flowers, fruits and roots) spread over the soil surface. Soil organic matter confers high infiltrability or receptivity for water, as well as high permeability and large water-storage capacity, because of its efficacy as agent in the formation of stable aggregate soil structure. It also possesses high nutrient supplying capacity and confers large root room on the mineral soil down to the depth of organic penetration. Forest soils vary considerably in the degree to which these desirable features are expressed and this aspect has been duly considered in the choice of virgin forest land for cacao planting.

(i) *Partial or complete felling, with or without burning:* The usual procedure followed in establishing a cacao plantation on virgin forest land is to begin with selective thinning of the larger trees and the cutting out of the lower storey trees including undergrowths, particularly palms and lianes. Some of the large trees may be sold as marketable timber or used in construction work on the plantation or employed for making charcoal. The thinning should not be too heavy, otherwise the soil becomes exposed to the direct beating action of rain and to excessive insolation that cause surface erosion and loss of litter, soil crumb and humic soil which comprise by far the most valuable part of the soil in regard to suitability for plant growth. The rule in establishing a cacao plantation from virgin forest, therefore, is never to expose the soil to direct rainfall, nor to subject the environment to a too-drastic change of micro-climate, such as is brought about by increased insolation. This is the principle of the shelter wood which has proved to be of great service in the regeneration of forest in modern sylviculture. In selecting the trees of the uppermost storey of the virgin forest which are to be left to form the shelter wood, it is best not to retain the oldest trees, because these may later shed their branches and so damage the young cacao.

(ii) *Planting artificial shade:* If the shelter wood system is not to be adopted, but rather artificial shade is to be provided, then it is necessary to clear-fell the forest and to plant shade trees at suitable distance apart and in good alignment as early as possible after the forest has been felled. This necessitates the previous provision of a shade tree nursery and the selection of suitable species for planting. It also implies the need for the provision of temporary shade to be planted at the same time as the permanent shade. This unfortunately involves an interim period of one or two years' duration before the cacao can be planted without risk of excessive loss of planting material, during which time the land is unproductive.

(iii) *Drainage:* Attention should first be given to drainage where climate, land-relief and soil conditions indicate that this is necessary. The drains need not be dug deeply at first, but later, if run-off becomes excessive, they may gradually be deepened and the excavated soil spread over the inter-drain beds so as to form a camber. This ought not to be necessary except under unusual circumstances, such as the presence of a high permanent water-table, or excessively high rainfall.

(iv) *Spacing:* Next, a suitable spacing distance should be chosen according to prevailing circumstances *(6)*. In general, the less the root room, the greater should be the spacing distace, for cacao trees growing in shallow soil need greater horizontal distance for spread and root competition may soon become severe if the trees are too closely spaced. Not only root room but also size of canopy must be considered, however, in deciding spacing distance, and this varies with general growth conditions (ecological factors) and with the degree of shade and the botanical variety of cacao that is to be planted. The optimum spacing distance clearly depends on all the environmental growth conditions and hard and fast rules cannot be laid down *(6)*. The main aim of the planter is to obtain the greatest possible yield per unit of land area over a given period of time. In practice, spacing distances range from 5 x 5 ft. (1.6 x 1.6 m.) as practised by peasants in Ghana, West Africa, who grow cacao under shelter wood forest without articial shade, to 12 x 12 ft. (3.7 x 3.7 m.) as normally used in countries like Trinidad and Tobago where cacao planting is long established, to 15 x 15 ft. (4.6 x 4.6 m.) in places where environmental conditions are especially favorable to cacao growing, or where fertilizers are freely used. Yields per unit of land area at first are generally greater for close spacing, say, up to 4 to 6 years but later they may be greater for wide spacing. The pattern of spacing may be either (i) square (ii) rectangular (iii) triangular or (iv) hedge row *(6)*. Most plantings are based on the square system which, at a spacing of 12 x 12 ft. (3.7 x 3.7 m.), gives 300 trees to the acre, and at 10 x 10 ft. (3.1 x 3.1 m.), gives 435 trees per acre. The rectangular system is followed preferably when mechanization of operations, such as weeding and spraying against diseases and pests, is to be employed. A rectangular spacing of 18 x 9 ft. (5.5 x 2.8 m.) gives 270 trees per acre, and 11 x 9 ft. (3.4 x 2.8 m.) gives 440 trees per acre. The triangular system is adopted when it is desired to lessen a wide square spacing distance. It may easily be effected by planting a tree in the center of each square. The hedge row system may well be the "spacing pattern of the future" if and when cacao plantations become fully mechanized and tillage and manure spreading are customarily practised. In this system, the trees are planted close in the row with much wider spacing between adjacent rows or between alternate rows which are planted closer. The wider strips may be used for planting rows of other tree-crops such as rubber, or of suitable fruit, nut or tan-bark trees having commercial value, or simple planting with leguminous small trees or shrubs used for soil renovation or as wind breaks.

(v) *Lining:* Cacao lines are generally orientated at right angles to a base-line which may be the edge of a main road or river-bank or hill ridge by which easy access to the area is facilitated *(6)*. It is preferable to subdivide the plantation into small unit areas separated by roads or traces. The units may conveniently comprise strips of about 300 feet (92 m.) width. The lines are set out at right angles to the road. It is an advantage if they are orientated in an east and west direction so as to ensure uniform insolation along the rows of trees *(6)*. Where the land is hilly, planting along the contour is advisable particularly if drains are to be constructed at regular intervals to act as catchments for run-off water during unusually heavy rains. The drains may conveniently be dug along the slope side of horse tracks or mule tracks laid out zig-zag fashion on steep hill sides upon which cacao is to be planted. These slightly off-contour drains usually end in a small natural water course or artificial main drain running down the slope, which may need to be provided with check-dams at appropriate intervals in order to prevent gully formation.

The planting sites are marked in the line by pickets or stakes set at the chosen distance apart. Those intended for shade trees are usually included in the row at double the distance between the cacao trees. Thinning to twice this distance may be necessary at a later stage. After the pickets have been lined out and set, and after the permanent shade trees have been planted, the planting of temporary shade and of ground shade should immediately be started.

(vi) *Permanent shade trees for cacao:* Among the natural shade trees of the forest which are left to form a shelter wood are some that have considerable market value. These are therefore usually left untouched, even when the shelter wood is replaced by artificial shade, especially when they spring up naturally in the cacao plantation in which artificial shade was established from the start *(5)*. They include fruit trees such as *Spondias mombin* (jobo, hog-plum) *Calocarpum mammosum* (zapote) and *Artocarpus incisa* (bread fruit) as well as timber trees, for example *Cedrela mexicana* (Cedar) and *Cordia alliodora* (Laurel) *(5)*. In Java, Kapok *(Ceiba pentandra)* is grown as shade for cacao *(3)*. Its seed-fibre has several commercial uses. The seeds of all these trees are easily dispersed by men, birds or wind. In addition, certain short-lived second growth tree species are often left in the plantation because they are exceptionally quick-growing, for example species of *Cecropia, Ochroma, Heliocarpus, Trema* and *Hampea (5)*.

The tree genus mostly favored as permanent artificial shade is *Erythrina* (Papilionatae - Leguminoseae) of which two species are widely used in cacao plantations in all parts of the world, namely *E. Poeppigiana* and *E. glauca.* These may readily be propagated by stake cuttings or "quick sticks". Unfortunately, most species of *Erythrina* have spiny trunks which makes it difficult to prune them easily. It is stated that non-spiny individuals may be obtained by repeated selection and propagation by vegetative means of cuttings deliberately taken from the extreme ends of large branches of spiny trees of *Erythrina* species. Other leguminous genera that are often grown for artificial shade are *Inga, Pithecolobium, Pseudosamanea* and *Albizzia.* These all belong to the sub-family *Mimosoideae.* Another leguminous papilionate genus greatly favoured as nursery shade and as temporary shade in cacao fields is *Gliricidia* (madre de cacao) though it is not so large as the other trees mentioned. The chief drawback to large shade trees such as *Erythrina spp.* is that they are subject to windthrow or that they too readily shed their branches as they grow old which damages the cacao. This danger is negligible when the life of a cacao field is deliberately restricted to 20 or 30 years. Under such restriction it might be preferable to employ shade trees which produce valuable timber that could be harvested at the time when the cacao field is being replanted, for example, *Dalbergia sp.* and *Cordia alliodora (5).* In Mexico, *Cybistax Donnell-Smithii* (Primavera) and *Theobroma bicolor* are commonly used as shade *(5) (11).*

Distinction has been drawn between "tall, cool shade", provided by trees such as *Cybistax, Inga, Samanea* and *Artocarpus* which grow to over 60 feet in height, and "low warm shade", provided by *Erythrina* and *Gliricidia* which grow only to 40 feet. The former is said to induce a spindly habit in cacao and possibly to cause a reduction in crop *(11).*

The fact that shade trees are liable sooner or later to be attacked and damaged and even destroyed by diseases and pests renders it necessary that continued search be sustained for alternatives and for new and better substitutes. Thus, in Trinidad, both *Erythrina glauca* and *E. Poeppigiana* have been severely attacked by diseases, the first since twenty years ago and the second during the last few years, and these have caused the death of a large number of trees *(1).* Some alternative trees have been suggested, for example *Peltophorum ferrugineum, Schizolobium excelsum* and *Parkia roxburghii (10) (8) (1).*

(vii) *Interplanting:* Several kinds of economically-valuable tree crops have been grown more-or-less successfully along with cacao, provided that they are suitably spaced and the soil is good (3). Not only do they increase the profit per unit of land under certain market conditions, but they act as satisfactory shade for the cacao. Examples are *Hevea rubber* and oil palm *(Elaeis guineensis) (3).* Under certain circumstances, even coconut *(Cocos nucifera)* has been inter-planted successfully with cacao *(4).* Experience with these three crops when inter-planted with cacao has not, however, invariably been satisfactory. Thus, in Malaya, Cameroons and Western Samoa, attempts to grow cacao through *mature* or old rubber have invariably failed *(15)* but recently in Malaya cacao is being interplanted in rows between rows of young rubber and fertilizers are being ap-plied to both crops *(15).* So far growth has been satisfactory. Oil palm is more exacting than rubber; its slow growth necessitates planting it six years before the cacao and spacing it rather widely (9 m., or 29 ft.), best in double rows *(13).* Coconut has been successfully interplanted wide-spaced with cacao in New Guinea on deep pumiceous soil with a not too high water-table *(12) (4).* It was formerly believed that the Black Pod disease organism of cacao *(Phytophthora palmivora) attacked* the tapping panel of *Hevea rubber* trees but recent research has shown that the particular strain to which cacao is susceptible differs from that which attacks rubber, and that the two are specific in their relationships to their hosts.*

(viii) *Provision of temporary shade:* It is absolutely imperative that young cacao should be provided with adequate shade from the time of planting out in the field to the time when either it has grown large enough to become self-shading, or the permanent shade has become thoroughly established and has covered over satisfactorily. Nevertheless, overshading should be avoided at all stages of growth.

The choice of plants suitable for use as temporary shade is large, but there seems not to be any doubt that banana best meets the requirements. Under certain circumstances it may be permissible to grow marketable edible banana varieties for profit but, where praedial larceny is common, it is best to grow non-edible varieties, so long as they are tall-growing. Banana should be planted at least eighteen months before the time of planting out of the cacao. The banana suckers should be planted between the cacao rows, not in the cacao lines.

As alternatives to banana, quick-growing shrubs may be grown as temporary shade, including leguminous species that enrich the soil in nitrogen, such as species of *Crotalaria, Tephrosia, Cassia,* and *Leucaena glauca.* Other shrubby plants, for example, castor oil *(Ricinus spp.)* are also suitable.

(ix) *Provision of ground-shade:* Besides the provision of tall temporary shade, low- growing ground shade should be planted at the same time to provide soil protection. Examples of suitable ground shade plants which not only afford good protection but also produce saleable food materials are tannia *(Xanthosoma spp.)* cassava *(Manihot spp.)* and pigeon-pea *(Cajanus indicus).* The plants should be planted at a distance of about 2½ feet from each cacao plant, four plants to each cacao tree. Rapid growth should be encouraged by frequent weeding and hoeing, and complete ground protection should be ensured after three months growth.

(x) *Preparation and planting of planting holes:* Planting holes should be dug at the planting sites at least two months before the cacao plants are placed in them at planting time, which usually is 4 to 6 months after the permanent shade trees have been planted. The most suitable dimensions for the holes depend on the kind of soil. In compact soil, there is danger of water collecting in the hole during wet weather and injuring the root system. In this case it is better to dig the hole wide and fork up the soil at the base so as to loosen it and improve the drainage. The thrown-up soil, particularly if it is a clay soil, will weather or mellow, and it may then be mixed with a quantity of well-rotted pen manure (say 10 to 20 lb.) preferably fortified with up to ½ lb. of

* R. Orellana, Phytopathology, 44, p. 501, 1954.

mixed fertilizer, including a minor element mixture, before putting it back into the hole. The cacao plant may then be set at once, or after a few days' time in the hole and the soil heaped around it *(9)*. Care should be taken to ensure that the crown is not buried and that the soil around the plant is well firmed. After two weeks, the plants should be examined and any that are loose in the ground should be earthed up and the soil made firm. After-treatment consists mainly in eliminating weeds from the vicinity of the cacao and the shade tree plants and in adjusting the temporary shade by judicious cutlassing. Chemical weed-killers should preferably be employed for destroying weeds, thus obviating the risk of injuring the young plants which usually happens when the cutlass is used for that purpose (see Chapter 13).

(xi) *Mulching:* If there is a marked dry season, the application of cut-bush or grass, tree loppings or prunings, rice straw, sugar cane trash or sugar factory bagasse, maize stover, etc., to the soil surface immediately after the rains are over may prove beneficial, particularly where the overhead shade is too thin.

(xii) *Field maintenance after planting:*

First and second years: Control of weed growth and ground shade is the main operation at this stage. Supplying of ground shade plants may be necessary. Mulching should be regulated. Overhead shade should be maintained at about 50 per cent of full sunlight. The permanent shade trees should be kept growing more rapidly than the cacao by adjusting the temporary (banana) shade and by applying fertilizers *(7)*.

Third and fourth years: The ground shade may be removed in the third year, but the temporary overhead shade must still be maintained and supplied if necessary. It is afterwards gradually removed in the fourth year as the permanent shade trees emerge above it. Weeding and cutlassing should be carried out as required to ensure the right degree of shade. Pruning (formation) of the cacao trees and of the permanent shade trees should be carried out at intervals soon after the plants have become securely established, and the application of fertilizers should be continued annually according to the recommendations made in another place (see Chapters 5 and 16).

(2) SECOND-GROWTH FOREST

If sufficient time has elapsed after the primeval forest was felled, and particularly if it was not burnt, the soil under second-growth forest does not differ appreciably from that of the original forest. If the second growths have attained a good height, then a cacao plantation may be established by employing either the shelterwood system or by clear felling and replanting with temporary and permanent overhead shade and ground shade, exactly as described for virgin forest. If, however, the second-growth is still young, its successful conversion into a cacao plantation will depend almost entirely on the kind of soil and particularly on its content of organic matter and the depth of organic penetration. If the soil is suitable, it may only be necessary to clear strips about three feet wide through the second-growth forest and to plant the cacao at regular intervals along these narrow strips *(2)*. Certain of the larger trees are left standing to provide permanent shade. As the cacao trees grow, the strips are gradually widened by cutting out more of the second-growths. Undesirable gaps in the overhead shade may be filled by planting shade trees at an early stage.

(3) ABANDONED CULTIVATIONS

Abandoned cultivations such as old food gardens, sugar cane fields, citrus orchards, etc., unless they have been allowed to grow up in bush, seldom make good cacao plantations because their soil has usually suffered severe deterioration through continued cropping and surface erosion. Where the soil happens to be exceptionally deep and possesses satisfactory physical features, generally because of deep organic penetration, a cacao plantation may successfully be established, however, by the direct planting of artificial shade trees, followed by the planting of temporary shade after the bush has been removed, and then introducing cacao plants in the usual manner by lining, holing and planting out *(7)*.

In an experiment carried out at W. A. C. R. I. in Ghana, a plot of land was tilled and planted up with cassava and plantains between rows of cacao seedlings. After harvesting the cassava, the weeds were suppressed by cutlassing. Another plot of land was tilled and planted up with cassava and *Gliricidia* (a small leguminous tree) through the cacao seedlings, and bush was allowed to grow after the cassava had been harvested. In eight years' time, the cacao in the first plot was only 4 feet tall, the yield was nil, and there were many vacancies. In the second plot, the cacao was 20 feet tall, the yield was 1523 pods and there were not any vacancies *(14)*.

(4) PASTURE

In many cases, land that is pasture was originally allowed to go down to grass because it consisted of poor soil, in which case it would be quite unsuitable for cacao. If, on the other hand, the pasture soil possesses good physical features it may be cultivated by mechanical implements, laid out into beds, mechanically drained, and planted at once with shade trees and cacao in the usual manner *(2).)* Manures, fertilizers and soil amendments may be applied to build up fertility, and in that way the content of organic matter in the soil will gradually be increased through continued leaf-shedding and the incorporation of organic material into the soil.

SUMMARY

1. The preparation of the land for cacao planting is described for sites that originally were either (i) virgin forest, (ii) second forest, (iii) abandoned cultivations or (iv) pasture.

2. The steps followed in the case of virgin forest comprise (i) partial or complete felling with or without burning, (ii) planting of artificial shade when clear felling is practised, (iii) draining, (iv) spacing, (v) lining, (vi) interplanting with commercially-valuable trees, where desirable, (vii) provision of temporary shade, (viii) provision of ground shade, (ix) preparation and planting of planting holes, (x) mulching, (xi) after-maintenance.

3. The choice of permanent shade trees and of inter-row commercially-valuable trees for planting along with cacao is briefly considered.

4. Modifications of the usual procedure to be adopted for sites other than virgin forest are described.

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PART II

CACAO ECOLOGY AND PHYSIOLOGY

PART II:

CACAO ECOLOGY AND PHYSIOLOGY

CHAPTER 3

THE TEMPERATURE RELATIONS OF CACAO

(I) INTRODUCTION

The fact that cacao can only be grown profitably within a fairly narrow zone of latitude near the equator implies that temperature must be particularly important in controlling its growth processes. In his comprehensive study of the distribution of cacao-growing areas in South America, and of the fundamental factors that have there influenced cacao production, Dr. Ivar Erneholm *(4)* has attempted to determine the "cold limit" to the cultivation of cacao, that is, "the line beyond which the temperature is too low to permit permanent and profitable cultivation". He states that "the most southerly cacao plantations of Brazil, and probably of the whole world, are situated ... at about 22º south latitude". The mean annual temperature in the vicinity is about 22ºC (72ºF) and the mean daily minimum temperature in the coldest month varies from 13.2º to 14.7ºC (55.8º to 58.5ºF) though occasionally the temperature may fall to 10ºC (50ºF). The conclusion is reached from this and other evidence that the "cold limit" for cacao production is probably 15ºC (60ºF) at sea-level, with mean annual temperature 21ºC (70ºF).

Within mountainous country on or near the equator, temperatures as low as this "cold limit" prevail at an altitude of about 1300 metres (4200 feet) as for example, in the Chama Valley, situated near Merida in the Venezuelan Andes, which is perhaps the highest productive cacao area in South America. The mean annual temperature at 1000 metres (3250 ft) in the Cauca Valley in Colombia, where cacao has been profitably grown for many years, is 24ºC (75ºF) the mean daily minimum 19ºC (66ºF) and the absolute minimum, 12ºC (54ºF).

Over the tropical lowlands in general, the mean annual temperature ranges from 20ºC (68ºF) to 28ºC (82.5ºF) (11). Near the equator, the difference in temperature between the hottest and coldest months is less than 5ºC (9ºF). In small islands it may be less than 1ºC (2ºF). The lowest temperatures usually occur in the wet season and the highest in the dry season *(11)*. At increasing distance from the equator, the variation in seasonal temperature increases, though it seldom exceeds 13ºC (23.5ºF).

Daily temperature range: Besides being extremely susceptible to low temperature, the cacao tree does not grow satisfactorily when the range of daily temperature exceeds certain limits, which, for reasons to be considered later, should not be greater than 9ºC (16ºF). The mean daily range of temperature in the Tropics varies from 3ºto 16ºC (5º to 29ºF) *(11)*. Near the equator, minimum temperatures are high, but maximum temperatures are low and rarely exceed 34ºC (93ºF). The temperature range is therefore low near the equator. At the limits of the tropical zone, maximum temperatures are much higher and may reach 50ºC (122ºF) *(11)*. The range is correspondingly high.

Summary: The "cold limits" for commercial cacao-growing, according to the findings of Erneholm *(4)*, are.

1. Mean annual temperature 21ºC (70ºF)
2. Mean daily minimum 15ºC (60ºF)
3. Absolute minimum 10ºC (50ºF)
   To these should be added, for reasons to be explained later:
4. Critical mean maximum daily range 9ºC (16ºF)

(II) INVESTIGATIONS ON THE EFFECTS OF AIR-TEMPERATURE ON GROWTH AND PRODUCTION OF CACAO

Temperature data for typical cacao-growing areas: Within the cacao-growing zone as a whole, the mean annual temperature probably averages about 26ºC (79ºF) and the mean for the coldest month probably rarely falls below 25ºC (77ºF). These are the temperature limits occurring within the region of the Tropical Rain Forest *(11)* whose distribution more-or-less coincides with that of the cacao crop. The following tables present mean monthly temperature data for four cacao experiment stations where investigations on cacao ecology are being conducted, namely:

1. *Costa Rica:* "La Lola" Experiment Station, belonging to the Inter-American Institute of Agricultural Sciences, Turrialba, and situated on the Atlantic Coastal Plain, 20 miles from the eastern coast.

2. *Trinidad:* The Imperial College of Tropical Agriculture (I. C| T. A.), St. Augustine, situated 7 miles east of Port-of-Spain at the northern edge of the Central Plain.

3. *Ghana:* The West African Cacao Research Institute (W. A. C. R. I.), Tafo, situated 40 miles north-west of Accra.

4. *Brazil:* The Uruçuca Experiment Station, Bahia, situated 25 miles north-west of the coastal town, Ilheus.

These stations are each not more than 60 metres (200 feet) above sea-level. Their latitudes are 10ºN, 10ºN, 6ºN and 13ºS respectively. In order to make the data comparable, the monthly data for Brazil are staggered, the figures for July actually being recorded under January.

The data are given in two sections, the first in degrees centigrade and the second in degrees Fahrenheit. The thermometers were enclosed in standard Stevenson screens, 4 feet above ground-level in clearings in the vicinity of the cacao fields, not actually within the cacao plantings.

Summary of temperature data: The more important data given in Table I are summarised in Table II, which shows (a) the average monthly temperatures for the year, (b) the average monthly temperatures for the coldest period of the year and its duration, (c) the average monthly temperatures for the rest of the year and its duration, (d) the mean monthly ranges for the whole year and (e) the greatest ranges of the average monthly temperatures (differences between average monthly daily maximum and minimum temperatures) and the periods of the year when the greatest range occurs.

It will be noticed that the temperature data for Costa Rica and for Trinidad are similar, though slightly higher by about 0.5ºC (0.9ºF) for Trinidad, even though the two places have the same latitude, namely 10ºN. The temperature range for Trinidad is well over the critical limit (9ºC or 16ºF) as is also the greatest range for Costa Rica.

The data for Ghana show large fluctuation of maximum temperature which is relatively high for the first quarter and relatively low for the third quarter of the year. For minimum temperature, the fluctuation is much smaller, the values for Ghana resembling those for Costa Rica and Trinidad.

The data for Brazil also show large fluctuation for maximum temperature which, however, is extremely low for the period corresponding to the first quarter of the year in the northern hemisphere and quite high for the period corresponding to the third quarter, just the reverse of the data for Ghana. For minimum temperature, the fluctuation, unlike that for Ghana, is also large, the temperature being extremely low for the period corresponding to the first quarter of the year, and relatively high for that corresponding with the third quarter of the year in the northern hemisphere. The annual range of temperature for Brazil is the largest of all and is greater than the critical limit (9ºC or 16ºF) for ten months of the year.

All these temperature data refer to conditions occurring in the air within Stevenson screens and not within cacao fields which, of course, may differ considerably from the open air outside.

TABLE I

DATA OF AIR TEMPERATURE FOR TYPICAL CACAO REGIONS

CENTIGRADE (ºC)

(1) COSTA RICA (La Lola) (6)

	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Av.	23.8	24.0	24.5	25.2	26.1	26.1	25.6	25.9	26.2	25.6	25.1	24.7	25.2
Max.	28.0	28.4	29.3	29.9	30.4	30.6	29.6	30.2	31.2	29.9	29.1	28.4	29.5
Min.	19.5	19.5	20.0	20.5	21.8	21.6	21.5	21.5	21.2	21.2	21.0	21.0	20.8
Diff.	8.5	8.9	9.3	9.3	9.6	9.0	8.1	8.8	9.8	8.7	8.1	6.9	8.8

(2) TRINIDAD (I. C. T. A.) (20)

	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Av.	24.4	24.4	25.0	26.1	26.7	26.1	26.1	26.1	26.3	26.3	25.7	25.2	25.7
Max.	28.9	29.4	30.0	30.5	31.0	30.0	30.0	30.5	30.5	30.5	30.0	29.4	30.0
Min.	20.0	19.4	20.0	21.7	22.3	22.3	22.3	21.7	22.3	22.3	21.7	21.1	21.1
Diff.	8.9	10.0	10.0	8.9	8.8	7.7	7.7	8.8	8.2	8.2	8.3	8.3	8.9

(3) GHANA (W. A. C. R. I.) (19)

	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Av.	25.6	26.6	26.8	27.1	26.4	25.4	24.5	24.1	25.1	25.6	26.1	26.0	25.7
Max.	31.2	32.4	32.2	32.4	31.2	29.2	27.7	27.4	28.6	29.8	31.1	31.2	30.3
Min.	20.1	20.8	21.4	21.7	21.6	21.5	21.3	20.7	21.6	21.4	21.2	20.7	21.1
Diff.	11.1	11.6	10.8	10.7	9.6	7.7	6.4	6.7	7.0	8.4	9.9	10.5	9.2

(4) BRAZIL (Uruçuca) (6)

	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Av.	21.5	21.2	22.4	23.4	24.8	25.5	25.6	25.7	25.4	24.2	23.7	22.7	23.8
Max.	26.5	26.2	27.5	28.4	28.8	30.3	31.4	31.4	30.6	29.5	28.7	27.0	28.9
Min.	16.5	16.3	17.2	18.4	20.0	20.4	19.8	19.9	20.1	18.9	18.6	18.3	18.6
Diff.	10.0	9.9	10.3	10.0	8.8	9.9	11.6	11.5	10.5	10.6	10.1	8.7	10.3

FAHRENHEIT (ºF)

(1) COSTA RICA (La Lola) (6)

	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Av.	74.8	75.2	76.3	77.3	79.0	79.0	78.0	78.5	70.1	78.0	77.2	76.6	77.4
Max.	82.5	83.3	84.7	85.7	86.8	87.2	85.5	86.4	88.1	85.9	84.5	83.3	85.3
Min.	67.2	67.2	67.9	69.0	71.3	70.8	70.6	70.6	70.2	70.2	69.9	69.9	69.5
Diff.	15.3	16.1	16.8	16.7	15.5	16.4	14.9	15.8	17.9	15.7	14.6	12.7	15.8

(2) TRINIDAD (I. C. T. A.) (20)

	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Av.	76	76	77	79	80	79	79	79	79.5	79.5	78.5	77.5	78.3
Max.	84	85	86	87	88	86	86	87	87	87	86	85	86
Min.	68	67	68	71	72	72	72	71	72	72	71	70	70
Diff.	16	18	18	16	16	14	14	16	15	15	15	15	16

(3) GHANA (W. A. C. R. I.) (19)

	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Av.	77.9	79.9	80.3	80.8	79.5	77.7	76.1	75.4	77.1	78.1	79.0	78.8	78.3
Max.	87.9	90.3	90.0	89.9	88.2	84.6	81.9	81.4	83.4	85.7	87.9	88.2	86.6
Min.	68.0	69.5	70.5	70.7	70.9	70.8	70.3	69.4	70.8	70.6	70.0	69.4	70.1
Diff.	19.9	20.8	10.5	19.2	17.3	13.8	11.6	12.0	12.6	15.1	17.9	18.8	16.5

(4) BRAZIL (Uruçuca) (6)

	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Av.	70.7	70.3	72.2	74.2	76.9	77.8	78.1	78.2	77.7	75.7	74.6	72.8	74.9
Max.	79.6	79.3	81.5	83.3	83.9	86.7	88.7	88.7	87.2	85.3	83.7	80.6	84.0
Min.	61.8	61.4	63.0	65.2	68.1	68.9	67.6	67.7	68.2	66.1	65.6	65.1	65.7
Diff.	17.8	17.9	18.5	18.1	15.8	17.8	21.1	21.0	19.0	19.2	18.1	15.5	18.3

FIGURE 1

MONTHLY TEMPERATURE

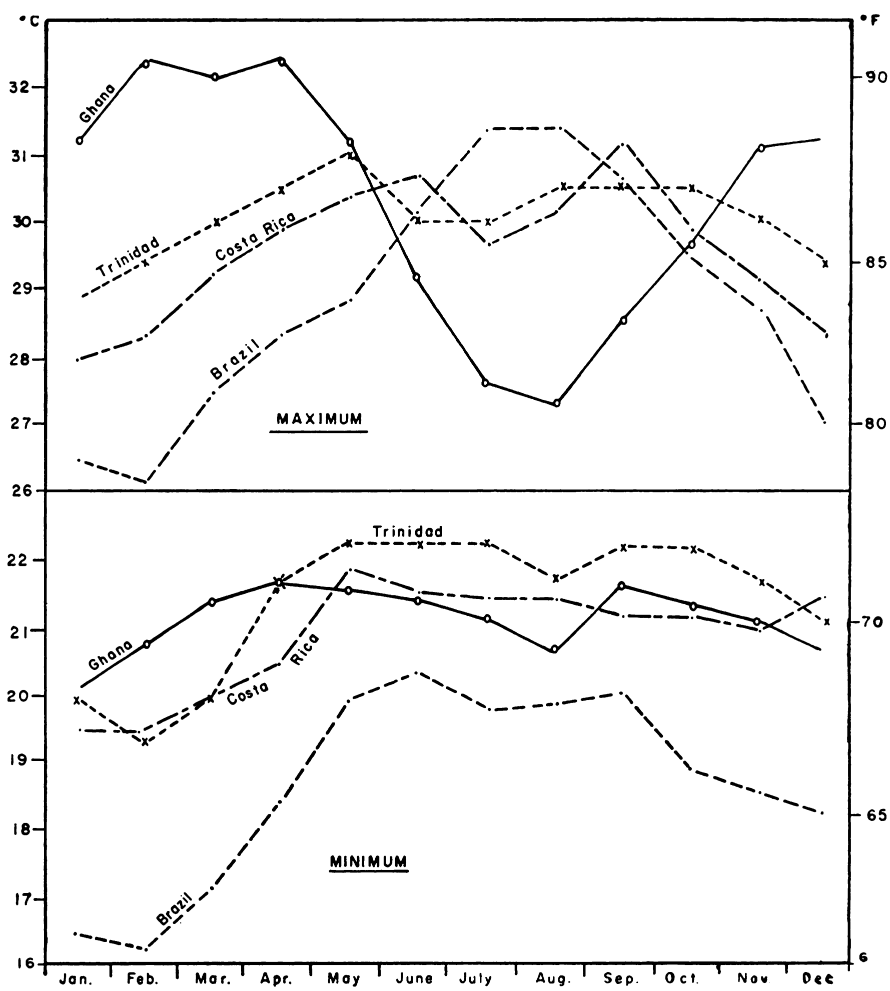

TABLE II

MONTHLY TEMPERATURES: COLDEST PERIOD: RANGE

(A) CENTIGRADE

PLACE	Mean Annual	LOWEST LEVEL				GREATEST RANGE			
		Coldest period		Rest of year		Period of greatest range		Rest of year	
Costa Rica	25.2	Jan - Mar	24.1	Apr - Dec	25.6	Feb - Apr*	9.2	May - Jan	8.4
Trinidad	25.7	Jan - Mar	24.6	Apr - Dec	26.1	Feb - Mar	10.0	Apr - Jan	8.5
Ghana	25.7	Jne - Sep	24.8	Oct - May	26.3	Nov - May	10.6	Jne - Oct	7.2
Brazil	23.8	Dec - Mar	21.9	Apr - Nov	24.8	Jly - Oct	11.2	Nov - Jne	9.7

* Also Sep 9.9.

(B) FAHRENHEIT

PLACE	Mean Annual	LOWEST LEVEL				GREATEST RANGE			
		Coldest period		Rest of year		Period of greatest range		Rest of year	
Costa Rica	77.4	Jan - Mar	75.4	Apr - Dec	78.1	Feb - Apr*	16.5	May - Jan	15.1
Trinidad	78.3	Jan - Mar	76.3	Apr - Dec	79.0	Feb - Mar	18.0	Apr - Jan	15.2
Ghana	78.3	Jne - Sep	76.6	Oct - May	79.3	Nov - May	19.1	Jne - Oct	13.0
Brazil	74.9	Dec - Mar	71.5	Apr - Nov	76.7	Jly - Oct	20.1	Nov - Jne	17.4

* Also Sep 17.9

(III) EFFECTS OF AIR TEMPERATURE ON CERTAIN PHYSIOLOGICAL PROCESSES OF THE CACAO TREE

The magnitude of the air temperature and the degree of its seasonal and daily fluctuation affect to a marked extent certain physiological processes that proceed within the cacao tree and which largely determine the size of the crop. The more important of these processes are:

(A) Flower formation and fruit setting
(B) Bud bursting and leaf flushing
(C) Trunk growth
(D) Other effects:

(i) Black Pod disease of cacao
(ii) Decomposition of soil organic matter.

(A) FLOWER FORMATION AND FRUIT SETTING

1. *Costa Rica:* The factors which control the formation of cacao flowers and the setting of the fruits that result from their pollination have been specifically studied at "La Lola", situated on the Atlantic Coastal Plain of eastern Costa Rica, and also at "Las Damas" which is a cacao plantation situated on the Pacific Coastal Plain of western Costa Rica *(1)*. The main difference in the climate of these two places is the occurrence of a marked dry season at "Las Damas" in contrast to the fairly regular high monthly rainfall at "La Lola".

   The method of investigation employed was the collection of ripe cacao pods at monthly intervals during three successive years and the statistical comparison of the numbers of pods with the monthly records of air temperature and rainfall. The results obtained at "La Lola" showed a significant positive correlation between yield and monthly mean temperature. The highest coefficient of correlation was found to exist between yield and mean temperature five months before reaping ($r = + 0.519$). This is the time when the flowers are being formed. The correlation between yield and rainfall was far too small to be significant. On the other hand, the correlation between yield and air temperature at "Las Damas" was small, but that between yield and rainfall, 2, 3 or 4 months before reaping, was large and highly significant.

   Cacao pods are usually reaped during two periods in the year at "La Lola", namely, April to May and October to January. Not many pods are reaped during June to September. This implies that few flowers are formed during January to April which is five months earlier than the second of these periods and comprises a spell of low temperature (Table II). The mean temperature at this time is 24.1ºC (75.4ºF) as compared with an average temperature 25.6ºC (78.1ºF) for the rest of the year.

2. *Trinidad:* The climate of Trinidad resembles that of the Pacific Coastal Plain of Costa Rica, in that there is a marked dry season during the first 4 or 5 months of the year. Air temperature is lowest during January to March (24.6ºC or 76.3ºF) and few flowers are formed and set fruit. When the temperature rises later, during April, May and June, conditions have generally become too dry to permit the flowers to develop into mature pods, so that there is only a sparse crop in September to November *(8) (9) (10)*. Flowers formed during the hot wet season, before the temperature begins to fall again, develop normally and produce the main crop in December to February. In Trinidad, as in western Costa Rica, the effect of low temperature in inhibiting the formation of flowers and the setting of fruits is masked later in the year by the effect of dry conditions. These prevent the development of pods from flowers that are formed normally near the end of the dry season when the temperature begins to rise.

3. *Ghana:* In an investigation into pod producton, carried out in 1929, a high degree of correlation was established ($r = + 0.71$) between pod yield and monthly rainfall, but that between yield and air-temperature was apparently not investigated *(12)*. The climate of Ghana resembles that of Trinidad and western Costa Rica, in that a dry season occurs during the early part of the year, and this greatly affects the development of pods from flowers that have been formed just before the rains set in.

4. *Bahia:* As far as can be ascertained, specific investigations on the effect of air temperature on the formation of cacao flowers and the setting of fruit have not yet been carried out at Uruçuca. It is known, however, that pods are scarce on the cacao trees during the period January to March (corresponding to July to September in the northern hemisphere) which occurs five months after the period of lowest mean temperature, whereas they are plentiful during the other months of the year. The partial dry season which occurs during July to October (January to April in the northern hemisphere) is not severe and is scarcely recognisable (average "dry season" monthly rainfall, 4-6 ins.) so that conditions at Uruçuca more closely resemble those at "La Lola" than those at I. C. T. A. in Trinidad, or at W. A. C. R. I. in Ghana, and the temperature effect on flower formation here also seems definitely to be operative.

Summary: The findings of these investigations indicate that flower formation by the cacao tree is inhibited when the average monthly air temperature falls below 22ºC (72ºF). When the temperature rises above 25.5ºC (78ºF) flower-formation proceeds normally and the production of pods is then controlled mainly by fluctuation in soil moisture, and is prevented or reduced by the onset of a marked dry season.

(B) BUD-BURSTING AND LEAF-FLUSHING

Excessive leaf-flushing in the cacao tree is not desirable because it eventually kills the tree if it occurs too frequently. Leaf-flush greatly increases the number of points of attack by certain disease organisms of cacao, notably Witches' Broom disease *(Marasmius perniciosus)*. It produces also abundant young succulent leaf material upon which certain insect pests of cacao, for example, thrips, may feed. It may also divert nutrient substances which might otherwise be utilized for the growth and development of the pods. The circumstances controlling bud-bursting and leaf-flushing have been investigated at "La Lola" in eastern Costa Rica, and also at various places in Trinidad, and at W. A. C. R. I. in Ghana. The following is an account of the investigations carried out at these three centers of research.

1. *Costa Rica:* Fortnightly records were kept at "La Lola", during three successive years, of the number of buds and flushes on 80 cacao trees, aged 37 years, five branches on each tree *(2)*. The numerical results obtained, expressed as percentages of the total number of shoots under observation, were statistically compared with data for air temperature,

rainfall and hours of sunshine. A highly significant degree of positive correlation ($r = + 0.468$) was found to occur between leaf-flushing and the magnitude of the daily range of air temperature four weeks before, that is, between temperature range and actual bud-bursting. Other positive correlations were also established between leaf-flushing and hours of sunshine, and between leaf-flushing and maximum air temperature, though this last-named relationship was not statistically significant.

There are two main periods of leaf- flushing at "La Lola", namely, February - March and September - October. These periods occur about four weeks after the time of greatest divergence between mean daily maximum and minimum air temperatures *(Tables I and II)* when the average range of temperature is 9.2ºC (16.5ºF) as compared with an average 8.4ºC (15.1ºF) for the rest of the year. *(Table III).*

The reason why hours of sushine are positively correlated with leaf-flushing at "La Lola" is stated to be because the absence of cloud is generally associated with cool nights and hot days, that is, with a wide range of daily temperature. High temperatures in general apparently favor flushing at "La Lola", but more particularly when accompained by a large daily range of temperature.

2. *Trinidad:* Here, leaf-flushing occurs several times during the year, at intervals of about three months. There is usually a well-marked flush at the beginning of the dry season in February - March, and another (the main flush) at the beginning of the wet season in June - July. There are generally one or more lesser flushes later in the year, of which one in September is especially well-marked.

Measurements of air temperature, made actually within two cacao fields having different degrees of overhead shade, showed that the greatest daily range of temperature occurs during January to March and during September to October *(8).* The actual mean values were 8.3ºC (14.9ºF) and 5.5ºC (10.0ºF) for the two periods for the well-shaded field,and 11.8ºC (21.3ºF) and 7.9ºC (14.2ºF) for the poorly- shaded field. The maximum temperatures reached during the two periods were 30.2ºC (86.4ºF) and 31.3ºC (88.4ºF) in the two fields. *(Table III)* The first of these periods coincides with the big dry season flush and the second with the September flush. The other recorded leaf-flushes probably may be accounted for by fluctuations in soil moisture. The climate of Trinidad, as has already been stressed, differs from that of eastern Costa Rica, in that there is a marked dry season, so that the effects of variable soil moisture are superimposed on those resulting from diurnal changes in temperature.

A later investigation *(6)* demonstrated that bud-bursting is apparently initiated whenever the air temperature within the cacao field exceeds 83ºF (28.3ºC). Re-examination of the published data and graphs indicates, however, that the periods of highest temperature were usually accompanied by the widest range of temperature and that they coincided fairly closely with the occurrences of the main flushes. The average temperature range associated with leaf-flushing in this investigation was 10.3ºC (18.5ºF). Certain of the minor leaf-flushes, however, cannot be explained in this instance by temperature changes and again it was suggested that they may have been caused by variations in soil moisture supply.

3. *Ghana:* Leaf-flushing has also been investigated at W. A. C. R. I. *(5).* Weekly records were made of the amount of flushing occuring in three plots of cacao trees, 15 to 25 years old, having overhead shade, and in three plots without shade. Leaf-flushing was observed chiefly to occur (i) in the dry season, December to March (2 flushes), (ii) early in the wet season in May, (iii) during the heavy rains in October and (iv) toward the end of the wet season, in November. A long dormant period normally occurs from June to September. This sequence is similar to that which occurs in Trinidad. The flushing times were plotted in graphs along with data for air temperature, soil moisture and for other environmental growth factors. Temperatures were measured within the cacao plots.

The conclusions were drawn that leaf-flushes occur, as in Trinidad, when the maximum air temperature exceeds 83ºF (28.3ºC) and that no other factor apparently influences flushing. The first conclusion agrees with the results obtained in the second investigation carried out in Trinidad.

The range of temperature for the unshaded cacao recorded in the Ghana investigation was 22.1ºF (12.3ºC) during the dry season, when the two big leaf-flushes occur, but only 11.3ºF (6.3ºC) during the wet season months, July and August, when the trees were dormant. The corresponding ranges of temperature recorded for the shaded cacao were 16.7ºF (9.3ºC) and 9.7ºF (5.4ºC) *(Table III).* These results agree closely, not only with those obtained in Trinidad, but also with those obtained at "La Lola" in eastern Costa Rica. They may be accepted as proof that leaf-flushing is mainly controlled by fluctuations in air temperature.

4. *Bahia:* Apparently attempts have not specifically been made at Uruçuca to correlate bud-bursting and leaf-flushing of cacao with any environmental growth factor, but the facts concerning these processes seem to agree with those established for the three other places. Leaf-flushing is stated to be conspicous at Uruçuca three times during the year, namely, in February, May and October. The greatest temperature range occurs, according to the data given in *Tables I and II,* during January to April and in September-October, which coincide fairly closely with these times. The mean values for the temperature range are 11.2ºC (20.1ºF) and 10.2ºC (18.3ºF). These temperature data refer to conditions within the Stevenson screen. To what extent they actually represent the temperature conditions within the cacao fields could only be ascertained by further measurement.

Summary: It is evident that bud-bursting and leaf-flushing in cacao tend to occur during periods of high air temperature but particularly when the difference between the daily maximum and minimum temperatures is large. The critical temperature range when bud-bursting is likely to take place is apparently around 9ºC (16ºF) *(2).* The recorded values given for each of the four places under consideration agree with this finding for, in practically every case, leaf-flushing was associated with temperature ranges above this critical value. The average figure for all the data cited for shaded cacao is 9.3ºC (16.7ºF). The greatest range occurred however where overhead shade was absent or where the shade was least dense *(Table III).*

TABLE III

SUMMARIZED DATA FOR AIR TEMPERATURE PREVAILING DURING LEAF-FLUSHING

Place	Conditions of cacao field	Maximum range of temperature °C (°F)	Mean range for rest or year °C (°F)	Average temperature during flush °C (°F)
Costa Rica	Shaded	9.2 (16.5)	8.4 (15.1)	30.5 (86.9)
Trinidad (1)	Shaded	8.3 (14.9)	5.4 (9.8)	30.2 (86.4)
	Poorly shaded	11.8 (21.3)	7.7 (13.8)	31.3 (88.4)
(2)	Shaded	10.3 (18.5)	7.1 (13.0)	— —
Ghana	Shaded	9.3 (16.7)	5.4 (9.7)	— —
	Unshaded	12.3 (22.1)	6.3 (11.3)	— —
Means	Shaded	9.3 (16.7)	6.6 (11.9)	— —
	Unshaded	11.9 (21.4)	7.0 (12.5)	— —

(C) TRUNK GROWTH

The general growth conditions of the environment of a tree directly affect the activity of the cambial tissue of the bark of the trunk and the branches and fluctuations in these conditions cause the formation of annual rings. It should therefore be possible to assess the relative efficacy of the environmental growth factors by periodically measuring the girth or diameter of the tree by means of a dendrometer. This has been done in Costa Rica and in Trinidad.

1. *Costa Rica:* Dendrometer readings were taken every two weeks during 1953 - 1955 of 12 cacao trees at "La Lola", and the numerical results were statistically correlated with data for various meteorological factors, including air temperature *(3)*. The greatest growth increments were found to take place during June - July. The highest significant degree of positive correlation ($r = + 0.366$) was shown to occur between growth increment and average air temperature which was highest in June - July. A small but non-significant positive correlation was demonstrated for growth and rainfall, and a significant negative correlation for growth and hours of sunshine, this last finding being explained by enchanced water loss by transpiration under direct insolation.

   Trunk growth at "La Lola" was found to diminish during periods of intense leaf-flush. Greatest growth occurred when the average air temperature rose above 25.5°C (78°F).

2. *Trinidad:* Results obtained at I. C. T. A. on one cacao tree only *(7)* were different from those obtained at "La Lola", and this difference may perhaps be attributed to the much more irregular rainfall distribution in Trinidad. Greatest increase in growth occurred at the onset of rainy periods following dry weather. This was attributed to "hydration of the external tissues of the bark" *(7)*. The trunk contracted again during dry periods. Greatest growth increments occurred during intense leaf-flushes. This contradicts the findings at "La Lola". The possible effect of air temperature on trunk growth was not considered in this investigation, but it is evident that, as with leaf- flushing, the effects of fluctuating soil moisture mask, or are super-imposed upon, those caused by changes of air temperature.

Summary: Growth increments of the trunk of the cacao tree are mainly determined by high air temperature at sites where soil moisture supply is adequate and regular throughout the year, but the relationship may be greatly modified when soil moisture content fluctuates appreciably.

(D) SOME OTHER EFFECTS OF AIR TEMPERATURE

Two other effects of temperature on the cacao tree are indirect in action in that they do not affect its physiological processes. The first concerns an important cacao disease, and the second relates to the decomposition of soil organic matter.

(i) *Black Pod disease* *(Phytophthora palmivora)*

Rapid spread of this organism is generally attributed to high humidity, but recent investigations have shown that it is controlled just as much by air temperature as by humidity. Thus, in Bahia and in Ceylon, it has been found that the spread of the fungus causing Black Pod increases rapidly at temperatures approaching 15.5ºC (60ºF) becoming more rapid the lower the temperature. In Bahia in July (corresponding with January in the northern hemisphere) the artificial production of a dense smoke screen within the cacao fields on cold cloudless nights is sometimes resorted to in order to raise air temperature so as to diminish the spread of Black Pod disease.

(ii) *Soil organic matter*

Rise of temperature accelerates the rate of decomposition of organic matter brought about by biological breakdown and chemical oxidation. According to Dr. E. C. J. Mohr, the critical temperature in Java above which the rate of loss of organic matter exceeds the rate of its accumulation on the forest floor is 25ºC (77ºF). Temperatures well above this figure are frequently realised in cacao fields in which the soil is exposed to direct insolation through lack of adequate shade, or during the period between forest-felling and the planting of the crop, or during the early stages of rehabilitation or replanting.

Loss of organic matter disposes the soil to surface erosion through destruction of crumb structure and causes rapid deterioration in productivity.

(IV) DISCUSSION

(1) *Cacao air temperatures:* The evidence adduced in this chapter strongly supports the contention that the temperature relations of the cacao tree are particularly important in determining the efficiency of many of its essential physiological processes. It is now possible to prescribe with greater accuracy the environmental circumstances under which the cacao tree should be grown to ensure high production, especially in regard to temperature. The temperature requirements may be stated simply as follows:

(i) The mean annual temperature should not be below 21ºC (70ºF).
(ii) The lowest mean daily minimum temperature should not be below 15ºC (60ºF).
(iii) The absolute minimum should not be below 10ºC (50ºF).
(iv) For abundant flower formation and pod setting, the air temperature should not fall below 22ºC (72ºF).
(v) In order to ensure regular but not excessive bud-bursting and leaf-flushing, the maximum temperature should not rise above 28ºC (83ºF) and the daily range of temperature should not exceed 9ºC (16ºF).
(vi) For rapid trunk growth, the mean air temperature should be above 2.5.5ºC (78ºF).
(vii) In order to lessen the chances of infection by Black Pod disease (*Phytopthora palmivora*) the mean daily minimum temperature should not fall below 15ºC (60ºF).
(viii) In order to conserve soil organic matter, the temperature of the air should not rise above 25ºC (77ºF).

From all these considerations, the temperature limits for cacao may be set at 15ºC (60ºF) as the monthly mean minimum and 30ºC (86ºF) as the monthly mean maximum. The optimum temperature lies somewhere between these extremes, and the question now arises whether a steady uniform mean temperature is best, or a fluctuating temperature having some particular amplitude.

It is nowadays recognised that optimal thermoperiodicity is the controlling factor in plant development *(13)*. In the case of cacao, the best range of temperature or optimum amplitude appears to be 9ºC (16ºF) because this is the particular range of temperature fluctuation which is necessary to initiate bud-bursting. Nevertheless, in order to ensure uniform and regular growth of the tree and abundant flower formation and pod setting, and in order to spread out the bursting of buds and the flushing of leaves over the whole year rather than concentrate them into two or three main periods, the median or optimum average temperature throughout the year should be around 25.5ºC (78ºF) and the range of daily temperature should be 9ºC (16ºF) or: Optimum temperature = 25.5º $\pm$ 4.5ºC, or 78º $\pm$ 8ºF. This incidentally approximates closely to the temperature regime at I. C. T. A., Trinidad (Table I).

Seasonal temperature variations should, of course, be small for best results. In other words, the annual mean temperature, as well as the diurnal range of temperature, should be constant and unvarying throughout the year.

These conclusions regarding air temperature are based on the assumption that all other growth factors which affect the physiological processes of the cacao tree are optimum. This particularly applies to soil moisture which is the chief environmental factor that seriously modifies or masks the effects of air temperature, as has amply been demonstrated by the experimental evidence adduced in this chapter. Irregular water supply can be corrected ,of course, by irrigation and good results are generally obtained when cacao growing under optimum temperature is properly irrigated.

(2) *The effect of latitude:* It has already been indicated that the range of both annual and diurnal air temperatures is lowest at the equator but increases considerably with increasing latitude. These characteristics refer to places at sea-level, not to places occurring within mountainous country. The range is least of all in low-lying oceanic islands situated on or near to the equator. Hence the best temperature conditions for cacao growing occur naturally nearest to the equator. Temperature conditions become progressively less suitable with increasing distance from the equator.

(3) *The effect of land relief* on air temperature may be considerable. Places situated in deep valleys running north and south, and places situated on slopes with the wrong aspect, receive less insolation and consequently air temperatures are generally lower than places situated on flat plains or on slopes with a sunny aspect.

(4) *The effect of cloud* on air temperature may also be sufficiently pronounced as to become an important factor controlling the growth and production of cacao. A regular alternation of cloudy and sunny weather may greatly affect both the mean annual temperature as well as the daily range of temperature.

(5) *The effect of high and continuous rainfall* on air temperature may also be considerable in that falling rain tends to lower the average temperature and to reduce its fluctuations. Rainfall and cloudiness are closely associated in this respect.

(6) *The effect of artificial shade:* It is possible to diminish both the average temperature and the temperature range in cacao fields by establishing artificial shade over the cacao trees. For example, the investigations on leaf-flushing carried out at W. A. C. R. I. *(5)* revealed the facts that the mean diurnal range for the wet season was only 9.7ºF in the shaded plots as compared with 11.3ºF in the unshaded plots, although it rose in the dry season to mean values of 16.7ºF in the shaded plots and 22.1ºF in the unshaded plots. These dry season temperatures are above the critical limit, 16ºF. Maximum temperatures were 1º to 4ºF lower in shaded plots and minimum temperatures were 1º to 3ºF higher than in the unshaded plots, a maximum difference of 7ºF in regard to air temperature.

In the earlier Trinidad investigation *(8)* it was found that the mean diurnal range in the wet season was 9.0ºF in a well-shaded "good" plot of plantation cacao, as compared with 12.3ºF in a poorly-shaded "bad" plot. It was 13.9ºF in the "good" plot and 20.4ºF in the "bad" plot during the dry season. The last figure is well above the critical limit. Maximum temperature was 1.5ºF lower and minimum temperature was 3ºF higher in the well-shaded plot as compared with the poorly-shaded plot.

The obvious conclusion to be drawn from these data is that the total elimination of shade trees in established cacao fields, or the planting of new fields of cacao without any artificial shade, may be highly undesirable in some instances, since there may be a grave risk of widening the temperature range, especially in places situated in latitudes remote from the equator, or at altitudes high above sea-level, or in places situated on broad flat plains within large continental areas, particularly if the sky is cloudless for the most part and the degree of insolation is high.

(7) The effects of direct insolation. Cacao trees grown without artificial shade are usually planted closely so that they become self-shading within a few years. Nevertheless, exposure to direct sunlight may induce repeated peripheral leaf-flushing which, if accompanied or soon followed by persistent leaf-shedding, may bring about stem "die-back". This imparts a "stag-headed" appearance to the trees and eventually leads to debilitation and death. If the general soil conditions are satisfactory, however, that is, if there is sufficient root room, and if there are adequate supplies of water, air and nutrients, the peripheral leaves may persist and not be prematurely shed, and the foliar canopy of the trees will remain intact and free from die-back. Such a favourable combination of circumstances cannot be expected to occur frequently, and in those places where soil conditions warrant the planting of cacao without shade, at least the young plants should be afforded shade protection until they have grown large enough to become fully self-shading.

(V) NEED FOR FURTHER INVESTIGATIONS

There are many problems concerning the growth of the cacao tree suggested by the foregoing consideration which still require investigation. The following are some examples:

1. A possible relationship between flowering and temperature *fluctuation* is suggested by the finding that flowering and pod-setting are mainly controlled by air temperature. A high degree of correlation has been established between pod yield and mean air temperature but the degree of correlation which may exist between yield and *range* of temperature may be greater still.

2. The cacao tree apparently produces flowers continually all the year round under suitable conditions of air temperature, air humidity and soil moisture, but it may be necessary in order to produce a large number of pods that a shock or series of shocks be imparted to the tree at some time, or at various times, during the year. Such a shock is probably provided by the sudden onset of dry weather. The experimental evidence so far accumulated, coupled with the known facts of cacao-growing in countries like eastern Costa Rica where a dry season does not normally occur, seems not, however, to support this contention.

SUMMARY

1. The temperature relations of cacao are described in regard to certain physiological growth processes, namely, flower formation and fruit setting, bud bursting and leaf flushing and trunk growth. In addition, the effects of temperature on the spread of Black Pod disease and on the decomposition of soil organic matter are also discussed.

2. Actual temperature data which were recorded in connection with field investigations carried out in east and west Costa Rica, Trinidad, Ghana and Bahia, are presented in tables and in a diagram.

3. The results of these investigations are separately summarised for each of the places mentioned.

4. Following a discussion of the results as a whole, the conclusion is drawn that the optimum range of temperature for maximum production of cacao is 21º — 30ºC, or 70º — 86ºF.

5. The effect of shade trees on air temperature within cacao fields at three of the places mentioned is discussed and the results of actual temperature measurements within shaded and unshaded cacao fields are given in a table. In general, shade trees reduce maximum air temperature range by obout 2.6ºC or 4.7ºF.

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CHAPTER 4

THE WATER AND AIR RELATIONS OF CACAO

Cacao Ecology: By "ecology" is meant the study of the environment in relation to the growth and production of a plant. The environment presents many different growth factors some of which act directly on the physiological processes of the plant and others act indirectly. The *indirect* factors have already been mentioned when the selection of site and land for the establishment of a cacao plantation was being considered. The chief of them are latitude, altitude relief and rainfall. The *direct* factors may be subdivided into atmospheric factors and soil factors, thus:

(A) ATMOSPHERIC FACTORS

1. Air temperature
2. Air humidity
3. Air movement (wind)
4. Light.

(B) SOIL FACTORS

5. Water supply
6. Air supply
7. Nutrient supply
8. Harmful factors
9. Root room
10. Soil temperature.

It has been pointed out that certain of the direct factors depend on indirect factors, for example, air temperature depends on latitude and altitude and soil water supply and air humidity depend on rainfall. Some of the direct factors are inter-dependent one on the other. For example, soil water supply and soil air supply both partly depend on root room and each is complementary to the other, in-so-far as both water and air may occupy the pore-spaces of a soil at one and the same time. Soil temperature depends on air temperature, at least in the upper soil layers.

It is logical to regard the soil, the plant and the atmosphere as components of a single physical system since each reacts directly or indirectly on the other. For example, when the soil in which a plant is rooted is saturated with water whilst the atmosphere is unsaturated, the tension set up in the water columns within the conducting tracts by transpiration draws water, containing dissolved nutrients, into the plant at a rate depending on the evaporating capacity of the atmosphere, as determined by its temperature, humidity and air movement. Thus the condition of the atmosphere partly decides the nutritional relationships of the plant.

Law of limiting factors: In order for a plant to grow satisfactorily and to produce its maximum crop, each of the direct growth factors must be at its optimum quantitative expression. The main object in studying the ecological aspects of crop production is to identify the particular factor or factors that may be limiting the proper development of the plant and then to attempt to correct it by some appropriate, but not unduly costly, means. In the long run, this essentially scientific procedure is likely to be less wasteful of time and material resources than haphazard empirical methods.

Dynamic aspects of ecological relationships: The different environmental growth factors fluctuate in magnitude with time. Hence, in attempting to evaluate them in an ecological investigation, it is necessary to make periodic determinations at frequent intervals within one or more growth cycles, and to correlate the data with the responses of the plant. In this way, for example, the effects of air-temperature on flower formation and leaf flushing of cacao, described in the last chapter, were identified and assessed *(1)*.

Water and air relations of cacao: As a further example of the ecological method, the water and air relations of the cacao tree will next be considered. Soil may be regarded as a porous medium which is capable of holding both air and water. Soils differ greatly, however, in their capacity simultaneously to supply water and air at the requisite rate to satisfy the needs of the rapidly growing plant.

Soil texture and soil structure: Soil stores air solely within its interstices but it stores water partly in the interstices but mostly in the minutely porous colloidal matter comprising clay and humus, which is abundantly present in the best soils. Obviously, soils that consist solely of sand grains must lack water storage capacity. Their capacity for storing air depends on their total pore space which varies with the size of the particles, the proportionate amount of particles of different sizes, and the mode of packing of the particles. This is clearly shown in the accompanying geometrical diagrams *(Figure I)*. The percentage amount of particles of different sizes may be determined by mechanical analysis which describes the *texture* of the soil. The dimensions of the size grades are generally those given in the international scheme.*

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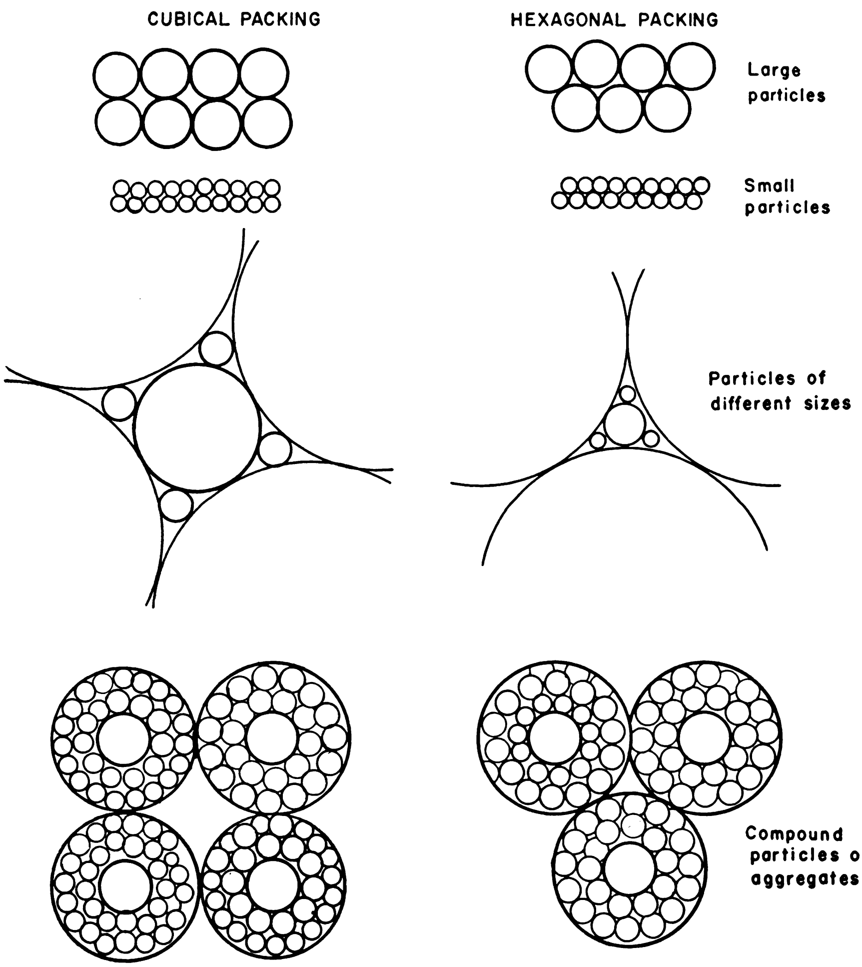
* International scheme for the mechanical analysis of soils

Fine gravel	4.0	—	2.0	mm.
Very coarse sand	2.0	—	1.0	mm.
Coarse sand	1.0	—	0.5	mm.
Medium sand	0.5	—	0.2	mm.
Fine sand	0.2	—	0.02	mm.
Silt	0.02	—	0.002	mm.
Clay	0.002	—		mm.

FIGURE 1

KINDS OF PACKING



Viewed in section, the size of the pore spaces formed by spherical particles in contact depends on the size of the particles themselves. For close hexagonal packing, the relationship between the two is approximately given by Slichter's formula: Diameter of pore = 0.3 × diameter of particle. The size of the pores determines the permeability of the soil to water and air. It also determines the ease of penetration of the soil by plant roots.

Root penetration: Root tips, protected by root caps, have finite dimensions, ranging from 0.1 to 0.5 mm. or over. Hence, in order for a sandy soil consisting of uniform particles with hexagonal packing to permit root penetration, the diameter of the particles should range from 0.1 ÷ 0.3 = 0.33 mm. for the smallest roots, to 0.50 ÷ 0.3 = 1.67 mm. for large roots. These are the dimensions of medium coarse and very coarse sand grades. Particles of fine sand, silt and clay in close packing have dimensions that are much too small to allow root tips to insinuate themselves between them, unless the grains can be pushed aside which may not be possible if the material is too compact *(6) (11)*. The fact that a sandy soil must be coarse grained if it is to be free draining and easily penetrated by plant roots explains the failure of propagating media that are too fine in texture. The best sandy medium for use in rooting bins for cacao cuttings, for example, is very coarse sand or fine gravel, whose particle size is about the same as that of a small grain of rice.

Compound particles or aggregates; soil structure: Soils that comprise compound particles consisting of small particles of different sizes, including clay particles, aggregated together and having the overall dimensions of very coarse sand and fine gravel (1.0 to 4.0 mm.) not only are highly permeable to water and air and easily penetrated by roots, but they also have a high storage capacity for water and are therefore more suitable as a medium for growing plants than single grain compact rigid sands. When wetted, they readily disintegrate, however, unless stabilized by some sort of cement. The naturally occurring cements include mucilage, produced by soil organisms such as worms, blue-green algae and certain bacteria; humus, produced by decaying organic matter; hydrated ferric oxide (limonite) and calcium carbonate. The so-called soil conditioners which have recently been suggested as aggregate cements resemble bacterial mucilage and act in a similar way in forming and stabilising soil crumb. Ferric oxide hydrates are the commonest aggregate cements in humid-tropical soils, especially in the lower layers that lack humus. These soils generally consist of highly stable, non-coherent, uniform aggregates, colored red, brown or yellow by ferric oxide cement.

Soils composed of particles of different sizes, including a high proportion of silt and clay cemented into water-stable aggregates, usually have a soft, loose, spongy consistency and allow roots, not only to penetrate easily but also to grow rapidly in thickness. They have a total pore space volume of over 62 percent. Assuming that the specific gravity of the solid material is 2.65 (which is that of quartz and of kaolinitic clay) the apparent specific gravity of the soil is less than 1.0.* This value may therefore be taken as an index for gauging

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* Formula: — $$\text{Pore space (vol. percent)} = \frac{\text{True sp. gr. } minus \text{ appar. sp. gr.}}{\text{True sp. gr.}} \times 100$$

the physical structure of a soil in respect of its capacity for storing air and water. It may also be employed for roughly assessing its permeability to water, since soils having a pore space volume of such high magnitude usually contain a sufficiently high proportion of pores with sufficiently large cross sectional area to permit the free passage of water.

In general, soils having apparent specific gravity greater than 1.60, corresponding to a total pore space volume of less than 40 percent (assuming they are chiefly composed of quartz and kaolinite) do not permit root penetration and are therefore not suitable for crop growing *(10)*. The apparent specific gravity of a soil may easily be determined by drying and weighing constant-volume cores of soil obtained at different depths in soil sections exposed by digging pits in the field. Apparent specific gravity is the most useful of all the physical constants for determing the suitability of a soil for growing plants.

The water supply of a soil: There are two distinct aspects that should be considered in attempting to assess the water supplying capacity of a soil. The first is the total quantity of water that can be stored within the rooting zone, and the second is the degree of availability of the stored water to the growing plant.

Root room: The volume of the rooting zone, that is, the volume of soil having suitable pore space dimensions to permit easy root penetration, is termed "root room". In crop plants such as cacao its limits are determined by planting distance and by the depth of an impeding layer (hard pan) or water table below the surface of the highly porous soil.

Storage capacity: The maximum storage capacity of an undrained soil of known root room is equal to the root room volume multiplied by the total pore space volume percentage. It may more conveniently be expressed, however, as inches of rain required completely to fill the pore space within the rooting zone. Thus, for a soil having 50 percent total pore space, one inch of rain will fill the pores to a depth of 2 inches but, for a soil having 66 percent total pore space, it will only fill the pores to a depth of 1½ ins. In general, the number of inches of rain (R) required to fill the storage capacity of a soil having rooting depth d (ins). and total pore space P (volume percent) is given by the formula

$$R = \frac{dP}{100} \text{ ins.}$$

Field capacity: A soil maintained at full storage capacity by continuous rain would not support the growth of plants, because it lacks aeration. It is described as waterlogged. Plant roots respire and in so doing they liberate energy which is used to activate the process of water absorption. In order to ensure rapid root respiration, a cacao soil should contain at least 10 percent of its total volume occupied by air. If it contains less than this, there may be danger of asphyxiation because of oxygen shortage.* When a fully saturated soil is allowed to drain freely, water at first runs away under the pull of gravity, but many days may elapse before the water ceases to drip into the drains. When this stage of depletion is reached, the water that remains in the soil measures its *field capacity (4)*. This soil constant, as thus defined, is a somewhat vague and unprecise conception, but it possesses considerable practical value for roughly comparing soils in the field. Sandy soils have a field capacity of less than 15 percent by weight whereas clayey soils have a field capacity up to 50 or 60 percent.

Capillary and non-capillary pore space: An early theory of soil moisture considered field capacity water to be held by the minute capillary pores occurring within the structure units or aggregates. It was accordingly termed capillary water. Water occupying the larger pores, including cracks, root-traces and worm holes, occurring between the structure units in a fully saturated soil at storage capacity was likewise termed non-capillary water, and sometimes gravitational water, because it runs out more or less freely under the pull of gravity. The diagrams in *Figure* 2 show differing degrees of soil porosity.

Wilting coefficient: Not all the water contained in a moist soil originally at field capacity can be abstracted by a growing plant whose roots exert a steady suction. A point is eventually reached when the force with which the soil holds its water is equal in magnitude to the suction force exerted by the roots. The plant then wilts. The amount of water remaining in the soil at the permanent wilting point, expressed either as volume or as weight percentage, is termed its wilting coefficient. It may be determined by growing maize or sunflower seedlings *(5)* in a moistened sample of the soil packed loosely into a small container and sealing the surface with a layer of wax in order to prevent evaporation. When the plants have wilted, the residual moisture content of the soil is determined by drying and weighing. Sandy soils have low wilting coefficients (W) ranging from 10 to 20 percent (by weight) in the coarser kinds, whereas clayey soils have wilting coefficients ranging from 30 to 40 percent (by weight) or about two- thirds of their field capacity (F); *ie.* $W = 0.6\ F$ (approximately).

Suction force; pF value: The various soil constants merge one into the other without definite breaks. The water content of a soil should be regarded as comprising overlapping phases which are held with gradually increasing force as the soil dries out. At wilting point, the suction force is equal in magnitude to the pressure of a column of water of length 16,000 cm. (520 ft.) which is 16 times the height of the water barometer whose pressure is one atmosphere. It is customary to express suction force by the logarithm of the length in

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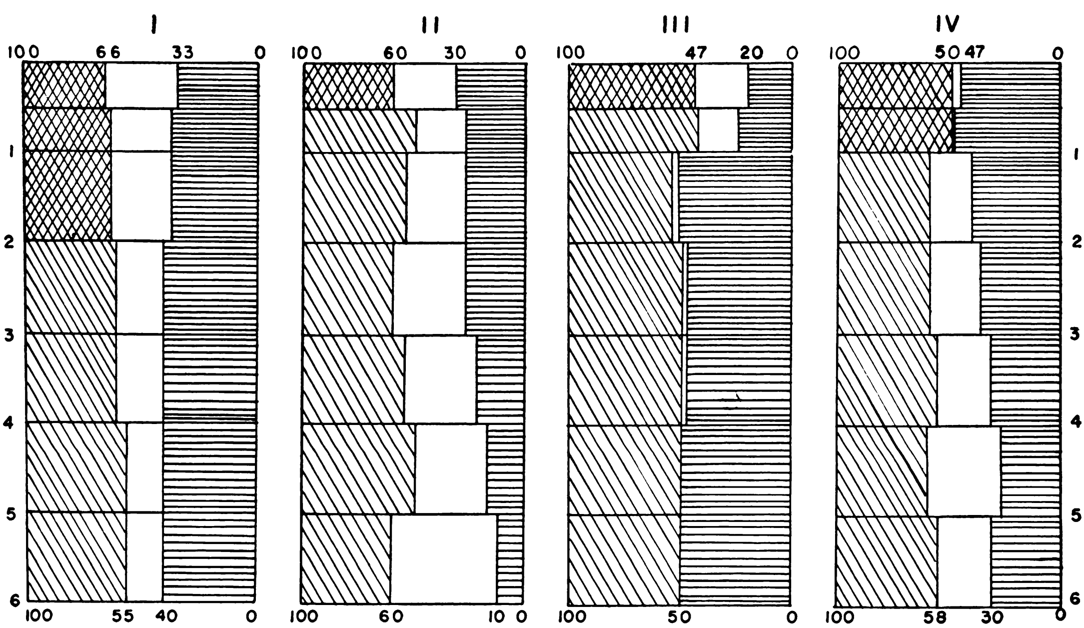
* The growth of roots diminishes when the content of oxygen in the soil air falls below 10 percent from its initial value of about 20 percent. In highly permeable soils, having large non-capillary pore space, gaseous diffusion normally prevents serious oxygen depletion *(6)*, but in compact, badly aerated fine grained soils, toxic concentrations above 5 percent of carbon dioxide may accumulate in the stagnant soil air.

FIGURE 2

SOIL POROSITY



Loamy Soil Highly Aggregated	Sandy Soil Gravelly Below	Sand Over Clay Compact Below	Clay Over Sand Cracks in Dry Wheather.
Humic to 2 ft.	Humic to 6 ins. TOO DROUTHY	Humic to 6 ins. TOO DROUTHY	Humic to 1 ft. TOO DROUTHY
IDEAL SOIL	**UNSATISFACTORY**	**CACAO**	**SOILS**

centimeters of the corresponding water column. This is termed pF value. Thus the suction force which holds water in a soil at wilting point would be expressed as pF 4.2 (log 16,000 = 4.2) and that which holds water in a soil at field capacity as pF 3.0 (log 1000 = 3.0). Recent investigations have shown that, when the pF value of the water content of a soil growing a crop increases above, say, pF 3.5, water strains are set up in the conducting tracts and these cause a marked diminution in the growth rate long before the wilting point (pF 4.2) is reached.

Availability of soil water: These facts regarding the state of occurrence of water in moist soils indicate that only a certain proportion of the total water content is available to and usable by the plant. In theory, the total available water is that which lies between full storage capacity and the wilting coefficient. Since a fully saturated (or waterlogged) soil lacks aeration, however, and cannot support healthy root growth, a soil must be partly drained and lose at least 10 percent of its volume of water before root respiration and water absorption can proceed at a normal rate. Thus the minimum non-capillary pore space of a soil which is to be used for growing crops is 10 percent by volume.* Coarse sandy soils and well-aggregated clay soils usually have much greater non-capillary pore space than this critical value, and many massive silt soils and clay soils develop this amount of non-capillary pore space on partial drying because of the formation of cracks. On the other hand, many poorly-structured compact clays and silts have less non-capillary pore space than the critical 10 percent, and are therefore unsatisfactory as media for crop growing.

Optimum usable water: Usable water may be defined therefore as that which occurs between the 10 percent limit and wilting point. *Optimum* usable water is that fraction of it which may easily be abstracted by a plant without setting up harmful water strain. It is held by a force whose magnitude ranges from about pF 2.5 to about pF 3.5, occurring on either side of the field capacity value, pF 3.0.

In regard to cacao, it has been shown by observations on stomatal behaviour, photosynthesis and growth *(2)* that the physiological processes responsible for pod production diminish progressively as soil moisture content falls below 50 to 70 percent of the total content of available water. They cease completely at the wilting point.

The force relationships of the moisture contents of a sandy and a clayey soil are indicated in the accompanying diagram *(Figure 3)*. The magnitude of the optimum usable water may be gauged from the curves to be only 5 percent of the soil's dry weight for the sand and 12 percent for the clay.

Wetting of soil by rain: The rain which falls on the land may be subdivided in the following ways:

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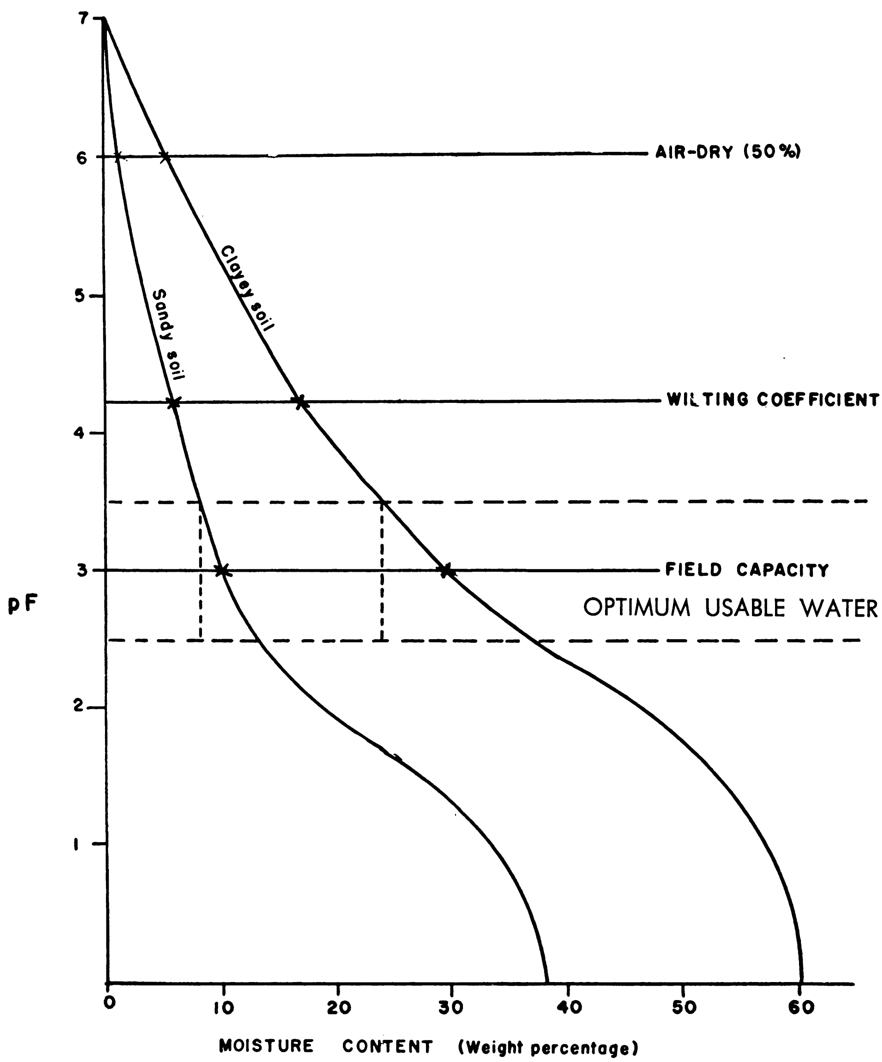
* Some authorities define available water as that which occurs between field capacity and wilting point, though clearly this definition cannot apply to soils with low non-capillary pore space.

FIGURE 3

FORCE RELATIONSHIPS OF MOISTURE IN SANDY AND CLAYEY SOILS



(1) Part may be intercepted by foliage without ever reaching the soil surface
(2) Part may run away off the land depending on surface infiltrability or water acceptance
(3) Part may evaporate from the soil surface
(4) Part may run through the rooting zone and escape as drainage water
(5) Part may remain within the rooting zone
(6) Part may be transpired from the leaf surfaces.

(1) *Interception:* This may amount to over 20 percent of the rain falling on forest or cacao land. The intercepted water merely wets the leaves and quickly evaporates in dry air without ever reaching the soil.

(2) *Run-off:* This is negligible over forest and cacao land that is well shaded, because of the high infiltrability of undisturbed soil covered with leaf litter and decomposing organic materials.

(3) (6) *Evapotranspiration:* This depends solely on atmospheric conditions, namely, air temperature, humidity and wind velocity, which vary in different places on the earth's surface, being climatic factors.

(4) *Deep drainage:* The water that percolates through the rooting zone may accumulate as ground water whose upper surface constitutes a water table, or it may escape as water springs. Water tables may be either permanent or temporary (perched). Water trickles out below a permanent water table into a pit but it does not do so below a perched water table.

(5) *Storage:* It has been explained above that the maximum storage capacity of a soil is determined by its total pore space but it is determined by its field capacity when the soil is fully drained. Since most soils take a long time to drain completely, storage capacity may include a proportion of the finer non-capillary pore space as well as all of the capillary pore space.

Importance of soil permeability and its relationship to rain showers: Soil permeability varies in magnitude from zero to 10 ins. per hour, and rain intensity from zero to about one inch per hour. Thus soils that have only moderately slow permeability (0.8 to 0.2 ins. per hour) are capable of coping with the heaviest rains, provided that they are deep and freely drained below. When a rain shower having magnitude less than the percolation rate penetrates into a deep soil, part of it, equal to the volume of the capillary pore spaces within the structure units, is immediately absorbed by the uppermost soil layer, the remainder passing downwards through the non-capillary pore spaces into the layer below. A further portion of the water is similarly absorbed by this layer and successively by the lower layers in turn until all the water is retained. Evapotranspiration then proceeds until the next shower of rain occurs, and the process is repeated. The maintenance of the necessary degree of aeration in a soil that is subject to intermittent wetting in this manner thus depends partly on its permeability, partly on its depth to an impeding layer or water table, and partly on the periodicity and the total amount of the incident rainfall. The greater the total rainfall and the more frequent and the longer the showers, the greater should be the permeability of the soil if waterlogging is to be avoided. Lack of balance between the rainfall characteristics and the permeability and depth of the soil generally result either in temporary drainage impedance accompanied by repeated flooding or in periodic excessive drying out. Since the optimum usability of soil water is confined to quite a narrow range of moisture content, the importance of this balance between the features of the rainfall and those of the soil can scarcely be overstressed.

Measurement of soil moisture in the field: The simplest method for determining soil moisture content is to dry and weigh soil samples abstracted with an auger. This method is unsuitable however for application to deep layers. A method of wider use is to measure the electrical resistance of porous blocks of gypsum or of nylon buried at the required depths in the soil *(9)*.

Soil moisture relations of cacao: Investigations on the effect of fluctuations of soil moisture on the growth of the cacao tree have been carried out in Trinidad *(8)* and in Ghana *(7)*. The soil auger was used for collecting weekly samples for soil moisture determinations. The results obtained in Trinidad for two contrasted plots of cacao are depicted in the accompanying diagrams *(Figure 4)* which illustrate the relationship between the mean monthly soil moisture contents, the rainfall and the chief physical constants of the soils in question as set out in the following table and depicted in *Figure 5*.

PHYSICAL CONSTANTS OF CONTRASTED CACAO PLOT SOILS (TRINIDAD)

(Volume percentages)

Soil constants	SANDY SOIL - "GOOD"		CLAYEY SOIL - "BAD"	
	Topsoil 0-6 ins.	Subsoil 6-12 ins.	Topsoil 0-6 ins.	Subsoil 6-12 ins.
Saturation capacity	53	47	61	54
Field capacity	26	25	50	49
Wilting coefficient	14	14	28	32
Non-capillary pore space	27	22	11	5

It will be seen in the first set of diagrams *(Figure 4)* that the moisture content of the "good" sandy soil fluctuated around field capacity and only once in the topsoil, during May, did it fall to near wilting point, whereas the moisture content of the "bad" clayey soil lay mostly below field capacity and on two occasions during the dry season it fell to near wilting point, both in the topsoil and in the subsoil. The more pronounced drying of the clayey soil was mainly owing to

FIGURE 4

WATER RELATIONS OF CACAO SOILS

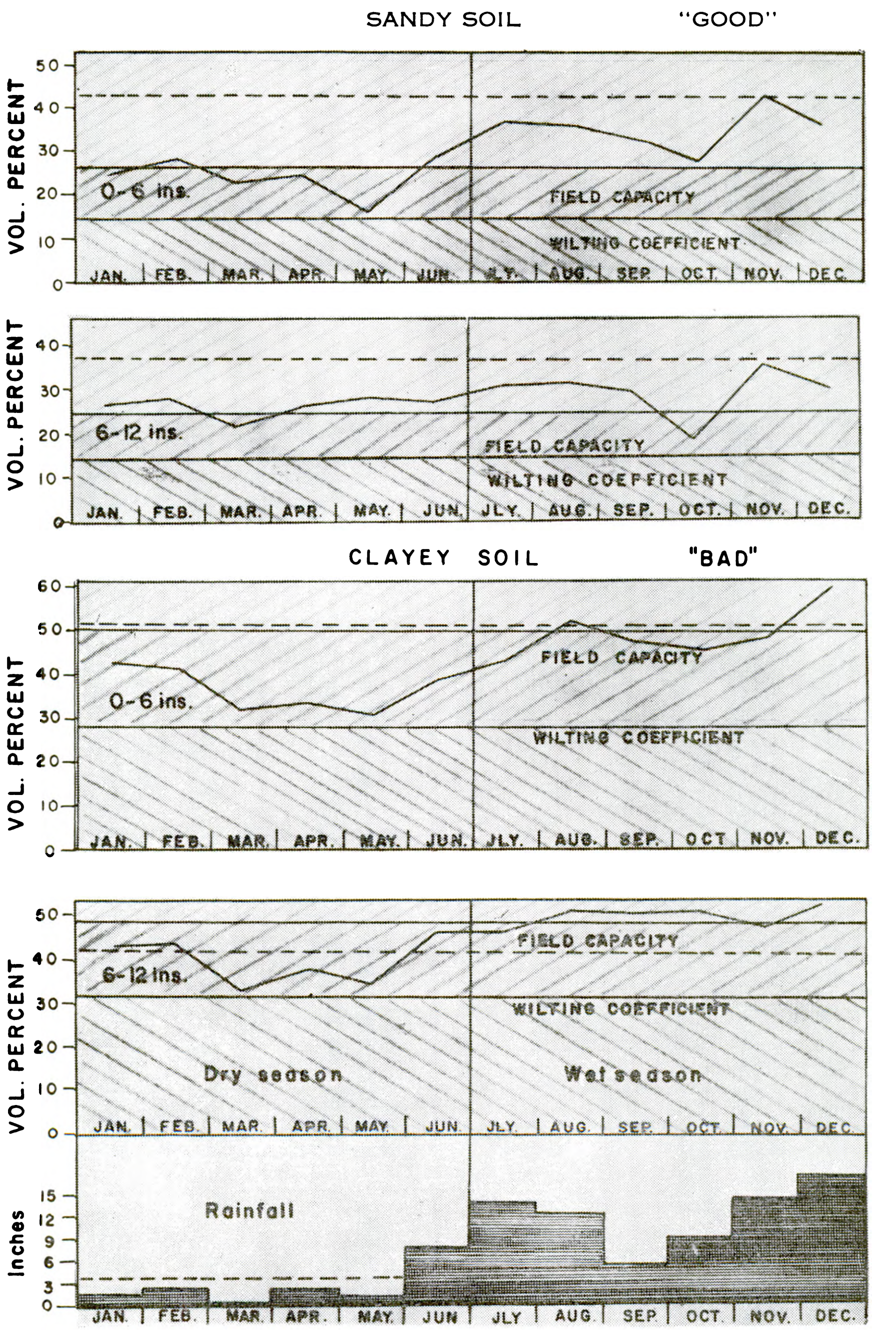
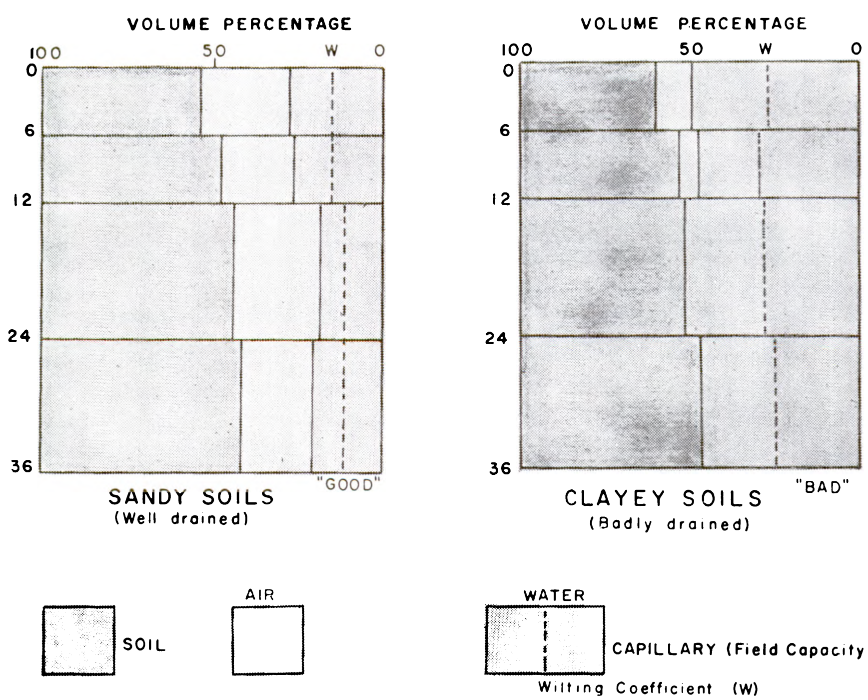


FIGURE 5

POROSITY DATA FOR CACAO SOILS



deep cracking. The degree of aeration was much less during the wet season in the clayey soil than in the sandy soil, especially the subsoil which was almost waterlogged for the greater part of the wet season. Conditions for root growth were clearly much more favorable in the sandy soil.

The porosity data for these two soils are depicted in the second pair of diagrams *(Figure 5)* down to the 36 ins depth. Capillary pore space (field capacity) is divided into two categories by the wilting coefficient. Non-capillary pore space or air space, as shown in the diagrams, is much greater in the "good" sandy soil and its high value is sustained down to the 36 ins depth. In the "bad" clayey soil, the non-capillary pore space or air space is zero at depths below 12 ins., except when the soil dries out and deep cracks develop.

The results obtained in Ghana *(7)* were expressed in line graphs as available water (total soil moisture *minus* wilting coefficient) down to 12 ins. depth. The data (not here reproduced) showed close correlation with rainfall; they indicated consistently higher values for a plot which was shaded than for a plot which was not shaded, but this difference could not be wholly attributed to shade, since the subsoil (6-12 ins.) of the shaded plot was more clayey than that of the unshaded plot. The available moisture content fell to about 4 percent above wilting point in mid-February in the unshaded plot.

Leaf moisture relations of cacao: In accordance with ecological principles, the moisture content of the leaves of a plant fluctuates with that of the soil in which the plant is growing, though a time lag between the two often occurs. As the moisture content of leaves diminishes below a certain critical value, the stomata start to close. In the case of cacao, the critical value has been found to be about 95.5 percent of the initial leaf moisture content *(2)*. Stated in other words, when only 4.5 percent of the initial leaf moisture content has evaporated, the stomata completely close. Leaves of other tree crop plants, for example, coffee, citrus and banana, are not so sensitive to water loss. Whereas a cacao leaf, having wide open stomata when freshly plucked from a tree, shows stomatal closure, through drying, within 5 or 6 minutes, leaves of these other plants do not show stomatal closure until 20 or 30 minutes have elapsed *(1) (2)*. The method used for testing closure was to apply drops or smears of mixtures of xylol and heavy paraffin oil in graded proportions to the under leaf surface. The extent to which closure has proceeded is gauged from the particular mixture which just penetrates or infiltrates into the leaf tissues, forming a translucent spot.

The leaves of seedling cacao trees growing in potted moist soil which was allowed to dry out slowly began to show stomatal closure when the soil moisture content had been reduced to 60 percent of the total available water, reckoned as the difference between field capacity and wilting coefficient *(2)*. Whether the leaves of mature cacao trees growing in the field show stomatal closure when the soil has only partially dried out was not ascertained, though it is likely generally to occur, especially in soils having restricted root room. The possibility of using the infiltration method for deciding when a cacao field in dry weather should be irrigated also needs to be investigated. It is recommended that irrigation might be needed when stomatal opening has decreased to about 50 percent of the maximum original opening. This corresponds to about 50 percent of available soil moisture, as defined above, according to recorded results *(2)*. Further results with this method of stomatal testing have shown that rain and dew do not affect the stomatal behaviour of the leaves of *mature* cacao trees, although they induce closure in leaves comprising the first flush of cacao seedlings *(2)*.

The rapid response of the leaf stomata of the cacao plant to drying conditions in the soil readily explain its characteristic susceptibility to drouth. Nevertheless, despite the low resistance to water shortage shown by cacao, the crop has been grown successfully in regions where the dry season is long and severe as, for example, Cauca Valley, Colombia, and the Arriba district of Ecuador as well as eastern Costa Rica. At these places, however, the dry season coincides with a period of low air temperature when the absorption of soil moisture takes place more slowly than during periods of high temperature *(2)*. One of the physiological effects of diminishing temperature is a reduction in the rate of absorption of water by plant roots. In regions where the dry season regularly coincides with a period of high temperature, for example, Bahia, Brazil, water shortage causes a reduction of crop and may even bring about the death of cacao trees in severe cases *(2)*.

Shade in relation to soil moisture: One of the chief effects of shade trees grown in association with cacao is to lower the mean maximum temperature and to raise the mean minimum temperature of the air within a cacao field, and consequently to diminish the daily temperature range. Measurements made in Trinidad and in Ghana showed that the daily range was reduced by shading from 11.8ºC (21.3ºF) to 8.3ºC (14.9ºF) at the first place and from 12.3ºC (22.1ºF) to 9.3ºC (16.7ºF) at the second.* This effect on air temperature, not only regulates bud bursting and leaf flushing which become less frequent and less sporadic under shade, but it also lowers the rate of transpiration from the leaf surfaces of the cacao trees and thus conserves leaf moisture. The temperature of cacao leaves exposed to full sunlight was found at "La Lola", Costa Rica, to be about 47ºC (116.5ºF) whereas that of leaves under shade was found to be 28ºC (82.5ºF) a difference of 19ºC (34ºF) *(3)*. This large difference in leaf temperature resulted in a two to three-fold increase in the rate of transpiration in leaves exposed to full sunlight *(3)*. The fact that cacao leaves exposed to direct sunlight transpire more rapidly than leaves in the shade has been demonstrated by weighing detached leaves at one minute intervals by means of a delicate spring balance *(2)*. In one such experiment, it was found that exposed cacao leaves lost 15 to 20 mg. weight per square decimeter of surface area per minute as compared with 7 to 10 mg. sq. dm. per minute for shaded leaves. After an interval of about two minutes from the time the leaves were plucked, the stomata began to close because of water loss by transpiration. Complete stomatal closure occurred within five minutes in direct sunlight but only within six to eight minutes in shade *(2)*.

The behaviour of the leaf stomata of the various tree species that are customarily grown as shade for cacao has apparently not yet been investigated. Assuming, however, that the leaves of shade trees are less susceptible to loss of water than those of cacao and continue to transpire even when soil moisture content is low, then the presence of shade trees in a cacao field might deprive the cacao trees of water by undue competition and the cacao leaves may suffer

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* See Chapter 3, Table III.

severe damage by desiccation during periods of drought *(3)*. In most cases, however, shade trees are deciduous and lose their leaves during dry weather, thus effectively reducing tranpiration to zero. If they do not, then a judicious pruning, such as is generally practised in coffee cultivation, might achieve the same result, namely, to diminish the uptake and transpiration of water by the shade trees and to release a larger proportion for the transpiration and growth of the cacao trees. Evidence is lacking to prove that the root systems of shade trees normally occupy a lower stratum of the soil than that occupied by those of cacao trees, and there would seem not to be any valid reason why they should. Nevertheless, because shade trees are larger and quicker-growing than cacao, and because their roots probably possess greater root vigor, shade trees attain more extensive contact with the soil aggregates and thus abstract an undue proportion of the soil mositure for their own use.

Certain other factors affect the moisture relations of shaded and unshaded cacao and these should not be left out of account in deciding whether or no shade is desirable when soil moisture content is deficient. One of the most important of these additional factors is wind which, when excessive, not only damages the cacao and the shade trees mechanically, but also is responsible for a large part of the total evapotranspiration, particularly when the moving air has low relative humidity. The presence of shade trees undoubtedly reduces the amount of wind damage to the cacao trees, unless the shade trees are old and tall or diseased so that they easily shed their branches onto the cacao, It also diminishes the rate of transpiration by the cacao leaves by acting as a wind break, although at the same time the rate of transpiration of the shade tree leaves is not diminished.

Shade trees intercept a considerable proportion of the rainfall up to about 20 percent of the total. This intercepted water is evaporated without ever reaching the ground. In evaporating, it uses up a certain amount of the total radiant solar energy available for evapotranspiration so that there is less energy left for leaf transpiration and for surface soil evaporation. Thus the content of soil moisture is not diminished through rainfall interception by shade trees and is exactly the same where shade trees are absent and interception does not occur, for, according to the theory of evapotranspiration, a soil maintained say at field capacity and completely covered by dense vegetation can only lose water at a fixed rate, no matter how many canopy storeys there are, determined ultimately by the rate of incidence of radiant solar energy which, of course, varies at different places on the earth's surface and at different seasons or months of the year. The magnitude of the potential evapotranspiration within the tropical cacao belt lies between 4 and 5 ins. per month and does not vary greatly from one month to another.

SUMMARY

(1) The most important environmental growth factor affecting cacao is the *root room* afforded by the soil. This is determined by the porosity and depth of the soil. It usually coincides with the depth of humic penetration. Soils having the greatest root room mostly comprise highly aggregated humic loams and clays.

(2) Aggregated loam and clay soils offer the best *water supply* and *air supply,* because they have large field capacity (capillary pore space) for water and their air capacity (non-capillary pore space) is above the critical value, 10 percent, required by cacao roots for respiration. They also have high surface infiltrability and high permeability to water.

(3) Diagrams are presented to illustrate the water and air relations of sandy and clayey cacao soils.

(4) Not all the water contained in a moist cacao soil is equally available to or usable by plants but only that which is held by a force not far removed from that with which a soil holds water at the field capacity stage, namely, pF 3.0.

(5) Cacao is particularly sensitive to water shortage. When the soil moisture content is reduced below field capacity, the drying out of the leaves rapidly causes the stomata to close and transpiration then ceases. Thus shade trees, by protecting cacao from direct insolation and by reducing air temperature, help to conserve leaf moisture and to prevent injury to the leaf tissues.

(6) On the other hand, shade trees compete with cacao for soil water and, unless they are naturally deciduous, they deprive the cacao trees of water during drouth. This effect is least severe where the storage capacity of the soil is great and where root room is large.

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CHAPTER 5

THE NUTRIENT RELATIONS OF CACAO

The chief nutrients required by green plants comprise the basic radicles, K, Na, Ca, Mg (major) and Fe, Al, Mn, Zn, Cu (minor) and the acid radicles, NO_3, PO_4, SO_4, Cl (major) and BO_3, MoO_4 (minor). These are all supplied by rock minerals. *Nitrogen* comes from the air and is fixed in the soil by micro-organisms, some of which are free-living whilst others are associated with the noduliferous roots of leguminous plants. Nitrogen forms microbial protein which decomposes in the soil into amino-acids and then into ammonium (NH_4) salts which are quickly oxidised to nitrite and nitrate in well-aerated soil. Certain plants, notably forest trees (including cacao) absorb and utilise nitrogen in the form of ammonium (NH_4) radicle, whilst others only utilise nitrate (NO_3) radicle. The intermediate stage, nitrite (NO_2) radicle is toxic to plants but it is transient, being rapidly oxidised to nitrate in well-aerated soil.

The basic and acid radicles are more-or-less readily leached out of the soil by percolating water. Of the basic radicles, the first to go is calcium, then magnesium and potassium last. Of the acid radicles, nitrate goes first, then chloride, then sulfate and phosphate last. A heavily leached base-depleted soil is highly acid. When the degree of acidity rises above that represented by pH 5.5, toxic aluminum, and possibly also iron and manganese, are liberated and the soil becomes infertile to certain crops, notably maize and sugar-cane. Other crops, such as cacao, coffee and tea, are more tolerant. Certain families of weed plants, for example, Melastomaceae, Rubiaceae, Lycopodiaceae and Filicineae, are tolerant to toxic aluminum and are able to grow under extremely acid conditions. They are called "aluminum plants" and their flowers or fruits are usually colored blue *(6)*. They serve as indicators of acid soils in the field.

Under alkaline conditions (reaction values above pH 7.5) iron, manganese, zinc and copper are fixed as insoluble hydroxides, basic carbonates or phosphates. Over-liming an acid soil should therefore be avoided because it results in lime-induced chlorosis in plants owing to iron shortage. The use of excessive amounts of phosphatic fertilizer fixes iron, manganese and possibly even zinc as insoluble phosphates, and crop plants, including cacao, then suffer from shortage of these minor elements. Too much alkalinity (reaction values above pH 8.5) liberates toxic aluminate radicle (AlO_2). Soil alkalinity ranks as an even greater harmful factor in plant-growth than soil acidity.

Most crop plants are productive only within the reaction limits pH 5.5 to pH 8.5. For example, whilst cacao will grow in soils of reaction below pH 5.5 or above pH 8.5, it only produces good crops when grown in soils of reaction around pH 6.5 which may therefore be accepted as optimum for cacao. High acidity and high alkalinity, however, are not in themselves harmful to plants; it is the adverse factors associated with, or developed by, these conditions that are harmful. Besides the processes which have already been considered, the incidence and multiplication of both useful and harmful bacteria and other soil micro-organisms, many of which are pathogens, are controlled by soil reaction. Undoubtedly, pH value is the most useful and significant single chemical soil constant for diagnosing the nutrient status of a soil and for indicating the possible presence of harmful factors.

Nutrient-deficiency symptoms in cacao: These mainly concern the leaves which develop characteristic patterns when cacao plants are grown in water or sand cultures in which each minor element in turn is omitted. The leaf appearances have been fully described *(15)* and illustrated by colored pictures *(19)*.

Leaf symptoms caused by nutrient deficiencies are not common in cacao plantations. Those most likely to develop are nitrogen deficiency, sometimes seen in unshaded. weed-infested cacao fields, phosphorus deficiency, common in most infertile soils, and iron deficiency induced by inadequate aeration in badly drained soils. Leaf scorch, caused by shortage of soil potassium *(22)* as well as by soil salinity and the excessive use of fertilizers, is also fairly common. Shortage of magnesium and calcium occurs in extremely acid soils *(4)*. Shortage of zinc has been reported in West Africa *(9)* and in Ceylon. When grown in calcareous soil or overlimed soil, cacao develops lime-induced chlorosis because of the suppression of iron *(11)*. The following scheme illustrates the main features of the different leaf symptoms shown by cacao grown in soils deficient in the major and the minor elements *(3)*.

Key to deficiency symptoms in cacao

(After P. de T. Alvim *(3)*)

(A) *Plants markedly chlorotic*

1. Leaves pale-green, reduced size, often necrotic (Common in unshaded, weedy cacao) .... *Nitrogen*

2. Leaves pale-green, normal size, veins pale (Uncommon in the field) .... *Sulfur*

3. New leaves only yellow, normal size, old leaves green (Common in badly-aerated soils lacking organic matter, or highly alkaline) .... *Iron*

(B) *Chlorotic mottling between veins*

1. Old leaves only pale-green, necrotic areas between veins, or marginal (Common in acid soils and on nursery seedlings) .... *Magnesium*

2. New leaves only pale-green within inter-veinal areas and leaf margins, never alongside veins (Uncommon except in highly alkaline soils) .... *Manganese*

(C) *Leaves chlorotic*

1. Old leaves, margins necrotic, sharp wavy division between necrotic and healthy tissue (Common in highly-leached acid sandy soils) .... *Potassium*

2. New leaves, necrotic areas between veins, symmetrical on each side of mid-rib. Premature leaf shedding (Uncommon in the field) .... *Calcium*

3. Old leaves, necrotic areas at least. No premature leaf shedding (See (B) 1.) .... *Magnesium*

(D) *New leaves deformed*

1. New leaves reduced size, curved to spiral; lamina hard, brittle (Occasional in leached acid soils) .... *Boron*

2. New leaves narrow, margins wavy, lamina sickle shaped, chlorotic between secondary veins. Old leaves with chlorotic spots on sides of main veins (Common in alkaline soils) .... *Zinc*

3. New leaves, reduced size, compressed near apex; secondary veins reduced in number, irregularly distributed; necrotic apices (Uncommon in the field) .... *Copper*

(E) *Absence of chlorosis, necrosis or leaf deformities*

1. Plant reduced size, lower leaves shed early, occasional necrosis near leaf apices; sometimes leaves bronzy color (General in infertile soils) .... *Phosphorus*

2. New leaves narrow, translucent; faint chlorotic mottling in interveinal areas; marginal necrosis in older leaves (Uncommon in the field) .... *Molybdenum*

Treatment of soils and cacao trees deficient in minor elements: In cases where the soil is deficient in minor nutrients such as iron, zinc, manganese and copper, the lacking elements may be added to the soil as simple salts or sprayed onto the foliage in readily-absorbable form as chelates. These are salts of ethylene-diamine tetra-acetic acid (EDTA) and similar substances which contain the basic element in such a form of combination that it is not precipitated in the soil, even if it be alkaline or contain an excess of calcium carbonate *(13).* The quantity needed to rectify a shortage ranges from 2½ to 30 lb. per acre of chelated compound.

Toxic effects of nutrient excesses on cacao: Most of the minor nutrients when present in excess in cacao soils, or added in too large dosages as salts or sprayed in solution on the foliage, produce characteristic symptoms which should be clearly distinguished from those caused by nutrient shortages (7). For example, a solution containing 4 parts of manganese per million may be beneficial when sprayed onto cacao suffering from manganese deficiency, whereas one containing 10 p. p. m. may be harmful. Similarly, a solution containing 10 p. p. m. of copper may be beneficial, whilst one having 50 p. p. m. may be highly toxic. Cacao is also damaged by excess of common salt contained in saline soils or deposited on the plants by moist sea breezes, and by overdoses of soluble fertilizers, particularly chlorides which produce leaf symptoms resembling marginal leaf scorch caused by potassium deficiency *(22)*.

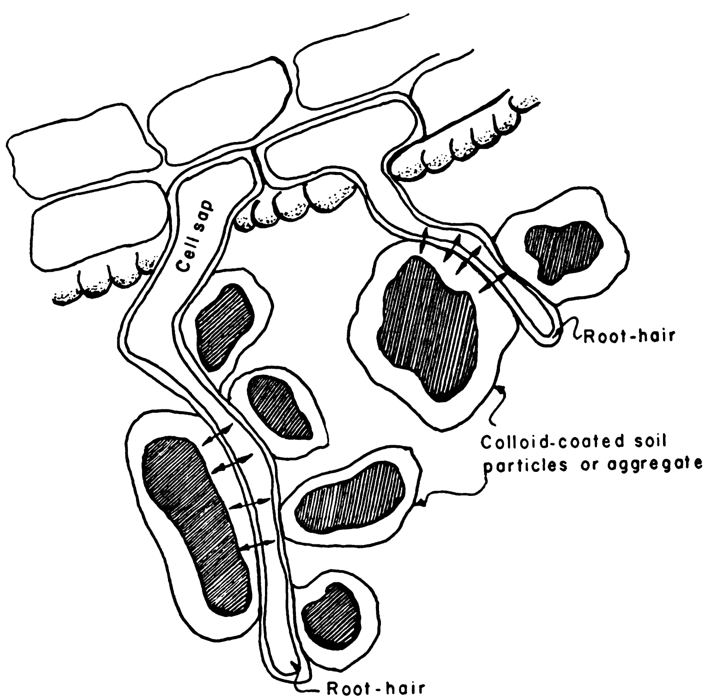
Soil chemical analysis: *Exchangeable bases:* A useful theory of plant nutrition is that the root hairs of plants wrap around the colloid-coated soil particles and strip their surfaces of adsorbed exchangeable bases by substituting hydrogen-ion diffusing outwards from their acid cell sap. (See *diagram)*. This explains why the determination of exchangeable bases (K, Ca, Mg) is a useful method of soil analysis for available nutrients. Phosphorus is not present in exchangeable form in soils but occurs chiefly as free phosforus having different solubilities in water and dilute acids. Phosphorus is therefore usually determined by extraction with acid, as in Troug's method which employs a dilute solution of sulfuric acid as extracting agent. This gives a good correlation with the response of cacao to phosphatic fertilizers although a better correlation is obtained with soils containing insoluble iron and aluminum phosphates by extracting them with stronger reagents. In the following table are given some provisional standard values for assessing reaction, total nitrogen, available phosphate, and exchangeable (available) potash, lime and magnesia (18). They are based on data obtained for cacao soils of Trinidad and West Africa.

PROVISIONAL STANDARDS FOR ASSESSING NUTRIENT STATUS OF CACAO SOILS

(Top 6-ins. layer)

(Imperial College of Tropical Agriculture, Trinidad, 1956)

CATEGORY	pH value	Total N %	C/N ratio	AVAILABLE P_2O_5 (Truog) ppm.	AVAILABLE K_2O (Exch) ppm.	EXCHANGEABLE BASES CaO Mg.eq./100 g.	EXCHANGEABLE BASES MgO Mg.eq./100 g.	EXCHANGEABLE BASES K_2O Mg.eq./100 g.
High	7.5	0.35	11.5	120	260	24.0	6.0	0.55
Medium	6.5	0.20	9.5	60	170	12.0	3.0	0.35
Low	5.0	0.05	7.5	20	90	4.0	1.0	0.20



EXCHANGE PROCESS IN NUTRIENT ABSORPTION
BY PLANT ROOT HAIRS

These standards are, strictly speaking, only applicable to cacao soils having loamy texture (base exchange capacity around 24 mg. eq./100 g.). The figures merely indicate whether the quantitative data obtained by chemical soil analysis denote sufficiency, adequacy or deficiency of the different nutrients determined by standard methods. Recent investigations on mineral cacao nutrition, carried out in Ghana *(5)* and the Belgian Congo *(14)* have shown that magnesium is especially important for cacao growth. The ratio between exchangeable lime and exchangeable magnesia in the more-productive cacao soils (Ochrosols) is around 3.5 and that between lime plus magnesia to potash approximates to 30, whereas, in the less-productive soils (Oxysols) the value for the first ratio is around 5.0, and for the second, about 10.0.

The productivity of cacao soils is also correlated with the numerical value for carbon: nitrogen ratio, the yield being highest for soils having the highest ratio and *vice versa*. This relationship can be explained on the grounds that highly-productive cacao soils possess surface layers that are constantly being replenished by high-ratio organic matter and at a greater rate than the poorly-productive soils whose cacao tree canopies are smaller and less bulky and therefore produce lesser amounts of litter, or have suffered more from erosion *(18)*.

Nutrient antagonism: The excessive concentration of one nutrient may suppress the uptake of another. For example, an excessive amount of potassium may suppress the absorption by cacao roots of magnesium and of zinc and the plant may consequently suffer from shortage of one or both of these two essential nutrient elements. Similarly, excess of soluble manganese may induce deficiency of iron.

Soil analysis and root room: The chemical analysis of soil samples collected at arbitrary depth, for example 0 to 6 inches, has little practical value for tree crops such as cacao whose rooting zone has varying depth. Its main usefulness is that it indicates gross deficiencies of the chief nutrients when the results are compared with arbitrary standards. Consider two sites, A and B, at which are growing cacao trees of equal age and size, and assume that the root room at A is twice that at B. Clearly the soil at B must contain twice the concentration of nutrients, reckoned, say, in grams per 100 grams of soil than the soil at A, but the fact that the trees have attained the same size implies that the *total* amount of nutrients taken up by each tree has been the same. Had soil samples been collected at each site and analized, the conclusion might erroneously have been reached that site B was more likely to produce a larger cacao crop than site A, whereas, in actual fact, because the root room at site A is twice as large as that at site B, the roots of the cacao tree at site A have explored and exploited twice as much soil volume, and so have equalized the total uptake of nutrients. Where the root systems of crop plants occupy equal root room, as is the case of cereals grown in soil plowed to uniform depth, chemical analysis of samples of the surface layer of soil are much more likely to provide reliable comparative data on which to base fertilizer treatments than in the case of tree crops having varying rooting depth.

Relationship between nutrient status and shade: The question of shade provision for cacao depends, not only on water, air and light relations, but also on the nutrient relations and the root room of the soil. When photosynthesis is greatest under high light intensity (full sunlight) the uptake of nutrients should be greatest also in order to translocate and utilize the manufactured carbohydrate by transforming it into protein *(2)*. This necessitates a fully developed root system established in a well-aerated soil adequately supplied with water and containing a plentiful supply of nutrients in readily available form. Under high light intensity, the products of photosynthesis, if not used up in this way because of a gross shortage or imbalance of nutrients, accumulate to such an extent as virtually to poison the plant. The length of life of the leaves is greatly reduced and repeated leaf flushing occurs as compensation. In extreme cases, the peripheral leafy shoots turn yellow and shrivel. The cacao tree consequently develops die-back and eventually assumes a "stag-headed" appearance. The leaves are progressively shed and the tree ultimately dies *(20)*.

Under the protection of shade, the demand on the supply of nutrients in the soil is greatly diminished because of reduced photosynthesis and reduced transpiration. It follows therefore that shade protection is needed most where soil conditions are least satisfactory, but that it may be dispensed with altogether where they are fully adequate, in particular, where root room is large and nutrient supply is plentiful. As the cacao tree grows from the seedling stage, the degree of natural self-shading increases and the relationship between light intensity, transpiration, overhead shade requirement and nutrient requirement changes also. Not only will there be an increasing demand for nutrients, but also for an alteration in the ratio between the quantities of the different nutrients that are available to the plant, for example, there will be less need for nitrogen and greater need for potassium *(20)*.

An important effect of shade is that it slows down the rates of nutrition and metabolism and therefore of growth of the cacao tree so that shading enables a crop to be obtained when cacao is grown in soils having low fertility. It also "buffers" the tree against the harmful effects of sudden changes in the enviroment.

Leaf analysis: The chemical analysis of leaf tissue and of leaf ash has proved to have considerable value for determining the nutrient status of crop plants and soils, and for diagnosing approximate fertilizer requirements. The main drawback to its satisfactory application to cacao is the difficulty of procuring leaf samples whose chemical composition truly represents the nutrient status of the tree *(8)*. The chemical composition of cacao leaves varies greatly depending on the content of available nutrients in the soil, as well as other environmental growth factors, the age and position of the leaves and the time of the year when they are collected *(12)*. Results so far obtained have indicated that the chemical composition of leaves collected in a certain way reflects the differences in fertiliser treatment between plots in field experiments, but a satisfactory technique for accurately diagnosing the fertilizer requirements of a single cacao tree or group of trees still remains to be elaborated *(16)*.

Pot tests: These provide a simple and useful means of comparing the nutrient status of soils in the greenhouse. The essential feature of the method is that, through careful manipulation and packing, the physical conditions and the root room of each pot-full of soil are identical. Care is taken to ensure that each pot receives uniform watering. When this is accomplished, then all the ecological factors, except the nutrient-supplying capacities of the soils that are being compared, are assumed to be equal. The customary procedure is to add fertilizers in amounts equivalent on an area basis to large field dressings and in various combinations, for example, O N P K NP NK PK NPK (8 treatments) or, more simply, O NP NK PK NPK (5 treatments). A standard test plant, for example Sudan grass *(Sorghum)* rice, tomato, lettuce, radish or sunflower, is grown in each pot and the dry-matter yield of each culture is determined at a suitable stage of growth such as flowering. The results are expressed as weight percentages of the yield of the no-treatment culture. Photographs are taken of the cultures at different stages of growth.

In order to test the effect of liming, a second series of pot tosts is carried out. Pot tests may also be used for determining possible deficiency of magnesium and of minor element deficiencies but, in this case, the fertilizer substances used must be chemically pure, and water which has been highly purified must be used throughout the whole period of growth. The minor elements should preferable be added as chelates to ensure absorption. Pot tests form a suitable and, in cases of abnormal soils, essential preliminary to fertilizer field experiments, insofar as they identify any deficient nutrients. They also supply reliable information regarding the best combinations and the most effective quantitative levels of fertilizers to be employed in field experiments, particularly if they are set up on the factorial plan.

The nutrient requirements of the cacao tree are being directly investigated by the use of large pots at Yangambi in the Belgian Congo *(14)*. The ultimate object is to formulate ideal fertilizer mixtures for cacao. Small clonal plants were grown in pure quartz sand with a complete nutrient mixture including minor elements together with extra dosages of potassium (K) calcium (Ca) and magnesium (Mg) in association with nitrate (N) sulfate S) and phosphate (P) comprising nine separate treatments in all. The plants were weighed after one year's growth. The results showed that the plants which had been given extra magnesium together with extra nitrate weighed more than eight times as much as the control plants which had been given only the basal treatment. Plants grown with extra potassium gave the lowest yields; thus:

Control	N-Mg	S-Mg	N-Ca	P-Mg	P-Ca	S-Ca	N-K	S-K	P-K
100	837	748	676	600	543	439	348	252	39

Fertilizer needs of cacao: The amounts of nitrogen (N) phosphorus (P) and potassium (K) removed from the soil by a 500 lb. per acre crop of dry beans are 12, 3 and 10 lb. respectively *(1)*. These are equivalent to a fertilizer dressing of 60 lb. of ammonium sulfate, 40 lb. of single calcium superphosphate and 25 lb. of potassium sulfate, or 125 lb. of mixed fertilizer per acre, assuming that the husks are left on or returned to the land. The husks themselves contain 10, 1 and 22 lb. of nitrogen, phosphorus and potassium respectively, equivalent to 50, 14 and 55 lb. of the three standard fertilizers. In order to produce really large crops of cacao of magnitude 2000 lb. per acre of 300 trees (which is the ceiling for cacao production) four to eight times these quantities would have to be supplied by the soil or added as fertilizer, that is 500 lb. per acre of mixed fertilizer, which is quite a large dressing. The need for fertilizers for high production must be accepted in growing the cacao of the future in all but the most naturally fertile soils.*

Fertilizer experiments on cacao: Experience has shown that fertilizer experiments on *old* shaded seedling cacao seldom give statistically significant differences due to fertilizer treatment, mainly because of soil heterogeneity as well as the great variation in the bearing capacity of the individual trees *(17) (21)*. In order to demonstrate significance, differences in yield of the order of 25 or 30 percent are required in fertilizer xprimnts on old cacao. Nevertheless, spectacular results have often been obtained in Trinidad and elsewhere with fertilizer experiments on mature derelict cacao. For example, in cases of soils highly deficient in phosphate or in potash, increases in yield of 50 to 100 percent have been obtained with phosfatic and potassic fertilizers. The yields of the no-treatment plots (controls) however, are usually so low (around 120 lb. cacao per acre) that the increase in yields obtained is seldom remunerative. Greatest proportionate response is given by trees bearing the fewest pods.

It was found in the early experiments in Trinidad *(17)* that shaded cacao did not respond to nitrogenous fertilizers but responded markedly to potassic fertilizers. This was partly explained by the fact that the shade trees are leguminous and the bacteria in their root nodules fix large amounts of atmospheric nitrogen.** On the other hand, unshaded cacao frequently responded greatly to nitrogenous fertilizers and manures. The failure of old cacao in Trinidad in the past to respond regularly to fertilizers and, in cases where response was obtained, to produce yield-increments which were not commensurate with the amounts of fertilizers used, implies that some environmental growth factor other than nutrient supply, was limiting the yields. This is believed to be lack of root room, or unsuitable water and air relations of the soil which have been found to be highly unsatisfactory at many of the sites where the fertilizer experiments were carried out *(10)*.

The effect of fertilizers on the growth and production of young clonal cacao is now being investigated in Trinidad and in Ghana. In a short term experiment at I. C. T. A., Trinidad, marked responses were obtained from NPK fertilizer applied to young cacao under varying degrees of shade *(12) (20)*. The results showed that young cacao has a greater requirement for nitrogen when grown under high light intensities than when grown under shade. This may partly explain why shaded cacao has usually failed to respond to nitrogenous fertilizers in the field.

A long-term large-scale experiment begun in 1949 at River Estate in Trinidad, in which shade and no-shade, close and wide spacing and different combinations of NPK fertilizers constitute the variable factors, has already given marked response to nitrogenous fertilizer applied to unshaded cacao, and less-marked response with

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* Recommendations for fertilizer usage in the commercial growing of cacao, based on these considerations, are given in Chapter 16, in which the kinds and quantities of fertilizers for cacao are discussed.

** It has been found in Trinidad that 50 Immortelle shade trees growing on one acre of land contribute about 20 lb. of nitrogen by their fallen flowers alone, and possibly an equal additional amount by their fallen leaves and twigs. This equals a total of some 200 lb. of ammonium sulfate fertilizer per acre.

cacao shaded with Immortelle *(Erythrina Poeppegiana,* a leguminous tree). The response in the latter case entirely disappeared after 5 years under dense shade with close spacing *(12).*

Since 1945, clonal cacao in Trinidad has been planted in fields undergoing rehabilitation as well as in new plantings, and fertilizers have been systematically applied in most cases. The response has been variable; yields have ranged from 300 to 100 lb. per acre of dry cacao from trees varying in age between 7 and 9 years. Low yields in some instances have been attributed to the absence or inadequacy of shade, but high yields appear to be invariably associated with soils having especially good physical properties *(12).* The importance of good management and the choice of the best planting material was indicated by the results obtained in the field.

Fertilizer experiments carried out in Ghana *(2)* have given variable results on young cacao. In one recent experiment at W. A. C. R. I., a mixed NPKMg fertilizer increased the yield of shaded Amelonado cacao by over 40 percent. The removal of shade alone gave an increase of 66 percent without fertilizer addition, but with fertilizer, a yield of 150 percent more than that given by the control plot was obtained. Other fertilizer trials have been started in different parts of Ghana, since it is thought to be unlikely that areas where cacao trees have had to be removed because of the ravages of virus disease will again support new plantings without the use of appropriate fertilizers applied in the right amounts.

Conditions requisite for response to fertilizers: In order for cacao to respond adequately to fertilizers added to the soil, the following conditions must be observed:

(1) The cacao tree population should be homogeneous
(2) The water supply of the soil should be adequate
(3) The retentivity of the soil for fertilizer nutrient components should be high
(4) The level of natural soil fertility should be low
(5) The fertilizers should be applied properly.

These conditions will be considered in turn.

(1) *Homogeneity of tree population:* The cacao tree population must be homogeneous, that is, the stand must be uniform with every picket or planting site occupied by a bearing tree not damaged in any way nor affected by diseases and pests. The most homogeneous population is one which comprises a single clone grown from selected seedlings, cuttings, buddings, or marcots, carefully planted and established under temporary shade. Usually, however, the planting of one clone only is not advised for several obvious reasons but, where more than one clone is planted, a regular pattern of planting should be followed so as to ensure uniformity.

(2) *Water supply:* Unless the water supply of the soil is maintained continually at a little above field capacity, the uptake and utilisation of nutrients, both those naturally liberated by mineral weathering and the decomposition of soil organic matter, as well as those adde das fertilizer, cannot proceed satisfactorily. An adequate supply of water can only be ensured by a regular and well-distributed

rainfall which exceeds in magnitude the value of the potential evapotranspiration at all times of the year. If a dry season occurs, supplementary irrigation, preferably applied by the sprinkler system, should be provided if possible, except where a high permanent water table occurs in the soil.

(3) *Nutrient retentivity:* Basic nutrient entities or ions are retained by the colloidal components of the soil through the operation of the base exchange process. Thus the ammonium-ion (NH_4) and the potassium-ion (K) added in fertilizer salts replace calcium-ion combined at the colloid surfaces and so become firmly held against the leaching effects of percolating water. In this form, cacao roots can liberate and readily absorb them, as has already been explained. Ammonium-ion can be utilised directly by the cacao tree, as by most forest trees, or it may be oxidised *in situ* to nitrate and some of it absorbed and utilized in this form. Nitrate, not being retained by soil colloids, is partly lost by rapid leaching under heavy rainfalls. Even colloidally-held ions like those of ammonium and potassium are slowly leached downwards by percolating natural water containing carbonic acid, but, where certain clay minerals are present, potassium may be so firmly fixed in the mineral lattice that plant roots no longer are capable of releasing and absorbing it.

Phophate added as soluble fertilizer (super-phosphate) is usually retained in the surface layer of the soil of thickness no greater than a fraction of an inch but, in this case, it is not generally retained by surface exchange but simply by transformation or reversion into mineral calcium phosphate.

In the case of soils containing appreciable amounts of colloid, such as clays and loams and humic soils, fertilizer retention varies with the base exchange capacity whose magnitude ranges in such soils from about 10 to 30 milligram equivalents per 100 grams of soil (m. e. 100 g.). In the case of soils containing considerable amounts of organic colloid (humus) the base exchange capacity is higher, up to 50 or 60 m. e. 100 g.

Sandy cacao soils having extremely low base exchange capacities do not retain ammonium nor potassium nor other basic nutrient-ions and therefore must be treated with fertilizers in small doses added several times a year, unless they possess a well- marked organic layer in which case the added fertilizers are retained therein and are taken up by the surface feeding roots. Sandy cacao soils lacking organic matter are difficult to manage and their improvement by applying fertilizers is seldom economic unless organic matter is first incorporated into their surface layer.

(4) *Natural fertility:* A soil which is already highly fertile by virtue of a high content or organic matter or of fresh mutable mineral particles would not be expected to respond to fertilizers as well as one deficient in these components. Nevertheless, in order to ensure maximum crops of cacao, fertilizers are required even for soils of naturally high nutrient supplying capacity. The values for exchangeable (available) potassium, calcium and magnesium, and for available phosphate and total nitrogen in cacao soils having high, medium and low nutrient status, are given in a table above. It should be noted that the value 100 p. p. m. corresponds to 200 lb. per acre 6 ins. of soil.

(5) *Method of fertilizer application:* Fertilizers that are carelessly applied, or that are applied at the wrong time, are often washed away by rain without penetrating into the soil and becoming retained. It is therefore best to apply them at the end of the dry season or during dry spells and to rake over the litter on which they are spread so as not to expose them to direct rainfall. Exposure to highly humid air causes a certain amount of solution and penetration, and thus aids in fertilizer conservation.

SUMMARY

1. Plant nutrients, except nitrogen, originate in the minerals of rocks. Nitrogen comes from the air and is fixed by micro-organisms.
2. Leaching depletes soils of bases and causes soil acidity. The formation of high acidity is accompanied by the development of aluminum toxicity.
3. Excessive soil alkalinity, caused for example by overliming, is harmful because it immobilises essential minor elements.
4. Soil reaction affects soil micro-organisms, both harmful and beneficial.
5. Nutrient deficiencies are revealed by distinctive leaf symptoms. Those of cacao are briefly described. Methods for correcting deficiencies are mentiond.
6. Soil chemical analysis, including base exchange determination, is briefly discussed and its value for assessing the nutrient status of cacao soils is considered.
7. The importance of root room in interpreting the results of chemical analysis of cacao soils is stressed.
8. The relationships between the nutrient status of cacao soils and the effects of shade in cacao growing are explained.
9. The possible application of foliar analysis for diagnosing the nutrient status of cacao soils is examined.
10. The value of pot tests as a preliminary means of ascertaining the proportionate amounts and kinds of fertilizers to use in field experiments is considered.
11. The specific fertilizer needs of cacao are given, partly based on the average composition of cacao beans and pod husks.
12. Experience with fertilizers applied to mature and old cacao trees is recounted. Failure to respond has been traced mainly to unsatisfactory physical soil conditions and to heterogeneity in the tree population.
13. Some recent results obtained in fertilizer expriments on young clonal cacao in Trinidad and Ghana are presented.
14. The five main conditions requisite for response to fertilizers applied to soil on which cacao is growing are mentioned and discussed.

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CHAPTER 6

THE LIGHT RELATIONS OF CACAO

The effects of solar radiation on the physiological processes of plants will be considered under two main headings; (A) thermal or heat effects, and (B) the effects of illumination.

(A) THERMAL EFFECTS

There are three important plant processes that are directly affected by the temperature of the air and of the soil, namely (1) growth of plant tissues (2) metabolic activity and (3) transpiration. The effect of temperature on these three processes is a manifestation of the transference of the sun's radiant heat to the plant through the medium of the air and of the soil.

(1) *Growth:* The effect of heat on the growth of plant tissues has already been considered in regard to cacao when the temperature relations of the tree were discussed in Chapter 3, in particular, the changes in girth of the trunk. A close correlation between air temperature and trunk growth was found to occur at "La Lola" in eastern Costa Rica where soil water supply is abundant and regular, but such a relationship was not found to occur in Trinidad where there are distinct wet and dry seasons, causing great irregularity in soil water supply.

Cacao pods grow more quickly in Ghana during the hot wet season (March to June) than during the cool dry season (July to September). It was found that 10 weeks' old pods were 9.9 cm. long when the daily maximum temperature averaged 90ºF but only 8.5 cm. long when it was 80ºF *(1)*.

(2) *Metabolism:* Processes such as fruit ripening which involve enzyme activity are greatly accelerated by rise in temperature. Thus, in the case of cacao, it has been found that developing pods exposed to direct sunlight mature more rapidly than those in the shade, and that, in general, pod-ripening is more rapid during the hotter months of the year.

(3) *Transpiration:* This has already been considered when the water and air relations of cacao were being discussed. Whilst the temperature of the surrounding air is one of the chief factors determining the rate of transpiration of the leaves of plants, direct sunlight greatly increases the

transpiration rate by raising the temperature of the leaf surfaces, and consequently of the air immediately in contact with them. Actual measurement has shown that, in the case of cacao growing in Costa Rica, the magnitude of the rise of leaf temperature may be as much as 18°or 20°C (32° or 36°F) and that the corresponding increased rate of transpiration may be two or three times as great as the rate of transpiration of cacao leaves in the shade *(3)*.

(B) ILLUMINATION EFFECTS

There are three important plant processes that depend on the effects of direct illumination, namely, (1) photosynthesis, (2) movements of stomata and (3) enlargement of the cells of certain plant tissues.

(1) *Photosynthesis:* Light is essential to the process of photosynthesis whereby carbohydrate is manufactured in illuminated leaves from carbonic oxide gas and water through the agency of chlorophyll. Carbonic oxide enters the leaves through the stomata. The stomata of plant leaves are normally wide open under direct sunlight in the early morning and thus allow free entry of carbonic oxide gas, but they close up later in the day, either because of the effect of changing light intensity on the turgidity of the guard cells which regulate the size of their apertures, or because of the loss of water from the leaves by transpiration, enhanced by a reduction in the water supply of the soil.

The rate of photosynthesis by the leaves of the cacao plant has been determined by weighing at regular intervals young seedlings or cuttings that had been subjected for varying lengths of time to light of different intensities. The results obtained, expressed as net assimilation rate in grams of dry matter per square decimeter of leaf surface produced per hour, were as follows:

Trinidad

Reference *(10)*:	20 percent of full sunlight, 0.099 g. dm^2 hr.
Reference *(1)**:	75 percent of full sunlight, 0.188 g. dm^2 hr.
	10 percent of full sunlight, 0.042 g. dm^2 hr.

Ghana

Reference *(6)* :	20 percent of full sunlight, 0.072 g. dm^2 hr.

Compared with results obtained under similar conditions with temperate crop plants such as potato and apple, these values are low, being only about one-quarter as much but, compared with certain other tropical crops, they are somewhat high, for example, coffee gave results about two-thirds as high and coconut only one-sixth as high *(9)*. These differences between the photosynthetic activity of cacao and other tropical crops as compared with temperate crops cannot be attributed to differences in light

* Although published in an article describing the environmental requirements of cacao in Ghana, these experimental results were actually obtained in Trinidad.

intensity since this is on the average about the same in tropical as in temperate regions *(1)*. The lower net assimilation rate for cacao leaves grown at the lower light intensities indicates that photosynthesis is greatly retarded by shading. On the other hand, it is compensated for by the greater leaf area *(7)*.

The features of cacao leaves that have developed under different light intensities vary greatly *(7)*. Under full sunlight the leaves are small, pale and thick, with short internodes and long stipules. They are shed early. By contrast, leaves produced under heavy shade are much larger and often attain a length of 20 to 24 inches (50 to 60 cm.). Their color is darker; they are thinner and heavier, and they contain a higher proportionate amount of water, reckoned as percentage dry weight *(11)*. Their stomata are less numerous per unit area because the epidermal cells are larger in leaves produced under shade *(4) (11)*.

As the cacao tree grows, self-shading takes place. Leaves occurring over the periphery receive light at maximum intensity, assuming that artificial shade is not provided, and their rate of photosynthesis is great. Leaves occurring on the inside of the tree receive light of much lesser intensity and their rate of photosynthesis is low. When the outer layer of the canopy is disrupted by leaf shedding caused by large fluctuations or irregularities in the environmental factors, or by the ravages of diseases and pests, the leaves of inner parts become exposed to new conditions for which they are not adapted. Consequently they also suffer injury and leaf shedding and die-back progressively occur and the tree assumes a stag-headed appearance *(11)*. This often occurs when the shade trees in a field of mature cacao are removed suddenly.

The effects of full exposure to direct sunlight are diminished during periods of cloudiness or haze, so that the protective effect of shade is less evident and less important and the provision of shade trees is less necessary in regions such as the Atlantic Coastal Plain of Costa Rica and the Riverine Cacao Belt of Ecuador and also the cacao belt of Ghana where lengthy periods of cloudiness or of haze occur*, or in areas sheltered by high ridges so that sunshine illuminates the cacao trees for only a small part of the day, as in Grenada in the West Indies.

Measurements made out in the open with a light meter at the Pichilingue Experiment Station in Ecuador gave values for light intensity ranging from 950 to 3000 foot candles during the day (8 am. to 3 pm.) in the cloudy "garua" period of the year. The intensity of full sunlight at this time varied from 4500 to 6000 f. c. The critical value for the growth of plants like sunflower and tomato is stated to be about 450 f. c. which is considerably lower than the light intensity normally incident during cloudy days in the cacao-growing region of Ecuador. Under banana shade, the light intensity varied from 310 to 450 f. c. These results suggest that shade trees might with advantage be dispensed with in Ecuador or at least heavily pruned during the cloudy part of the year which occurs in June, July and August.

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* The mean duration of sunshine, reckoned in hours per day, is 4.3 for "La Lola", Costa Rica and 4.6 for Tafo, Ghana, in contrast to 7.3 for I. C. T. A., Trinidad and 6.0 for Uruçuca, Brazil.

It is generally conceded that, for best growth and development, cacao *seedlings* must be grown under dense or fairly dense shade, and experience proves that without it seedlings shed their leaves too frequently and often die prematurely. The chief reason for the failure of cacao seedlings grown is full sunlight is evidently the small amount and small surface area of leaf tissue that is produced, rather than the rate of photosynthesis of the leaves which indeed is usually higher in unshaded than in shaded seedling leaves *(7)*. The most suitable light intensity for cacao seedlings has been shown to be about 25 percent of full sunlight *(4)*. The amount of light may gradually be increased to 50 percent and later, *if all other environmental factors are favorable,* it may be increased to full sunlight when complete self-shading has been attained, the overhead shade being systematically removed *(4) (11) (12) (13)*.

(2) *Movements of stomata:* The stomata of cacao leaves occur solely on their lower surfaces. They vary in number from 35,000 to 60,000 per square centimeter (3). The thickness of the walls of the guard cells of the stomata is greatest on their concave sides. When the guard cells are turgid, the curvature is accentuated and the size of the aperture is enlarged. When the guard cells are flaccid the reverse movement occurs, and the size of the aperture is diminished. The changes in turgidity of the guard cells depend on their water content. Under normal growth conditions when acute water shortage in the plant tissues never occurs, the turgidity of the guard-cells of the stomata is controlled by the action of light. When strongly illuminated, the guard cells absorb water through the osmotic activity of the soluble products of photosynthesis that accumulate in the cell sap, their turgidity is enhanced, and the size of the aperture is maintained. When shaded, the guard cells lose water, their turgidity is diminished, and the apertures close. These normal movements of stomata are, of course, greatly modified when there is a marked shortage of water in the environment and when rapid transpiration is going on unaccompanied by a correspondingly large uptake of water by the roots from the soil. Under these circumstances, loss of turgidity occurs and the stomata close, even if the leaves are exposed to strong sunlight *(2)*.

By applying the oil-infiltration method for assessing the degree of stomatal closure described in the previous section, it has been shown that the stomata of cacao leaves exposed to the most intense direct illumination (for example, 13,500 foot-candles which measures full sunlight on a bright summer day at Turrialba, Costa Rica) remain completely open and transpire freely so long as the water supply at the roots is plentiful. By contrast, the stomata of coffee leaves partially close whenever the intensity of illumination exceeds 8,000 or 8,500 foot-candles *(3)* apparently because of the effect of excessive transpiration. In the shade, they remain always open, however,, provided the light intensity is not too low. In the case of cacao, the leaf stomata begin to close when the light intensity is reduced by shade to less than 500 to 700 foot-candles, which is about 5 percent of maximum tropical sunlight. This causes the rate of photosynthesis to fall to a low value. Under ordinary circumstances, the stomata of cacao which is not too densely shaded begin to open at about 6 a. m., and maintain their maximum size between 8 a. m. and 4 or 5 p. m., after which time they begin to close because of the effect of diminishing light intensity *(3)*. They are completely closed by 6.00 or 6.30 p. m. If cacao were a typical "shade plant", the stomata would begin to close immediately after maximum illumination had been attained *(3)*.

(3) *Cell enlargement:* Growth in size of a plant, due to the enlargement of the cells comprising certain of its tissues, in general is least when the light intensity is greatest. This is explained by the fact that the activity of growth hormones (auxins) is diminished or inhibited by direct illumination *(3)*. It is for this reason that the leaves of cacao trees grown under shade are much larger than those of cacao trees grown without shade. Similarly, the branches of shaded cacao trees are thinner and longer, and their stems "jorquette" or subdivide at a greater distance from the ground than do the branches and stems of unshaded cacao. The cacao tree, just as other plants, grows mostly during the night, because the cells of its cambial tissues enlarge greatly in the absence of light but cease growing when exposed to light of high intensity.

(4) *Survival capacity of cacao leaves:* When detached cacao leaves are placed in closed vessels illuminated by light of low intensities and the atmosphere is maintained at 100 percent humidity, they show different death-rates in accordance with the actual intensity of light *(3)*. After four weeks, 95 percent of the leaves subject to this treatment in an experiment were still alive under a light intensity of 17 to 20 foot candles, but all were dead when the intensity was 1 to 2 foot-candles. Under similar circumstances, coffee leaves showed 100 percent survival at all light intensities down to 4 foot-candles, and 85 percent were still alive after 4 weeks at intensity 1 to 2 foot-candles. These results prove that coffee is more adapted to conditions of low light intensity than cacao; they provide evidence that cacao is not likely to thrive under too dense shade.

(5) *Leaf-burning in cacao:* In certain localities where cacao is grown, for example, eastern Costa Rica and Bahia, Brazil, leaf-burning is a common feature and has been attributed to direct insolation or sun-scorch. Recent investigations have shown, however, that it is caused by heavy leaf infection by certain fungi, notably *Colletotrichum* (3) and *Phytophthora (8)*. The damage caused by fungal infection is not directly attributable to illumination but rather to the fact that, where the degree of exposure is greatest, dew is deposited during the night onto the cacao leaves because of the lowering of temperature by heat radiation. Burning of this sort does not occur if the cacao trees are regularly sprayed with fungicides, or if they are grown under shade.

Infestation by certain insect pests, for example, *Monalonion,* is often more severe on cacao leaves exposed to full sunlight than on leaves protected by shade, and may also be the cause of a kind of burning observed in Bahia *(3)*. It too disappears when insecticides, such as BHC, are applied. Similarly, thrips infestations have been noted to be most severe on under-nourished cacao leaves exposed to direct sunlight *(3) (5)*.

(6) *Photoperiodism:* The variation in day length within the cacao zone is small and generally not greater than one hour between winter and summer. For example, in Trinidad (latitude 10ºN) the longest day is 12 2/3 hours and the shortest is 11 1/2 hours. The duration of daylight is a little greater than 12 hours between March and September, but falls later to its lowest value in December. Because of its low magnitude, natural photoperiodism does not apparently greatly affect the physiological processes of the cacao tree, for example, leaf flushing occurs during both short-day and long-day periods. Some effect on trunk growth by photoperiodism was suggested by the data obtained in the investigations carried out at "La Lola" in eastern Costa Rica (See Chapter 3) and photoperiodism was invoked to explain the fact that trunk growth is greater in June-July than it is during August-September, even though the air temperature is the same during both periods, because day length is actually a little greater in June-July.

The possible significance of natural photoperiodism in the flowering and fruit setting of cacao has not yet been specifically investigated.

Recent investigations carried out in the greenhouse,* however, have shown that young seedling cacao plants show a remarkable response to a special sort of photoperiod. Plants exposed to a 12-hour light period broken in the middle by a one-hour dark period grew to a greater length than similar plants that were not subjected to a light-break. The possible effects of varying the length of the dark interval remain to be studied, as well as the degree of response to photoperiod of fan cuttings as compared with seedlings of the same clones and of both seedlings and cuttings of different clones. Although the results obtained in these experiments do not have any direct bearing on commercial cacao growing, they indicate possible means of expediting the growth of hybrid plants and therefore of producing earlier fruits and seeds which would save time in cacao breeding.

SUMMARY

1. The effects of solar radiation on the cacao tree are: (A) *Thermal effects* (1) growth (2) metabolism and (3) transpiration; (B) *Illumination effects* (1) photosynthesis (2) movements of stomata and (3) cell enlargement. Certain of these have already been considered in a previous chapter.

2. The rate of photosynthesis (net assimilation rate) in cacao is lower than that in temperate crop plants but it is commensurate with that of some other tropical crops. It is lower in shaded than in unshaded cacao.

3. The size of a cacao leaf varies with the amount of shade, being greatest in dense shade. The larger leaf size partly compensates for the lower rate of photosynthesis under shade.

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* Dr. A. A. Piringer, U. S. D. A., Beltsville, Md., U. S. A., Oct. 1959, private communication.

4. Self shading occurs in the mature cacao tree and greatly modifies its light relations.

5. When shade trees are suddenly removed from a field of mature cacao, or when the environmental factors fluctuate excessively, or when diseases or pests attack the trees, the outer layer of the canopy often becomes disrupted and leaf-shedding, die-back and "stag-headedness" occur. These effects are not so marked in regions where cloud or haze or hill ridges reduce the period of insolation or diminish light intensity.

6. Cacao seedlings grow best under shade (20 percent of full sunlight). Intense insolation kills them because it greatly reduces leaf size and causes too-frequent leaf shedding.

7. Stomatal movement in cacao that is not suffering from restricted water supply nor from excessive transpiration is controlled by illumination.

8. The activity of growth hormones is diminished by illumination which explains the reduced size of cacao leaves exposed to direct sunlight, as well as the etiolation of the stems of densely shaded cacao.

9. Evidence based on a fuller understanding of the influence of light on the stomatal movements, the survival capacity and the relationships between fungal and insect attack and burning of the leaves of cacao, as contrasted with true shade plants, indicates that, when all other environmental growth factors are favorable, cacao can be grown in full sunlight without fear of damage.

10. Photoperiodism is not marked in cacao though variations in the rate of growth of the trunk of the cacao tree may partly be attributed to photoperiodism. Increased growth of cacao seedlings has been induced by breaking a 12-hour light period by a one-hour dark period. The effect might be applied in plant breeding.

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CHAPTER 7

CHERELLE WILT OF CACAO

INTRODUCTORY

Cherelle wilt of cacao is the name given to the cessation of growth, followed by the drying out and shrivelling of young fruits. The pods turn yellow and then black. They later become mummified and infested with fungi. Generally the wilted fruits remain on the tree but sometimes, when completely dry, they fall to the ground. At the onset of wilt, the pod stalk or pedicel also shrivels. Shedding is not preceded by the development of an absciss layer. Young cacao pods appear to be particularly susceptible to wilt when about 50 days old. They are then about 2½ ins. (6 cm.) long. The proportionate amount of wilt varies greatly from tree to tree and from one place to another. Recorded figures range from 19 to 92 percent of the number of fruits that set at River Estate in Trinidad, and from 22 to 88 percent at Tafo, Ghana, West Africa.

RESEARCHES ON CHERELLE WILT

Most of the original observations on which the later specific investigations on cherelle wilt have been based were made in Trinidad during the years 1930-1940*. They have evoked various theories, some of which have survived the test of scientific study whilst others have been discarded. It was early suggested that cherelle wilt is induced by incomplete pollination, or by the initiation or onset of growth of the embyro which occurs when the fruits are about 50 days old. That neither of these is really an important cause was proved by hand pollinations carried out at regular short intervals throughout the year *(34)*. Hand pollination smooths out the effects of discontinuous flowering, setting, flushing and pod-wilting and so eliminates any physiological crisis or shock that results from these processes. It was therefore concluded that the cause of wilt is to be sought in the physiological state of the tree rather than in the biochemical condition of the developing fruit *(34)*.

In support of this contention, the effects of chemical fertilizers on the amount of wilt, which were first examined in Trinidad in 1932 *(26)* and subsequently

* *See* Annual Reports on Cacao Research, I. C. T. A., Trinidad, Nos. I to IX, inclusive, published in the years 1932 to 1940, in Trinidad.

tested in large-scale fertilizer experiments in 1934 and 1935 *(29) (30) (27) (28)* and again in 1937 *(35) (5) (7)* will be mentioned. It was found that potassic fertilizers reduced the amount of cherelle wilt when applied to cacao trees growing in a potassium- deficient soil. Wilting was found to be more severe in self-compatible cacao clones than in incompatible clones *(25) (35) (5) (6) (7)* although, in self-compatible clones, many more cacao pods are set so that their final yield is greater.

Among the various causes believed to be responsible for cherelle wilt, it is now generally agreed that fluctuations in environmental growth factors have great importance because, in most cacao growing areas, pod wilting is closely associated with leaf flushing which, as has already been shown, occurs when soil moisture supply and soil aeration are near the optimum. *(14) (15)* A strong positive correlation was established between the amount of wilt and the intensity of leaf flush *(26) (31)*.

In order to decide definitely the extent to which environmental circumstances are responsible for cherelle wilt, the most logical procedure would perhaps be to consider first the results of investigations carried out in eastern Costa Rica where the soil moisture factor is less variable than in Trinidad.

(1) COSTA RICA

The first investigation on the cause of cherelle wilt to be carried out in Costa Rica comprised a field experiment, laid down at La Lola in 1950, to tests the effects of fertilizers on cherelle wilt. It involved a black of 120 seedling cacao trees, 32 years old, which were stripped of pods before the fertilizers were applied *(4)*. Fortnightly counts were made of the number of healthy and of wilted fruits. The fertilizer treatments were potassium sulfate and superphosphate, added singly in one and in two applications, and also applied together with sodium nitrate in two doses. The results obtained were compared by the analysis of variance. It was found that cherelle wilt could not be attributed to deficiency of potassium nor to that of phosphate nor nitrate in the soil of the experimental area. The soil at La Lola is a nutrient-rich loam and, as has already been stressed, the moisture supply is probably adequate throughout the year because of the regular high monthly rainfall. Cherelle wilt at La Lola was consequently thought to be mainly caused by fungal diseases and leaf hopper insects (Membracidae). It was reduced by spraying with Bordeaux mixture. The fungus chiefly responsible was later shown to be *Phytophthora palmivora (33)*.

Another investigation carried out at La Lola during 1951 to 1953 *(3)* involved the fortnightly recording of the number of wilted cherelles on 40 cacao trees 35 years old and the collection of corresponing meteorological data for rainfall, air temperature and hours of sunshine. In addition, records of leaf flushing were kept and measurements of the rate of growth of the tree trunks were made with dendrometers. The numerical results were compared by statistical calculation. The data showed marked irregularity in the incidence of cherelle wilt throughout the year. The greatest amount of wilting occurred during or just after periods of heavy leaf flush which generally takes place at La Lola in February and March and again in September and October. At these times, trunk growth is checked

Figure 1. Cherelle Wilt in Cacao.

or diminished. A highly significant negative correlation (r = — 0.314) was established between trunk growth and cherelle wilt and a highly significant negative correlation (r = —0.336) was also established between intensity of flush and trunk growth two weeks after.

The relationship between trunk growth and environmental factors had previously been evaluated at La Lola and it had been found that trunk growth was positively, though not significantly, correlated with air temperature, and negatively, though not significantly, correlated with hours of sunshine. This last named relationship was explained by the effect of direct insolation on transpiration which is enhanced by rapid rise of leaf temperature and thus reduces the moisture content of the trunk tissues, causing them to contract. Trunk growth was found to be positively, though not significantly, correlated with rainfall, so that, within limits, increasing rainfall should cause increased trunk growth and should reduce or prevent cherelle wilt. During the period of greatest rainfall in late October and early November when over 20 inches of rain fell in two weeks, trunk growth was completely checked and, at the same time, cherelle wilt showed its highest incidence. This result was attributed to waterlogging which reduces soil aeration and therfore adversely affects the uptake of water by the roots of the cacao tree. These various inter-relationships suggest that the incidence of cherelle wilt is at least partly determined by environmental growth factors and is reduced when these factors favor the steady growth of the cacao tree.

Other investigations of a different nature were also carried out at La Lola in 1951. These concerned the relationship between the formation and translocation of carbohydrate and cherelle wilt *(2) (3)*. The method used was to ring the stems or branches of cacao trees carrying cacao pods of different ages by removing a circumferential strip of bark, either above or below, or both above and below, the points of pod attachment. It was found that fruits up to 12 months in age wilted within 3 or 4 weeks after ringing. This suggested that wilting is caused by failure in the supply of carbohydrate to the developing pod. In other ringing experiments, a strip of bark was removed from each of 20 branches carrying varying numbers, ranging from 3 to 15, of fully-grown leaves, each branch also bearing a single healthy young cacao pod. It was found that the least number of leaves needed to sustain the normal growth and development of a cacao pod varied from 6 to 10, for cacao growing under shade at La Lola.

(2) TRINIDAD

An attempt was made in 1939 to identify the environmental factor or factors mainly responsible for cherelle wilt at River Estate, Trinidad *(9)*. Fourteen trees, 26 years old, consisting of budded and grafted clonal scions of unknown stocks, were kept under weekly observation. Each new fruit was labelled and its development was followed. Weekly determinations of soil moisture were also made. Rainfall was measured and air temperature and air humidity were recorded by means of a thermohygrograph. Growth curves for each labelled pod were constructed, from which the date of setting and the age of each wilted pod could be ascertained.

The records showed that a caaco tree can bring to maturity in one season only a limited number of pods. In this experiment, many of the pods that set in

June or July (the early part of the wet season) eventually attained maturity, but most of the pods that set in August and September, during the time when the early crop was ripening, failed to develop but wilted and subsequently died. The size at which young pods wilted became smaller as the season advanced up to the time when the first crop had ripened, after which the size at wilting increased. Pods on the thinner branches, and therefore further from the roots, showed the greatest percentage of wilting. These results support the theory that cherelle wilt is primarily caused by deficiency of water and nutrients resulting from competition between pods at different stages of development.

The second part of the investigation *(10)* involved the collection of a large number of pods of different ages from 18 days to 170 days at which age the pods ripen. The pods were analysed in the laboratory for moisture content, ash content and contents of nitrogen, phosphate, potash and lime. The changes with age of each of these components were depicted in graphs. The data proved that potash is the mineral nutrient in greatest demand by the developing ccao pods at River Estate, Trinidad. These experiments were continued for another year and supplemented by others designed to provide further evidence of the cause of wilt *(11)*. The results substantiated those previously obtained but they failed to demonstrate any direct relationship between wilting and environmental physical growth factors, such as soil moisture supply and air humidity. The weather during 1939 and 1940, however, was abnormal in that both the dry and the wet seasons were less rainy than usual. It was thought that possibly the bulky cacao tree imposes a buffer system between the fluctuating environment and the developing pods which causes a lag in response to sudden changes in the growth factors and also smooths out the physiological reactions of the tree.

In 1941-42, another investigation was undertaken at River Estate, Trinidad, to examine the differential effects of variety of cacao and of soil type on the wilting of cacao cherelles *(12)*. Three pairs of clonal plants (ICS 1, 4 and 45) aged 5 years, growing in a good soil, and 3 pairs of the same clones, aged 5 years, growing in a medium soil were kept under observation and weekly records were obtained of pod set and pod wilt. It was found that a heavy leaf flush in September was followed by the loss of all the fruits that were on the trees, except a few which had set early on the trees growing at the good site. Some of the fruits which set after the flush was over ripened normally. The size of the fruits that wilted increased as the date of wilting advanced and then diminished as the remaining fruits matured. These facts indicate that young cacao trees do not contain sufficiently large reserves of nutrient materials but that the nutritional status of the trees is greatly improved by the production of each new crop of leaves. Differences were shown to occur in the intensity of setting and of wilting between the three clones, ICS 1 showing marked superiority in pod production, and ICS 45 showing marked lateness of setting. The percentage of fruits that ripened on each clone was greater in all cases for the good soil than for the medium soil (see Table).

COMPARATIVE PERFORMANCE OF YOUNG CLONES ON GOOD AND MEDIUM SOILS

Clone	GOOD SOIL			MEDIUM SOIL		
	Number of pods set	Number of ripe pods	Percent ripe	Number of pods set	Number of ripe pods	Percent ripe
ICS 1	533	53	10	251	15	6
ICS 4	169	42	25	80	5	6
ICS 45	96	20	21	191	25	13
Totals	798	115	14	522	45	9
Average per tree	133	19	14	87	7	9

Field observations showed that young cacao fruits are particularly susceptible to wilt up to the age of about 70 days, after which they ripen normally, or else become diseased, in about 100 days more. In order to explain these results, another series of investigations was started in 1942 *(12)* in which pods of various ages were collected and subdivided into fruit wall and pulp (which includes all developing tissues within the wall). These samples were analysed for carbohydrate and fat. Other portions of the samples were ashed and the ash was analysed for potassium, phosphorus, calcium and magnesium, and still other portions were analysed for total nitrogen.

The data obtained showed that the growth of the cacao fruit may be divided into two periods, namely: (a) the development phase, occupying about 75 days, and (b) the maturation phase, during which metabolic activity greatly increases. Each phase may be further subdivided according to the increases and decreases in amount of the various organic and inorganic chemical components occurring in the wall and in the pulp. The details need not here be considered, but certain conclusions of possible importance in the problem of cherelle wilt that are based on them may be noted. They concern the channels or ducts through which the different nutrient mineral elements apparently are transported from the tree into the developing cacao fruits.

Assuming that the proportionate amounts of the mineral elements in solution in the transpiration stream are constant, and accepting the physiological fact that calcium is not mobile within the phloem, it is possible to determine the comparative importance of the xylem and the phloem in the process of transportation during the development of the cacao fruit by calculating the ratios of potassium, phosphorus and magnesium to calcium present in fruits of different ages *(13)*. The results of this calculation showed that, within the first 50 days of growth, both the wall and the pulp receive their mineral elements solely by the transpiration stream moving in the xylem strands. After 75 days, however, additional sources of mineral supply *via* the phloem vessels apparently become available, and wilting caused by mineral nutrient deficiency is not likely subsequently to occur.

The last series of investigations on cherelle wilt that was carried out at River Estate, Trinidad, during 1943-44 concerns the seasonal changes in the carbohydrate and mineral reserves of the cacao tree *(13)*. Two groups of 10 heterogeneous trees of age 25 years were sampled monthly. The samples consisted of square pieces of bark and of radial wood turnings taken at 1, 6 and 12 feet above ground level. The samples were analysed for carbohydrate and mineral nutrient elements as in the case of pod samples. The results showed that peaks in the contents of carbohydrate, and usually also of mineral nutrients, occur at the times of leaf flush. A marked decline in nutrient contents followed, both in the bark and in the wood, immediately after the flush had started but reserves began to increase again 4 weeks after flushing began. There was less seasonal fluctuation in mineral reserves than in carbohydrate reserves. The magnitude of the difference in crop yield between any two groups of trees that were sampled was found to be inversely correlated with the difference in carbohydrate reserves of the two samples but not with the difference in mineral content except in the case of potassium, for which a positive correlation was obtained. It was therefore concluded that the size of the crop was not limited by the amount of carbohydrate available to the fruits but rather by the amount of available potassium. In other words, potassium appears to be the particular factor limiting the size of the crop at River Estate and therefore deficiency of potassium is the chief cause of cherelle wilt and controls the cropping potential of the environment at this site.

The cacao tree differs essentially from temperate fruit trees in that there are two or more periods, rather than only one, within a growing season when maximum demand on the nutrient reserves of the tree by the developing fruits occurs. Under the conditions obtaining in Trinidad, the greatest demand generally occurs twice, namely (i) in November-December from fruits initiated in June-July, and (ii) in April-May from fruits initiated in December-January. Fruits that are initiated at other times suffer by competition from earlier-formed fruits and usually therefore wilt and die.

Resting periods do not occur in cacao trees growing under ideal conditions but growth cycles regularly follow each other throughout the year, provided the environment is capable of maintaining the necessary supplies of organic and mineral nutrients and of water at sufficiently high levels. The initiation of a growth cycle, as has already been demonstrated, appears to depend on fluctuations of air temperature, but the capacity of the tree to react, and to continue to react, to the stimulus of temperature, appears from these investigations to depend mainly on the features and properties of the environment as a whole.

SUMMARY: The conclusion reached from the intensive investigations of cherelle wilt that were carried out in Trinidad during the 5 years' period, 1939 to 1944, have been summarised as follows *(13)*. They refer specifically to the conditions occuring at River Estate.

1. Cherelle wilt is caused by competition between pods for mineral nutrients.

2. Carbohydrate shortage is not a cause of wilt.

3. Competition is demonstrated by the facts that (i) cacao pods formed early in the season have the greatest chance of survival and of reaching maturity, (ii) pods formed successively as the season advances wilt at an increasingly younger age, (iii) pods formed on thin branches have less chances of survival than those formed on thick branches and stems.

4. Potassium shortage is mainly responsible for diminished cropping at this site.

THE ROLE OF HORMONES IN CHERELLE WILT

The fact that fruit drop in temperate crops such as apple has been proved to be closely associated with hormone deficiency and has been prevented or diminished by spraying the young developing fruits with dilute solutions of growth promoting substances, has encouraged attempts to overcome cherelle wilt of cacao by similar means.

The first of such attempts was made in Colombia in 1950 *(22)*. It was reported that spraying the young cacao pods with dilute solutions of alpha naphalene acetic acid greatly diminished the amount of wilting. In a later series of comparative trials with this and other growth promoting substances *(23)* it was reported that para-chloro-phenoxy-acetic acid in solutions containing 25 to 50 p. p. m. of active ingredient was the most effective of all the substances tried. It was also reported *(8)* that the growth promoting substances when applied in aqueous solution as sprays increased the number of cacao flowers that set fruits.

These experiments were repeated in 1952 in Trinidad *(21)* on 15 year old cacao trees which had previously been injected with solutions of potassium sulfate or of complete mineral nutrients. The results did not show response to any of the treatments in regard to their effect on the numbers of flowers that set fruit or of cherelles that wilted. It was suggested that the failure of the trees to respond might be attributed to the dry weather that prevailed during the experimental period which may have prevented the young pods from developing because of water shortage. The experiments were not repeated.

The natural growth-promoting substances occurring in various parts of the cacao tree were investigated at I. C. T. A., Trinidad in 1956 by extracting the material with solvents and separating the extracts by a chromatographic process *(24)*. The growth-active areas on the chromatograms were tested by the coleoptile method. In this way the presence of an acidic accelerator (auxin I) similar to, but not identical with, indolyl acetic acid, a neutral accelerator (auxin II) and an acidic inhibitor, was proved. The two auxins accumulate in the ovules and only attain maximum concentration 50 to 75 days after fertilization. This might explain why wilting occurs mainly in cherelles of age up to 50 days but seldom occurs in cherelles over 75 days old. At the 75 day stage, rapid growth of the embryo is taking place at the expense of the endosperm. In the case of temperate fruit trees, the growth of the embryo is accompanied by a diminution in the production of hormone and this may cause fruit drop to occur. The two cases are therefore not analogous. Fruit drop is associated with the formation of an abcission layer whereas cherelle wilt is not, but instead it is accompanied or preceeded by a shrivelling or contraction of the pedicel*. It is likely therefore that the hormonal control of cherelle wilt is "expressed through the medium of vascular differentiation" *(24)*. The simultaneous presence of auxins and the absence of growth-inhibitor from the pedicel were indeed demonstrated in this investigation. The conclusion reached is substantiated by the finding previously mentioned that mineral nutrient supply to the developing pod is transmitted in the

* Apparently, young cacao fruits may also be shed with their pedicels or fruit stalks still attached. This has been called fruit-fall to distinguish it from cherelle wilt. (A. L. Wharton, Annual Rept. W. A. C. R. I., 1957-58, p. 25). The anatomical differences between the two have not yet been described.

early stages solely by the xylem strands of the pedicel, though later the phloem vessels apparently take part in the conduction process *(13)*. Since cherelle wilt and fruit drop are apparently induced by different physiological and anatomical mechanisms, it could not be expected that the same growth-accelerating substances that are known effectively to diminish fruit drop in temperate fruit trees would necessarily diminish cherelle wilt in cacao. It is therefore important that more should be known about the identity and relationships and the method of operation of the natural growth accelerators occuring in the cacao flower and fruit. The source of growth-promoting substances in temperate fruit trees is the endosperm of the embryo, and presumably this also is the case in cacao. Young leaves of cacao were found to contain the acidic accelerator and the inhibitor, but old leaves at the stage when their abscission layers begin to form were found to contain only the inhibitor (24). The acidic accelerator is apparently therefore associated solely with tissues undergoing differentiation.

(3) GHANA

Investigations of cherelle wilt, carried out at W. A. C. R. I., Tafo, Ghana, at first chiefly concerned the hormone aspect. Preliminary experiments comprised the assessment of wilt in several hundreds of pods produced from periodic hand pollinations of three different types of caaco *(16)*. This showed that wilting occurs at two peaks, namely first wilt at 50 days and second wilt at 70 days after fertilization. No more wilting occurred after about 100 days. Young cacao trees exhibit only first wilt in April to June but old trees exhibit both first and second wilt, the second occuring in August-September. First wilt coincides with cell division in the endosperm and second wilt with rapid growth of the embryo. Spraying the cherelles with aqueous solutions containing 50 p. p. m. of either 2,4-dichloro-phenoxy-acetic acid (2,4-D) or naphthenic-acetic acid (NAA) failed to prevent wilting.

It was also found that the removal of leaf buds diminished wilting in young (small) cacao trees and caused the earlier production of a greater number of ripe pods *(16)*. This proves that flushing entails competition with the developing pods either for nutrients or for growth-promoting substance or for both. Repetition of this experiment on a larger, randomised block, scale with six clonal selections of young cacao trees, gave similar results *(17)*. The removal of buds was carried out in March to September; this reduced first wilt, the crop ripening in August, whereas the crop on the control trees, which had suffered more severely from wilt, ripened in September. The intensity of wilting was 74 percent for the debudded trees and 83 percent for the control trees. The total yield, however, was greater for the control trees, viz., 260 pods as compared with 219 pods for the debudded trees. There were two-and-a-half times as many leaves on the control trees in September which implies that lack of carbohydrate could not have been the cause of wilt.

Two further experiments were carried out later to test the effect of increased fruit setting on final yield of cacao. In the first *(18)* numerous flowers of 20 mature trees were hand pollinated and counts were made of the number of pods that set and the number that wilted. These were compared with the results obtained with 20 similar trees whose flowers were pollinated by natural agencies. It was found that hand pollination made little difference to the number of pods harvested. The actual yields were 631 out of 4075 pods that set for the hand pollinated trees and 615 out of 3431 for the naturally pollinated trees. Actual wilting intensity was 81.3 and 79.5 percent respectively.

In the second experiment *(18)* all the flowers and cherelles were removed from 24 mature trees up to the time of the April big leaf flush which few cherelles normally survive. The number of pods that subsequently ripened was compared with the number of ripened pods on an equal population of untouched trees. It was found that the removal of flowers and cherelles before the leaf-flush occurred did not reduce the size of the ultimate harvest although it delayed it considerably. The conclusion drawn from these experiments is that some unknown factor, other than the effects of leaf-flush, is responsible for cherelle wilt of cacao.

It was observed that the cacao pods that shrivelled during the second wilt had larger embryos but thinner pedicels than comparable healthy pods. This second observation conforms with the conclusion based on the investigations carried out in Trinidad *(13)* namely, that the transportation of nutrients from the cacao tree to the developing pods takes place mainly in the xylem tissue of the pedicel until the time of the second wilt, after which phloem transport normally becomes effective. The pods at this stage are particularly sensitive to competition for mineral nutrients. Consequently, if the phloem tissue fails to function normally, wilting occurs.

Experiments were next carried out in Ghana to test the effect of ringing the pedicel on pod growth *(19)*. Complete ringing, which removes all the phloem tissue, was found quickly to stop the growth of pods of all sizes even up to 15 cm. long, and wilting occured within 12 days. Half ringing was found to slow down pod growth only slightly but not to cause wilting. The special importance of the phloem tissue in the nourishment of the developing cacao pod is thus strikingly demonstrated by these ringing experiments. If, for any reason, the development or functioning of the phloem tissue of the pedicel is arrested, particularly at the time of second wilt, and especially if the supplies of organic and mineral nutrients and water are conjointly or severally inadequate, then wilting inevitably occurs and the fruit is lost.

The vascular development of the fruit pedicel is known in general to be controlled by growth hormones *(19)*. Thus it is possible that the fundamental cause of cherelle wilt in the cacao tree really is hormone shortage. Since growth hormones of the developing fruit are manufactured in the endosperm, it is possible that first wilt (which coincides with the formation of cell walls in the endosperm) occurs as the result of arrested development of the endosperm tissue causing hormone shortage, and that second wilt (which coincides with the rapid growth of the embryo) results from the heavy consumption of endosperm tissue and the concommitant depletion of hormone which brings about the disfunctioning of phloem tissue and thus again predisposes the pod to wilt. If the environmental conditions, or the metabolic activity within the cacao tree, are unsatisfactory at the time when the fruits are prone to wilt, and if there is also a shortage of essential growth hormones in the fruits, then wilting will occur and the size of the crop will be determined by these various circumstances. In order therefore to increase the yield of cacao pods, treatment of the developing fruits at the right stages of growth with the right kind of growth accelerating substance is strongly indicated and continued research, designed to discover the most suitable substance and the most effective time for applying it, is fully warranted. The particular need is for a growth promoting substance of greater potency for controlling the development of the vascular strands of the cacao fruit pedicel than those that have so far been tried.

Relationship between hormone deficiency and nutrient deficiency in cherelle wilt

The experiments carried out in Ghana prove that cherelle wilt is not normally the main physiological factor which limits the yield of cacao, since the number of ripe pods produced is unaffected by the number of cherelles that set earlier in the season. Indeed cherelle wilt appears to be merely the mechanism whereby the size of the crop is adjusted to the magnitude of the food reserves of the tree *(20)*.

Fruitfulness is determined by the relative amounts of carbohydrate and of mineral nutrients, especially nitrogen, within the plant. Furthermore, it is also known that insufficient supply of nutrients causes the abortion of the embryos of developing young fruits and that this reduces the supply of auxin (growth-promoter) thus inducing abscission or pedicel shrivelling. Old fruits produce more auxin than young fruits and abscission occurs in some cases because the old fruits are able to absorb a greater proportion of the nutrients than young fruits. This differential action further reduces auxin production in the young fruits which, under limited nutrient supply, consequently undergo abscission *(1) (35)*. In this way, auxin is the active agent which regulates the partition of nutrients between the developing fruits when nutrient supply is limited. In the case of cacao, it seems probable that the amount of cherelle wilt is determined in such manner for any given variety of cacao and any particular set of environmental growth conditions *(20)*.

The role of fungi and insects in cherelle wilt: Mention was wade earlier in this chapter that cherelle wilt occurring at La Lola, Costa Rica, has been at least partly attributed to attack by Black Pod disease *(Phytophthora palmivora)* and by leaf-hoppers. *(4) (33)*. In Ghana, cherelle wilt has also been attributed partly to attack by *Phytophthora*. At La Lola, large colonies of the membracid insect *Amastris obtegens* have been reported as feeding and ovipositing on the pedicels of young cacao cherelles *(32)*. Experimental evidence was adduced by caging cherelles and introducing a number of the insects into some of the cages leaving others empty as checks, which showed that wilting is more than twice as prevalent where the insects are allowed access to the young fruits than where they are absent. Nevertheless, for the reasons given, it is unlikely that the loss of cherelles, either through fungus or insect attack, is likely to influence the final yield of the cacao trees which is mainly determined by the size of the tree and the ecological environmental circumstances under which it is growing.

If this conclusion is accepted, then the use of hormone sprays (growth-promoters) in an attempt to increase the yield of a given variety of cacao growing in a given environment, is likely not to be effective. On the other hand, the application of fertilizers to cacao growing in an environment where all the growth factors other then nutrient supply are near to the optimum, should either increase the percentage of fruit that sets, leaving total and percentage of wilt unaffected, or should reduce the total and the percentage of wilt, leaving fruit set unaffected, thus in both cases producing a larger crop of pods.

Some quantitative considerations: Observations show that fungus and insect attack, provided it is not severe and does not assume epidemic proportions, is unlikely seriously to reduce the final number of ripe cacao pods that are produced by a mature cacao tree. The total number of pods per tree required to give an annual yield of 2000 lb. of dry cured cacao beans per acre of 300 trees (2273 kg. ha. of 750 trees) which has been proposed as the ceiling or maximum for commercial production, is about 50, assuming that seven ripe pods are required to give 1 lb. of cured dry cacao beans. Thus, out of the hundreds of flowers and the scores of cherelles that are formed by a mature cacao tree of age 8 or 10 years, only this small number of pods is needed per year to produce a maximum crop. This allows a wide margin of pod loss by cherelle wilt. It has been estimated that one mature cacao pod contains just about as much mineral matter as 30 cherelles each of length 5 cm., which is the average length at which they wilt. Thus, a tree producing 50 ripe pods, and having a wilting intensity of 80 percent, would lose through wilting only enough mineral matter to provide an additional 7 pods *(17)*. This conclusion is based on the assumption that wilting is caused solely by lack of nutrient materials.

For each mature pod produced, it has been shown that between 6 and 10 fully functioning leaves are required. Hence, to produce 50 pods, a cacao tree should carry some 500 mature leaves. Since there are about 5 mature leaves, together with several other pendulous young silky leaves, on each twig, the tree should carry at least 100 shoots. This requirement should be considered when the tree is being pruned and care should be taken, not only to ensure that an adequate leafy canopy is provided, but also that a sufficient area of bark, preferably situated on the trunk and the main branches, is retained on which the necessary number of flowering cushions can develop.

SUMMARY

1. Researches on the causes of cherelle wilt of cacao that have been carried out in Trinidad, Costa Rica and Ghana are reviewed.

2. These researches have demonstrated that cherelle wilt is not a malady or disease nor yet a factor limiting the size of the crop but that it is a mechanism, probably controlled by growth hormones (auxins) whereby a limited number of pods are brought to maturity, as determined by the ecological factors operating in the environment on the cacao tree.

3. Among the ecological factors, mineral nutrient supply is particularly important, but this is not the only factor involved because, in order to nourish a developing cacao crop, carbohydrate produced by photosynthesis which involves the light factor is also needed in balancing proportion.

4. Other important contributory factors involved in dimishing the degree of cherelle wilt and increasing the size of the cacao crop are root room and water supply.

5. The part played by fungi and insects in cherelle wilt is discussed and the conclusion is drawn that these agencies, provided they do not assume epidemic proportions, have only secondary importance in deciding the size of the crop.

6. The conclusion is reached that, unless the environmental factors are operating near to the optimum, the use of hormone sprays is likely not to offer any advantage as a means of suppressing cherelle wilt and increasing the size of the crop.

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PART III

CACAO PEDOLOGY

CHAPTER 8

CACAO SOILS

PEDOLOGICAL ASPECTS

In discussing the water and air relations of cacao, it was indicated that, in order to produce satisfactory crops of cacao, a soil should possess large *root room,* that is, it should consist of a deep layer of soil material having a highly porous structure and presenting large continuous pore spaces capable of allowing rapid infiltration and percolation of water, free passage of air and easy penetration by roots. At the same time, it should have a high water-retaining capacity, particularly if the incident rainfall is sparse and irregularly distributed throughout the year, and the water-table is not too deep to provide a supply of water by uplift into the soil, or is merely temporary. Such features are possessed only by aggregated clay or loam soils. Coarse sands, which may have the necessary pore space, lack water retentivity and suffer severely from drouth and so do not possess suitable water relations unless the rainfall is exceptionally high and continuous throughout the year with showers falling almost daily. Furthermore, coarse sands do not possess satisfactory nutrient relations and must be treated with frequent dosages of fertilizers, manures or mulches if they are to support healthy and high yielding cacao trees.

Whether or not a soil is likely to possess satisfactory water, air and nutrient relations, under a given prevailing climate with or without irrigation, can generally be determined by a careful study of the features displayed by its profile or section, augmented by simple physical measurements made on the undisturbed soil, and by physical and chemical examination of specially-collected soil samples carried out in the laboratory.

In order to understand the kind of information that may be procured by the study of soils in the field, it is necessary first of all to learn about the main characters of a typical soil profile. When these have been appreciated it is possible to "read" a profile and to diagnose the particular growth conditions that the soil presents to the plant.

THE SOIL PROFILE

By soil profile is meant a section of the soil exposed by digging a pit or by cleaning a road or river bank. The chief features of the soil profile under tropical wet forest before being converted into cacao are shown in the accompanying diagram and the table. *(Figure 1).*

SOIL PROFILE HORIZONS

(I) *Living Soil*

1. Aoo Freshly fallen litter
2. Ao Decomposing litter + root mat + organisms
3. Al(a) Crumb layer + roots + organisms + mineral matter
4. Al(b) Humic soil + roots + organisms + mineral matter
5. A2 Slightly humic soil + some roots + few organims + bleached mineral matter.

(II) *Dead Soil*

6. B Non-humic soil, few roots. Mineral matter only with various accumulations which impart colorations.

(III) *Soil Parent Material*

7. C Weathered parent rock (may contain unweathered fragments).

(IV) *Parent Rock*

8. D Unaltered minerals; various rock structures.

Some soil profiles show all of the features described above but others only show some of them. The thickness of the different horizons also varies greatly. In the case of soils that have developed under a hot-wet tropical climate, the total thickness of the horizons down to the unweathered parent rock is sometimes as great as 20 feet.

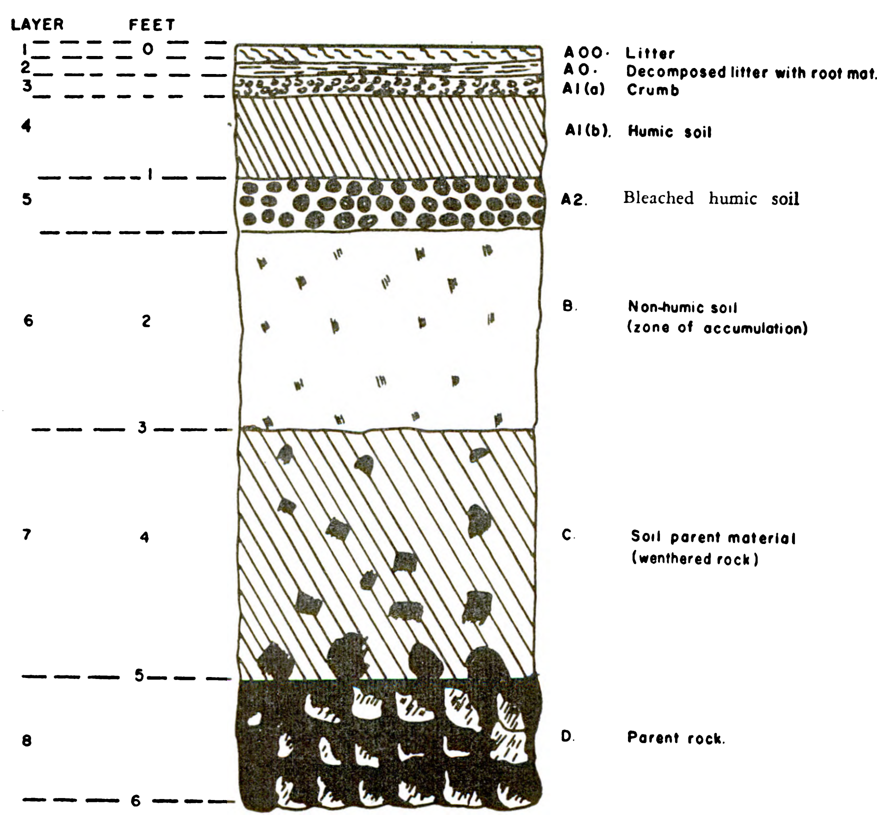
The lowermost layer or horizon (D) is the upper part of the unaltered parent rock from which the soil has been derived. The next horizon (C) is the parent material of the soil. It consists of broken-up pieces of rock, together with the products of rock decomposition or weathering from which all or most of the soluble substances have been dissolved out and leached away by percolating rainwater. It may also contain new secondary clay minerals. The nature of the soil parent material depends on the kind of parent rock and on the degree of decomposition and leaching. It largely decides the fertility of the soil. It varies greatly in thickness.

Soil formation from soil parent material consists in the incorporation of the products of decay of plant residues, including leaves, flowers, twigs, branches and roots, by the action of soil animals, notably worms, termites, ants and insect larvae. The incorporated organic materials are further broken down through the agency of micro-organisms into *humus*. The humic layer immediately below the leaf litter contains least mineral matter. It has a porous "crumb" structure and is extremely rich in plant nutrients. It is well aerated and, provided it is maintained constantly in a moist condition, it presents the best possible conditions for the growth of feeding roots which often form a mat over it. Below the crumb layer, the content of humus, micro-organisms and fine roots diminishes and the content of mineral matter increases. The structure of the soil is still open and porous, but the structure units are more compact and angular in shape. These units are often described as "nut" or "small clod". At the base of the humic layer the soil may be grey in color or bleached because of the removal of iron oxide by solution in organic acids liberated from the humic layer.

The highly-organic "living" soil, or A-horizon, merges downwards into the non-organic "dead" soil, or B-horizon, which is enriched by the accumulation of materials such as ferric oxide, manganese oxide and calcium carbonate, leached down from the A-horizon. These deposits impart characteristic colorations to the profile which are either uniform or mottled and spotted on a grey ground, depending whether the soil is well-drained and well-aerated or is waterlogged and poorly-aerated.

FIGURE N°1

THE SOIL PROFILE



"GOOD" AND "BAD" CACAO SOILS

The accompanying diagrams *(Figures 2 and 3) (1)* depict the main features of "good" and "bad" cacao soils occurring in Ghana, West Africa. The following are the main features of the "good" soils which distinguish them from the "bad".

(1) *Depth:* The depth of root-penetrable soil should be at least five feet. There are three main causes that limit rooting depth shown in Figure 3; d, e, and f. They are (i) hard-pan (impervious parent material, clay-pan, iron-pan) (ii) too-shallow soil profile (iii) high water-table. The presence of fragments of parent rock, quartz-gravel, ironstone-gravel or hard ferruginous concretions does not prevent root penetration provided the inclusions are only sparsely scattered throughout the profile and do not occur within the surface foot layer *(Figure 2; b, c, d, e)*. The occurrence of fragments of actively-decomposing parent rock within the rooting zone is a highly beneficial feature because it ensures a good supply of nutrient bases (potassium, calcium, magnesium) as well as phosphate and minor nutrients, which distinguishes a naturally highly-fertile cacao soil from an infertile sort.

(2) *Color:* Cacao soils that are red or reddish-brown in color below the humic horizon are usually better than those that are pale-colored or grey or white, because they are obviously less leached and therefore likely to contain a larger concentration of nutrients, though this is not an invariable rule. Red, brown and yellow colors imply complete oxidation (of iron oxide) and therefore mean good drainage and good soil aeration. Yellow colors are associated with constantly moist conditions conducive to a high degree of hydration of ferric oxide (limonite). Olive-green color is due to basic carbonates implying the occurrence of calcareous parent rock. Blue-grey and green-grey colors are due to ferrous oxide and imply imperfect or impeded drainage. Ashy white appearance denotes complete removal of iron oxide generally by excessive lateral water movement as on steep slopes.

Mottled, speckled or streaked coloration in red, brown, yellow or sepia-black colors implies impeded drainage if it starts at about the three inches depth, imperfect drainage if it starts at about the two feet depth, and free drainage if it occurs only below the four feet depth. The background color in mottled soil is blue-grey (gley) owing to the presence of ferrous oxide in variable quantity, depending on the degree of iron segregation. Grey gley becomes more and more conspicous with depth in poorly-drained soils which are uniformly grey and unmottled at great depth.

Black and brown coloration in the surface soil usually shows the depth of humic penetration but its color intensity cannot be accepted as a measure of organic content since, in red soils common in the cacao belt, humus apparently has a pale-brown color. Intense blue-black humous coloration is associated with poor drainage (swamps and marshes) and is usually accompained by high acidity and a peculiar waxy and sticky kind of humus.

(3) *Texture and structure:* Good cacao soils comprise aggregated clays or loamy sands. The presence of large amounts of gravel or coarse sand in

FIGURE 2 : GOOD CACAO SOILS.

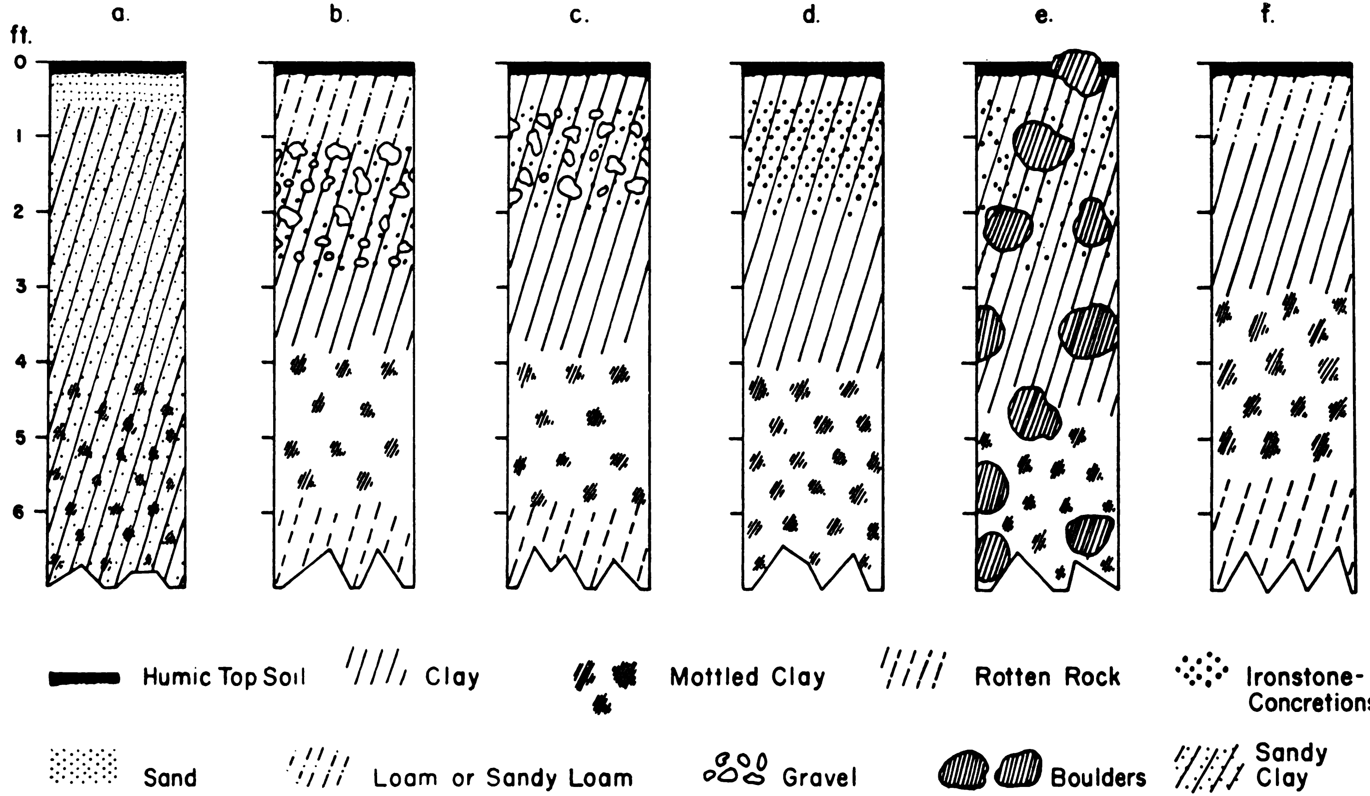


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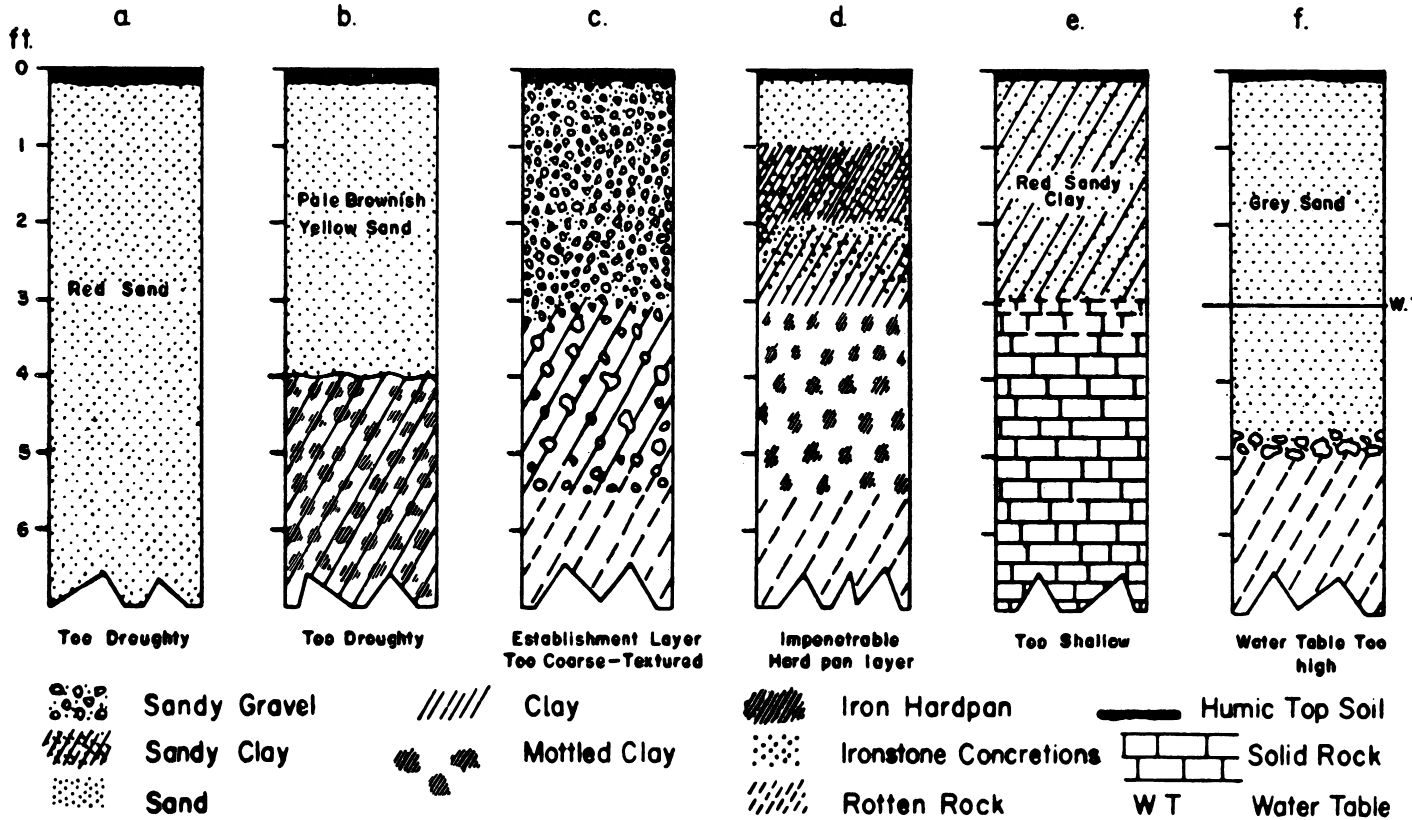
FIGURE 3: BAD CACAO SOILS



the subsoil is an undesirable feature in cacao soils unless the watertable is fairly high. Uniform coarse sandy soils (particle size, 2.0 to 0.5 mm. diameter) although they allow root-peneration, are unsuitable for cacao growing unless their nutrient status is good and the rainfall is high and continuous *(Figure 3; a, b, and c)*. They are too drouthy. Clayey cacao soils are usually the best provided they are aggregate structured (small-nut) and stable under constant wetting, drying and rewetting.

(4) Consistency: Cacao soils that are loose, crumbly, soft and plastic when moist are better than those that are compact, coherent, hard and rigid, because they permit easy root penetration since they have low apparent specific gravity which indicates a high degree of porosity. Undoubtedly the best structure most conducive to good aeration and rapid root growth is that possessed by highly humic soils, whether they be sands, silts or clays.

(5) Parent rock: Generally speaking, cacao soils that have developed over coarse crystalline igneous and metamorphic rocks, rich in dark-colored ferromagnesian minerals,* are much better than those that have developed over sedimentary or fine-grained metamorphic rocks such as sandstones, shales, schists and phyllite. This is because their diverse assortment of primary minerals ensures that the soils derived from them are well supplied with all the major and minor basic nutrients. Soils developed over unweathered recent volcanic ash, or over alluvial sands whose particles consist mostly of fresh unweathered primary minerals are the best soils of all for cacao growing, provided the climate is suitable.

CLASSIFICATION OF CACAO SOILS

Soil genesis: Soil is a product of the environment. It is a "bit of the landscape". It develops over different kinds of *parent rock* whose component minerals are decomposed or weathered by the action of the prevailling *climate* and whose products of weathering become intermingled with organic residues produced by the decay of dead *vegetation* and *micro-organisms* through the agency of *soil animals*. Given sufficient time and suitable drainage, as determined mainly *by relief*, mature soils, known as ZONAL SOILS ,are eventually formed. These have characteristic profiles which owe their chief features to the effects of the climatic factor (rainfall and temperature) although the nature of the parent rock, as well as the kind of vegetation, are also partly responsible.

Soil-forming factors: As indicated above, these are (i) rock (ii) climate (iii) organisms (iv) relief and (v) time. They vary in intensity and importance in different places. Their interplay determines the kind of soil that develops in any particular locality of the earth's surface. Every soil property (S) is a function of these five chief soil-forming factors *(2)*:

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* For example, syenite, granodiorite, diorite, monzonite, andesite, basalt and hornblendic and augitic gneisses. These rocks contain potash, soda and lime felspars, as well as ferromagnesian minerals and apatite which is a phosphatic mineral.

$$S = f(R, C, O, L, T)$$

Where the drainage is impeded or imperfect as, for example, over land having flat or depressed relief, the occurrence of a high water-table, whether permanent of fluctuating, imposes new conditions and other kinds of soil profiles, described as *hydromorphic,* develop. Again, where the parent rock contains excess of calcium carbonate, as for example, limestones and marls, or where it contains, or releases during decomposition, large amounts of soluble salts which are not removed by leaching under free drainage, still other kinds of soil profiles develop. These are respectively described as *calcimorphic* and *halomorphic*. Because hydromorphic, calcimorphic and halomorphic soils develop under any kind of climate, they are collectively known as INTRAZONAL soils. Climate is not the dominant factor in their formation, but either relief or kind of parent rock, or both.

Finally, where the time factor is relatively short so that the kind of unaltered parent rock mainly decides the features of the immature soil, the soils are called AZONAL. They do not belong to any climatic zone; climate has not played any part in their formation.

Soils of the tropics: The following scheme for classifying soils in the tropics is due to C. E. Kellogg (1950) and is based on that described in "*Soils and Men*", the 1938 year book of the U. S. Department of Agriculture, modified by experience gained in Belgian Congo *(3)*.

(A) ZONAL SOILS

Climate the chief factor; *relief* undulating; drainage free; *vegetation* tropical wet forest to tropical dry scrub. *Parent rock,* various. *Time,* long.

(I) *LATOSOLS:* Red, Earthy-Red, Reddish-Yellow, Reddish-Brown, Yellow, Black-and-Red

(II) *CHERNOZEM:* Reddish Prairie

(III) *PODZOLS:* Reddish-Yellow, Latosolic Brown, Grey Podzolic.

(B) INTRAZONAL SOILS

Relief (drainage) *lime* or *salts,* the chief factors.

(I) *HYDROMORPHIC:* Humic Gley, Low Humic Gley, Planosol, Bog and Half Bog, Peat Podzol, Gley Podzol, Ground Water Podzol, Ground Water Laterite

(II) *CALCIMORPHIC:* Rendzina, Brown Forest Soil

(III) *HALOMORPHIC:* Saline Soils, Alkali Soils, Soloti.

(C) AZONAL SOILS

Parent rock the chief factor
Regosols, Alluvial Soils, Lithosols.

Cacao soils: The most suitable tropical soils for cacao growing, in approximate order of preference, are:

1. *Regosols:*	Fresh, loose, deep soils developing over geologically-recent *volcanic ash.*
2. *Alluvial Soils:*	Fresh, loose, deep soils developing over geologically-recent, unweathered sediments comprising assorted primary minerals and undergoing periodic rejuvenation by addition of humic soil eroded from the slopes; *ie.:* "living" alluvial soils.
3. *Lithosols:*	Fresh, loose, deep soils developing on slopes recently denuded so as to expose rocks rich in nutrient minerals.
4. *Immature Latosols:*	Reddish-Brown and Red Latosols developed over sub-basic and basic igneous rocks; eg. granodiorite, monzonite, andesite, basalt. Profile not deeper than 5 feet to parent rock.
5. *Immature Hydromorphic Soils:*	Humic Gley and Planosol where not much affected by ground water and easy to drain.
6. *Calcimorphic Soils:*	Rendzina (deep phase); uneroded, thick humic layer, acid to neutral reaction.

CHIEF FEATURES AND RELATIONSHIPS OF CACAO SOILS

AZONAL SOILS: (Nos. 1, 2, 3): Of the six natural soil groups named in order of merit in the last section as suitable for growing cacao, provided they receive *good management but without the use of fertilisers or amendments,* the first three belong to the Azonal division. This means that they are young or immature soils in which the parent rock consists of only slightly altered minerals having high potential reserves of essential nutrient elements (K, Na, Ca, Mg, P, Al, Fe, Mn and other minor elements) occurring in well-balanced proportions. The only essential nutrient missing is nitrogen. This is supplied by the organic residues that collect in the surface humic soil. Nitrogen, together with some of the available mineral nutrients, goes into circulation between the forest vegetation which becomes established on the decomposing rock surface and the thin layer of developing humic soil in which most of the roots are located. When sufficient nitrogen has been assimilated from the air, the soil becomes capable of supporting cacao. The test as to whether there may be enough nitrogen in the soil is the thickness of the dark-colored humified organic layer (AOO, AO, Al). If cacao is grown with leguminous shade trees*, accretion of additional nitrogen will go on. Hence, under good management, continuous crops of cacao pods should be obtained without the use of fertilizers where cacao is grown on Azonal soils.

Root room in immature Azonal soils varies according to the physical features of the parent rock and the depth of the weathered layer. If the parent rock consists of loose, coarse, volcanic ejecta, or of alluvium or colluvium comprising grains of mixed minerals and having a speckled appearance, the root room should be adequate to support large and highly-productive cacao trees. If it consists of coarsely- crystalline, well-jointed igneous, metamorphic or sedimentary rock, as in the case of lithosols, root room inside the brashy or granular decomposing mass should also be adequate.

ZONAL SOILS: (No. 4): The fourth soil group in the list comprises Latosols (Reddish-Brown and Red). Typically, Latosols are mature soils in which the unaltered parent rock occurs at a considerable depth below the soil surface. The parent material (C-horizon) forms a thick layer, sometimes over 20 feet, of highly leached uniform mineral residues. In *Reddish-Brown* and *Red Latosols* the parent material has a well marked aggregate structure stabilised by ferric oxide cement and offers abundant root room. The next layer above (B-horizon) is indistinguishable and merges with the parent material but the uppermost layer (A-horizon) is dark-colored and highly humic. This too has a stable aggregate or crumb structure easily penetrable by roots. It is rich in reserves of nutrients accumulated by the forest growth during the maturation period.

Less mature phases of Reddish-Brown and Red Latosols have a thinner C-horizon, and the D-horizon (parent rock) is well within reach of plant roots which absorb mineral nutrients directly from the decomposing rock fragments. Such immature Latosol is more fertile than mature Latosol, especially when the humic layer of mature Latosol has been depleted by erosion. As a cacao soil, immature Latosol is much more dependable. Immature Latosols merge with mature Latosols as the thickness of the weathered residues (parent material; C-horizon) increases. The fertility of mature Latosols that have lost much of their nutrient-rich humic layer (A-horizon) by erosion may be greatly increased by the use of fertilizers.

INTRAZONAL SOILS: (Nos. 5, 6): The last two soil groups in the list of naturally suitable cacao soils are more difficult to diagnose than the other four. They are widespread in cacao growing countries, especially the hydromorphic groups *(Humic Gley, Planosol)* which may prove to be unsuitable to cacao production when the hydrological conditions are extreme as, for example, when the land is subjected to repeated flooding by overflowing rivers or by continuous rain.

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* Shade tree litter amounts to about 1000 lb. ac. per year (twigs, leaves, flowers) of Immortelle *(Erythrina poeppiguiana)* in Trinidad, having 4 percent nitrogen, *equals* 40 lbs. of N per acre per year, equivalent to 200 lb. of ammonium sulfate fertilizer per acre per year. Natural forest contains 17 percent of leguminous individuals whereas cacao with shade contains 14 percent of leguminous individuals.

Hydromorphic soils occupy alluvial flats or vegas and are favored by cacao planters because of their easy accessibility and good water relations, except when flooded. The effects of flooding may be overcome by planting the cacao in cambered beds separated by deep drains as successfully practised in Trinidad. Hydromorphic soils are easily distinguishable from Zonal Latosols and from Azonal soils by the variegated color of their profiles. The B-horizon is conspicously specked and mottled red or yellow on a grey ground. The mottling diminishes below and the greyness increases in the reduced gley layer. The humic A-horizon is usually peaty and highly acid in reaction. It is not suitable for growing cacao until the soil has been thoroughly drained. Aeration and root room are often lacking and harmful toxic conditions sometimes prevail because of the occurrence of ferrous compounds in the grey gley. Immature or undeveloped Hydromorphic soils are suitable for cacao cultivation provided they are under skilful management, but the continually moist environment is conducive to the spread of diseases and pests whose prevalence may reduce the crop to negligible proportions.

Calcimorphic soil groups *(Rendzina, Brown Forest Soil)* occur over soft limestone and marl. They are characterised by a thick, black or dark reddish-brown, well-structured, humic top soil (A-horizon) which sharply overlies the grey, yellow or bright brown parent material (BC-horizon). This in turn sharply overlies the white or grey calcareous parent rock. The parent material is a sticky clay, rich in shrinking clay minerals (beidellite, montmorillonite) which also occur in the humic soil, causing it to crack during dry weather. Calcimorphic soils grow excellent cacao provided their humic topsoil is thick (over 8 ins.) and neutral or acid in reaction. When they occur on steeply sloping ground, they are prone to erosion which, if severe, may expose the parent material, enriched by calcium carbonate, or the parent calcareous rock. If the cacao roots penetrate into these highly-alkaline materials, chlorosis may develop through suppression of the uptake of iron, accompanied by general malnutrition. Such chlorosis is known as "lime-induced chlorosis".

INTERPRETATION OF SOIL CONDITIONS FROM PROFILE FEATURES

1. *ROOT ROOM:* This may be deduced from:

   (i) *Thickness of the humic layer* which, in the case of fine sand and silt soils, determines the degree of stable aggregation. It should be *at least 6 ins.* for good cacao soil, better 12 ins., preferably more.

   (ii) *Structure of B-horizon* which may be markedly aggregated and stabilised by illuviation and deposition of ferric oxide within minute cracks and root traces, making it highly porous.

   (iii) *Structure of C-horizon* (Parent material) which may be aggregated or cracked depending on the nature of the parent rock and the degree of weathering.

(iv) *Structure of D-horizon* (Parent rock) which may be jointed or cracked, stratified or laminated, and horizontal or dipping at various angles.

(v) *Depth of water-table* (if any) and its fluctuations and degree of permanence.

(vi) *Depth of hard-pan* (clay-pan; iron-pan)

(vii) *Depth of parent rock.*

NOTE: *Root room* should be checked by observation of actual root penetration. The proposed West African standard of 5 feet for depth of soil required by cacao for satisfactory growth includes A, B and C horizons, where these are well-structured and easily penetrable by cacao roots.

2. *WATER SUPPLY:* (Storage water)

(i) *"Available" water:* May be deduced from humus and clay contents and the nature of the clay, and also from structure and texture. (Field capacity *minus* wilting point).

(ii) *"Usable" water:* May be deduced from degree of aeration above 10%.

(iii) *Permeability:* May be deduced from structure and texture (cross-sectional pores) degree of overlap of structure units and their orientation.

3. *AIR SUPPLY*

(i) May be deduced from structure and texture (porosity).

(ii) *Permeability to air:* May be deduced from structure and texture (cross-sectional pores).

4. *NUTRIENT SUPPLY:* May be deduced from:

(i) *Color* (degree of leaching). Red soils and grey soils are usually acid because of excessive leaching.

(ii) *Identity of parent rock minerals* and their degree of weathering.

(iii) *Identity of clay minerals.*

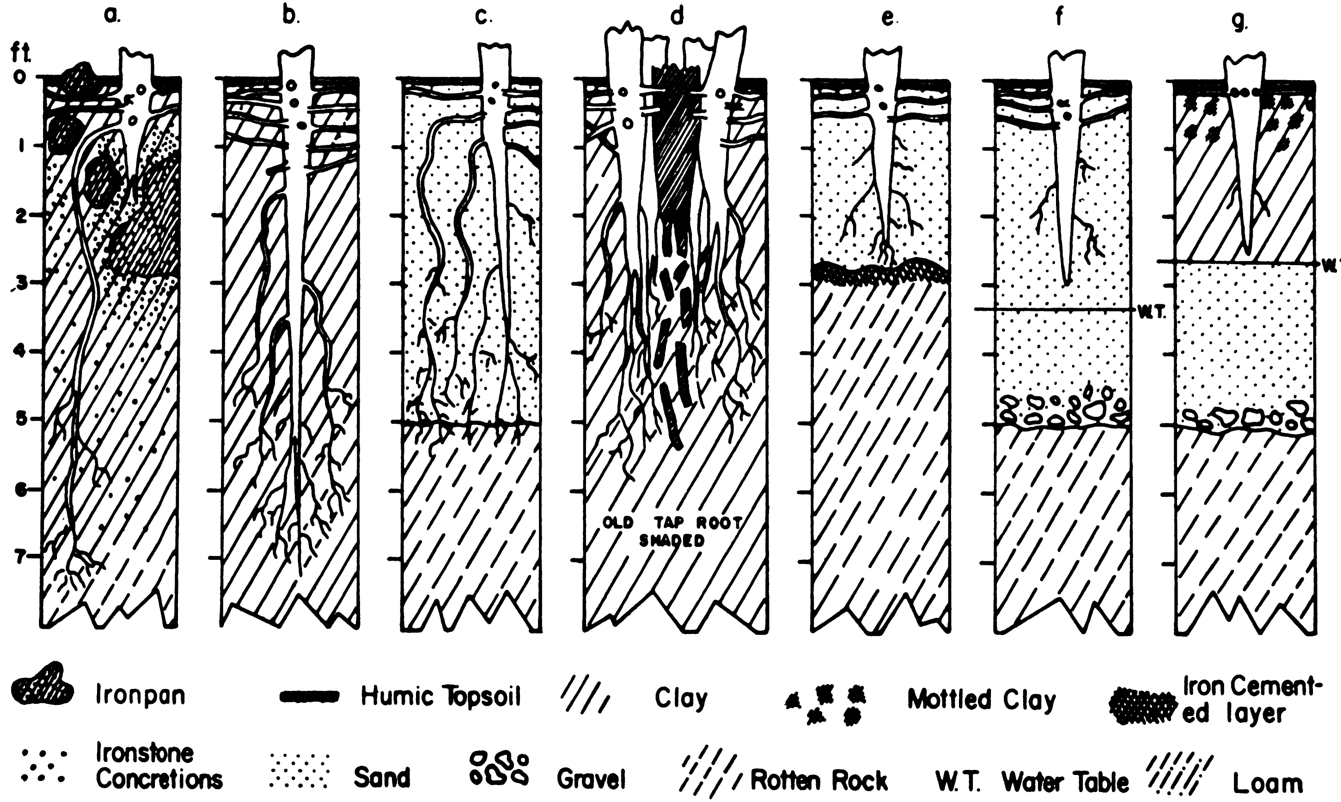
(iv) *Depth of parent rock* (brash and solid rock).

(v) *Presence of calcium carbonate,* gypsum, etc., and their depth of occurrence.

NOTE: The nature and composition of the vegetation often indicate the nutrient status of a soil.

FIGURE 4

MATURE CACAO ROOT SYSTEMS ASSOCIATED WITH TYPICAL SOIL PROFILES



5. *HARMFUL FACTORS:* May be deduced from:

   (i) *Color* (excessive acidity, excessive alkalinity).

   (ii) *Presence of harmful salts* (efflorescences)

   (iii) *Degree of aeration* (See 3) which indicates whether conditions are likely to be oxidising or reducing: *ie. whether* harmful protozoa are present.

The features of different kinds of cacao root systems associated with different kinds of soil profiles *(1)* are shown in Figure 4.

SUMMARY

1. The features of a satisfactory cacao soil are described. The formation of soil from parent rock and the development and differentiation of the soil profile are discussed. The distinguishing features of "good" and "bad" cacao soils are indicated in regard to depth, color, texture and structure, consistency and kind of parent rock.

2. The classification of cacao soils is considered in terms of the interaction of the five chief soil-forming factors, and the characteristics of six of the most suitable sorts are outlined.

3. The interpretation of the ecological relationships of cacao soils by inspection of the features of the soil profile is explained.

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PART IV:

HORTICULTURE OF CACAO

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CHAPTER 9

PROPAGATION BY SEEDLINGS*

(1) INTRODUCTION

The most commonly used method of growing cacao is from seed, and much of the cacao that is being planted at the present day is still produced by means of unselected seed, despite the fact that, in order to extend the highest yielding, disease resistant and good quality cacao, the production and planting on a large scale of rooted cuttings and buddings is essential. Nevertheless, renewed interest is being shown recently in the propagation of cacao from seed because of the remarkable performance of plants grown from seed produced by open pollination from selected clones, and particularly from seed of single cross hybrids between clones of Upper Amazon parentage and local selections, which have shown a high degree of hybrid vigor in their seedling progeny *(2)*.

The propagation of cacao by seedlings does not involve large investment in expensive propagating bins used for making cuttings, nor is any particular skill required such as is needed for making buddings and grafts. The growing of cacao from seed always incurs a risk, however, in that the producing capacity of the resulting trees cannot be predicted, since it varies considerably among the seedling progeny of a single pod.

There are two chief ways of growing cacao seedlings; (i) planting the seeds directly in the field and (ii) planting the seeds in a temporary nursery.

(2) DIRECT PLANTING

The cost of transplanting is saved by planting directly in the field, although it is more difficult to control diseases, pests and weeds in the field than in the nursery. During periods of drought, it is more economical to irrigate a small nursery than to irrigate a whole planted field. In a nursery, it is easier to eliminate a weak or poor plant. Although it may often be the intention of the planter who plants several seeds in one spot in a field to rogue out all but the most vigorous seedlings, in actual fact he does not like to pull up healthy plants, with the result that several trees are left growing in the same spot instead of only one.

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* This article is mainly based on a chapter by A. L. Erickson in the Cacao Manual, First Spanish (1957) Edition, pp. 57.64.

(3) PLANTING IN THE NURSERY

In the nursery, seeds are planted either in (a) specially prepared seed beds, (b) seed flats or (c) pots made of suitable material.

(a) Seed beds: For convenience, the nursery where the seed beds are to be constructed should be situated in the center of the area to be served by the nursery. It should be near a supply of water and accessible by road. The degree of shade should be carefully adjusted. The seed bed area should be level if possible, or situated on gently sloping ground. It should have good drainage. It should be sheltered from strong winds and it should have a fence built around it to keep out poultry, small domestic animals and nocturnal prowlers. If possible, it should not have been previously planted in cacao so as to avoid danger of soil infection from previous crops *(13) (4) (9)*.

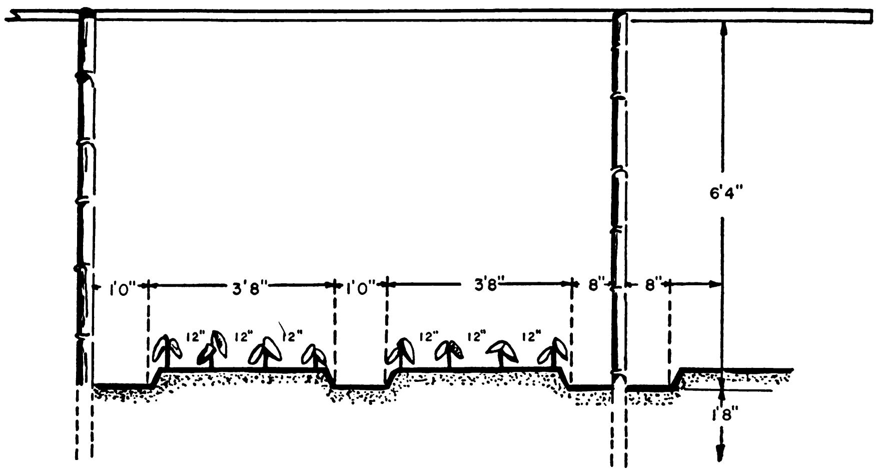
In the preparation of nursery beds, it is recommended to have the source of water in the center, especially if the nursery is large. No part of the nursery should be more than 50 or 60 feet from the water source because of the difficulty of handling a hose pipe more than 50 feet long. Some sort of a nozzle for the hose is needed to break the water pressure and to distribute the water over a wide area. Irrigation from small streams should also be provided if necessary. The beds should not be wider than 5 feet for easy working, and their surfaces should be raised so as to improve the drainage. An inclined roof should be erected over the seed bed to protect the seedlings from heavy rain showers.

The soil of the bed should be loose and friable. In order to avoid plant losses due to soil-borne organisms, it is advisable to plant the seeds in a surface layer of sawdust about 2 inches deep. If surface drainage is unavoidably unsatisfactory, planting the seed in a layer of sand will alleviate the condition.

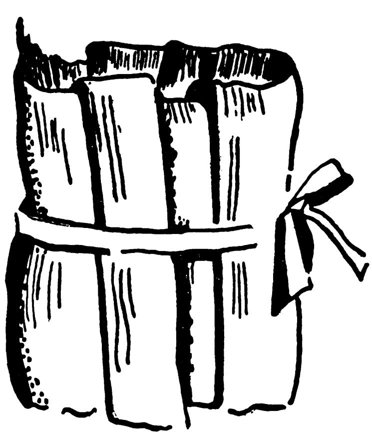
The depth of the soil in the seed bed should be large enough to allow unrestricted growth of the seedling. The structure of the soil should be such that seedlings can be lifted easily without damaging the tap roots. Many failures of transplanted seedlings can be traced to malformed or damaged tap roots resulting from careless nursery work or inadequate nursery supervision.

In regard to dimensions, a nursery of 35 square meters area, planted 30 x 30 cm., should supply enough cacao plants to plant up one hectare of land at spacing 5 x 5 m., or 52 square meters area for a spacing distance of 4 x 4 m. *(10)*. A suitable construction for a series of nursery beds is shown in the diagram below *(7)*.

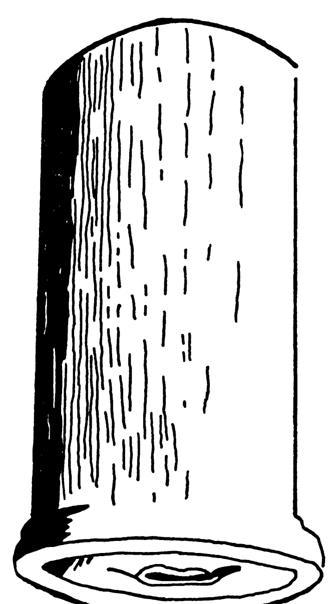
(b) Seed flats: These are considered to be less permanent than nursery beds and usually involve early transplanting to a more permanent site. This extra transplanting is a disadvantage. Each transplanting costs money and disturbs the seedling root system. Usually the seedlings in a seed flat are planted more closely than in a nursery bed. For this reason, fungus infection is able to spread rapidly from one plant to another. On the other hand, with such a concentration of plants in a relatively small area, it is easy to



Cross section of seed bed for cacao



Abaca pot



Bamboo pot

rogue out weak plants. Sometimes a farmer is forced to plant cacao seeds in seed flats when a shipment of seeds suddenly arrives without notice. His permanent nursery may not be ready and seed flats will serve as a temporary place until the nursery beds are prepared. Owing to the rather long tap root of a cacao seedling and the shallowness of the soil in the seed flat, it is best not to leave the seedlings for more than 30 days in the flat. In the preparation of a seed flat, the same general practices are carried out as for a seed bed. The soil should be loose, friable and well drained. The flat should also be adequately shaded.

(c) *Pots:* One advantage of planting seeds in pots is the ease with which they can be moved. If a cheap pot that disintegrates rapidly in the soil can eventually be found, the seedling with its pot could be placed directly in a hole in the ground, thereby not disturbing the root system. Sometimes the pots used at the present day disintegrate before the plants have been taken to the field and the plants have to be repotted. There are several types of pots that may be used, made from different materials, as listed below:

Banana leaf: These have the disadvantage that they generally decompose too quickly.

Abacá leaf (Musa textilis): These decompose too slowly and cacao roots have difficulty in penetrating the tough fiber. The fiber acts as a medium for certain fungus diseases which attack the root systems of cacao.

Asphalt roofing paper: Best results are obtained with 6-ply rather than 3-ply paper which disintegrates too rapidly. The pots are tubular in shape and the bottoms should be filled with dry straw or banana leaves.

Bamboo stem: This type of pot is the most commonly used. Thick bamboc stem is cut in such a way that the membrane at the node serves as the bottom of the pot. A hole is made in the membrane for drainage. The pot may conveniently be split into two pieces and afterwards tied together. When the split pot is placed in a hole in the field, the roots emerge between the halves of bamboo. Alternatively, the pot may be completely removed when the seedling is being planted.

Fiber: In Trinidad, pots made of a marantaceous plant, *Ischnosiphon arouma,* which grows in the forest, are bought ready for use. The fiber baskets used in Malaya are dipped in 1.2 percent solution of copper naphthenate; they last for 6 months. If they are treated with a more concentrated solution of this substance, they take too long to disintegrate when planted out in the field *(13).*

Cacao pods: It has been suggested that seeds may conveniently be planted in cacao husks.

Waxed newspaper: Although paper pots can be made up cheaply, they lack strength and durability.

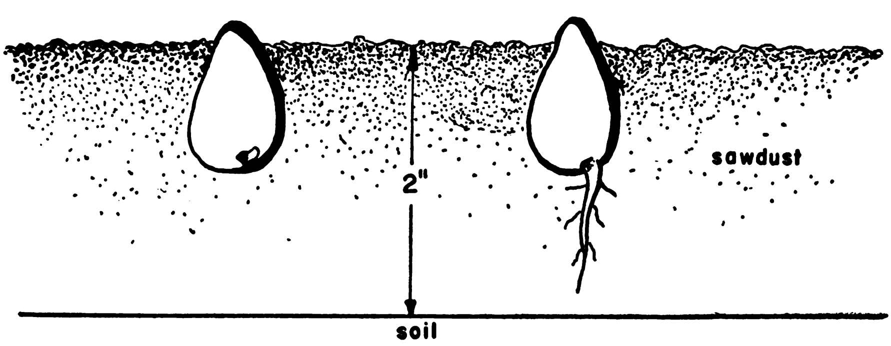
Burlap: Small bags sewn from burlap may be used, but these too lack rigidity.

Plastic: The newest, and in many respects the best, material for making pots is polyethylene or polythene sheet either white or black. Pots made from this plastic are cheap (about 2 cents U. S., 12 x 7 inches diameter.). They are extremely durable, light in weight and pliable. They are made with drainage holes in the side and base. They should not be placed in the planting holes when they contain soil with rooted plants, because the plastic material does not decompose quickly enough. The plants and soil must be taken out first, or the bags slit or cut and removed before planting.

Redardless of whatever type of pot is used, a well-composted soil should be prepared for filling them. A satisfactory compost may be made with the following ingredients *(13)*. Seven parts good soil, three parts well decomposed manure, two parts sand, plus 1 ounce of double superphosphate per pot.

(4) PLANTING THE SEEDS

Whether cacao seedlings are planted in nursery beds, seed flats or pots, they are planted in the same way. Only ripe pods should be used for the seed supply. Care should be taken in cutting open the pods that the seeds are not cut in two by the stroke of the knife. The seeds should be planted immediately. There is some doubt as to the advantages of removing the sticky mucilage. At Turrialba, it is not removed; in Malaya, the seeds are rubbed with sand *(13)* and in Trinidad with coconut fiber *(14)* to remove the mucilage. It has been recommended *(7)* that the seed be submerged in a suspension of plant ash for 20 hours to remove the mucilage and then washed with water. Peeling the seeds (removing the testa) speeds up germination by a few days, but the slight gain in time is hardly worth the labor involved. Soaking the seeds in dilute sulfuric acid, pH 3.8, for 12 hours before planting has been suggested *(3)*. The seeds should be planted about 2 inches deep, requiring 3 to 4 weeks for germination *(14)*. Strong seedlings may be obtained by planting the seeds 1 to 2 inches deep with the hilum scar downwards, or by planting them horizontally *(6)*. Many planters recommend using only the seeds that occur in the center of the pod. It is true that these weigh more than seeds at the ends but, provided undeveloped seeds are discarded, there is not any valid reason why all the seeds in the pod should not be used for planting.



How to plant cacao seeds

(5) CARE AFTER GERMINATION

It is necessary and advisable to control diseases with 2-2-50 Bordeaux mixture, or some other fungicide, sprayed onto the seedlings. Weeds must be kept down in the seed bed and, during dry weather, the seedlings must be watered.

(6) TRANSPLANTING

Whether seedlings should be transplanted with or without a ball of soil is debatable. If seedlings are transplanted with soil from the same nursery area over a number of years, a depression in the surface of the beds appears, owing to the constant removal of soil. An experiment aimed at comparing methods of transplanting using plants 15 months old, comprised the following treatments *(11)*. (i) Ball of soil and leaves intact, (ii) ball of soil and leaves cut in half, (iii) ball of soil and stem cut back to 30 cm., (iv) bare root and leaves intact, (v) bare root and leaves cut in half, (vi) bare root and stem cut back to 30 cm. The results of this experiment showed that the best method was No. (vi) bare root with the stem cut back to 30 cm.

Once the plants have been planted out in the field, the routine control of aphids, thrips and other insect pests is essential, employing insecticides such as Aldrin or Malathion. As the plants grow, the frequency of spraying with Bordeaux mixture, used for controlling diseases, should be increased. Plants ought not to be transplanted to the field unless adequate shade is provided. This should be regarded as a golden rule in cacao growing. Weed control is essential to the establishment of young cacao. Recent investigations, carried out at Turrialba, Costa Rica, show that, if young cacao plants are removed from the nursery and covered immediately with a polyethylene bag, they may be transplanted with excellent success without cutting back, provided they are planted under shade, and provided the polyethylene bags are not removed for three to four weeks following transplanting.*

(7) SHIPMENT OF CACAO SEED

The cacao bean is a non-resting seed which is ready for germination as soon as the fruit is ripe (8). It loses its germinating capacity after a short storage period. When the pod remains on the tree, germination often occurs within the pod. Seeds contained in pods that have been stored at 70º to 80ºF for 8 to 10 weeks are usually still viable *(8)*. It has been recorded that some 5000 cacao seeds sent from Ghana, West Africa, to the Far East (Malaya, Borneo, Sarawak) germinated satisfactorily *(12)*. Unsterilized charcoal was used as the packing material in all but two tins which were packed with damp vermiculite. Two parts of water-saturated charcoal were mixed with 9 parts of dry charcoal. All the seeds were packed with the pointed ends upwards. After 9 days of transport, 100 percent germination was obtained.

Cacao seed is stated to be viable for a considerable period of time before the pod is fully ripe *(5)*. While in storage, beans need free access of air but require protection against loss of water. Hence storing cacao beans in charcoal powder of 30 percent moisture content in a perforated container permitting a sufficient oxygen supply is recommended *(5)*.

Cacao seeds for air transport should be washed, dusted with Fermate and packed in alternate layers with charcoal in a perforated container. If weight is not an importat factor and cacao pods are preferred for shipment, it is advisable to dip the intact pods first into paraffin wax. The high cost of air freight precludes the choice of pods for international shipments and the less bulky seeds are preferable.

It has been recommended that seeds for transportation be dipped in a suspension of hydrated lime which helps to dry up the mucilaginous layer, and then the outer seed coat (testa) removed. Seeds thus prepared and treated with a suitable

* E. Camacho; private communication.

fungicide are then packed in polyethylene bags. It has been found that they remain viable for long periods when shipped in this way *(1)*. Recently a shipment of approximately one quarter of a million cacao seeds was made between Costa Rica and Nicaragua by a modification of this method in which sawdust was used instead of lime to facilitate the removal of the testa. Germination was entirely satisfactory.* Cacao seed prepared by the charcoal method may also be packed, together with the charcoal, in polyethylene bags and good germination may subsequently be obtained.*

(8) GERMINATION OF CACAO SEED

Recent experiments carried out at I. I. C. A., Turrialba, Costa Rica,* have shown that cacao seeds from which the testas have been removed will retain their germinating capacity only if kept in an atmosphere completely saturated with water vapour so that they do not lose any of their moisture content. In one trial, seeds exposed throughout the period of the experiment to air at 100 percent relative humidity for 29 days gave 87 percent germination and the moisture content of the cotyledons was maintained at around 50 percent throughout, whereas seeds exposed to air of 90 percent relative humidity showed complete absence of germination after 29 days and only 12 percent of the seeds germinated after 22 days. The moisture content of the seeds kept at 90 percent humidiy had fallen from 45.3 to 14.4 percent in 21 days. Seeds exposed to air of 50 percent humidity showed 48 percent germination after 8 days but none at all after 15 days; their moisture content had dropped to 10.0 percent in 7 days and to 6.8 percent in 14 days.

When the naked cacao seeds were placed in polyethylene bags, they showed 86 percent germination after 29 days and their moisture content had not dropped but had remained steady at about 50 percent. The relative efficiency of the polythylene bag method of storage during shipment, as compared with the moist charcoal method, was found to be much the greater. After 28 days, during which period the seeds were transported from Turrialba to San José and back, seeds stored in a polyethylene bag showed 70 percent germination and their moisture content was maintained at 51.2 percent, while seed stored in moist charcoal in a box began to germinate after 14 days and showed only 12 percent total germination, although their moisture content still remained high, presumably because the beans had absorbed a considerable amount of water from the moist charcoal. Such absorption, followed by germination in the box, might have been diminished or prevented by using less water for the initial moistening of the charcoal.

SUMMARY

1. Interest in the propagation of cacao by seedlings has recently been revived through the discovery that certain single-cross hybrids possess extraordinary vigor and that high-bearing, disease resistant, good quality cacao, produced by selection, is becoming available in increasing quantity as seeds for propagation by seedlings.

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* J. R. Hunter: private communication.

2. Propagation by seedlings is cheaper and easier than propagation by cuttings or buddings.

3. The procedures used in the nursery for raising cacao seedlings in seed beds, seed flats and pots constructed of different materials, are outlined.

4. The methods used in transplanting cacao seedlings from the nursery, and in shipping cacao seeds from one place to another, are described. The relative merits of the charcoal method and the plastic bag method for the transportation of cacao seeds are considered.

5. The conditions controlling the germination of cacao seeds are discussed in relation to seed transportation.

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CHAPTER 10

PROPAGATION BY CUTTINGS*

(1) INTRODUCTION

The environmental conditions that are necessary for the successful rooting of cacao cuttings were first investigated at the Imperial College of Tropical Agriculture in Trinidad *(30) (6)*. Subsequently, they received much attention at other centers of research.

The chief requirements *(10) (11) (12)* are:

(1) *Sufficient leaf area to ensure* the production of enough carbohydrate by photosynthesis to supply the needs of the developing root system and for the continued life of the cutting.

(2) *Adequate light intensity* for these same reasons.

(3) A steady air temperature between 80º and 84ºF 27º and 29ºC).

(4) *A completely saturated atmosphere* to ensure maximum turgor of the leaf cells.

(5) *A suitable moist rooting medium* allowing adequate aeration and free drainage and, at the same time, providing enough water to maintain cell turgidity in the leaf tissues.

(6) *Absence of pathogenic fungi and bacteria,* as well as other harmful organisms, including nematodes that sometimes infest the rooting medium.

(7) *Presence of growth hormone* in sufficient amount to stimulate root development.

These various conditions were fairly well realised in the original type of rooting bin or propagator developed in Trinidad in 1931 *(30)*. In recent years, improved types of propagators have been suggested and tried and some are described below. Certain of them aim at lowering the cost of construction in order that the apparatus can be made by the small cacao grower whose resources are limited.

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* This article is mainly based on a chapter by A. L. Erickson in the Cacao Manual, First Spanish (1957) Edition, pp. 65-90.

(2) NOTES ON THE FACTORS

(1) *Leaf area:* The exent to which leaf area may be reduced is determined by the amount of stem with which the leaves are associated in the cutting. It is minimum in the half single-leaf cutting sometimes employed for propagation. The usual number of leaves in a cacao cutting is 6 or 8, but often half of each of these is removed so as to prevent mutual over-shading.

(2) *Light* and (3) *Temperature:* The minimum light intensity to which cacao cuttings can safely be exposed depends on the air temperature in the bin *(11)*. It is necessary for success that the rate of photosynthesis slightly exceeds the rate of respiration, otherwise carbohydrate starvation will occur. At temperature 32°C and light intensity 100 foot candles (which is less than one percent of full sunlight*) the cuttings become starved of carbohydrate whereas, at 27°C and 300 f. c. light intensity, they are not starved and prolific rooting occurs in about 3 weeks' time. It is difficult to separate the effects of light from those of temperature in the closed cuttings bin, since the higher the light intensity the higher the temperature. In practice, the light intensity is kept below 5 percent of full sunlight (or between 300 and 700 f. c.) otherwise the temperature rises too high. On the other hand, if it be kept too much below 5 percent, starvation occurs and the leaves turn bright yellow, the yellow coloration beginning at the base of the lamina near the veins. The ultimate death of the leaves is assured by the action of parasitic bacteria. The best average light and temperature therefore are around 500 f. c. and 28°C (82°F).

Light of suitable intensity is provided in most propagating stations by overhead shade consisting of bamboo slats or special fibre netting which lets through about 25 percent of the sunlight, and by cloth or newspaper covers placed over the glass or transparent plastic lids of the bins, or by stout cloth or burlap which are sometimes used instead of glass. These covers further reduce the light intensity to about 5 to 10 percent of full sunlight within the bins. If the days are hot, the temperature of the air in the bins is kept under control by running or sprinkling or spraying water over the cloth or paper covers of the lids.

When cuttings are rooted in open bins or troughs or in shallow pits in the ground, without covers, the leaf temperature may be kept down by means of a continuous mist spray falling directly upon the leaves, irrespective of light intensity. Under high light intensity, however, there is a risk of bleaching the leaves through the destruction of chlorophyll. At light intensities less than 85 percent of full sunlight, bleaching is greatly reduced although the leaves may turn pale. At intensity 25 percent, paling does not occur appreciably and the condition of the cuttings is improved.

(4) *Humidity:* It is imperative to maintain the air in the cuttings bin at 100 percent saturation all the time *(11)*. This cannot be ensured, however, at light intensity 5 to 10 percent of full sunlight, except by frequent sprayings

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* Values given in the literature for full sunlight in the tropics range from 13,000 to 20,000 foot candles.

of the cuttings with water. The intervals between sprayings may be widened by providing a free water surface under the rooting trays in the bin. Even then the humidity often falls to 90 percent during the hottest part of the day, necessitating occasional supplementary spraying.

In mist-spraying, a saturated atmosphere is maintained by providing a sloping roof of tightly-stretched cloth immediately above the cuttings, and mist-spraying the surface of this cover instead of the surfaces of the leaves.

(5) *Rooting medium:* The suitability of a rooting medium depends on the amount and frequency of the watering. In the case of sand, the optimum amount of water varies with particle size. Media composed of solid discrete particles allow less latitude in amount and frequency of watering than media whose particles are porous and contain internal air spaces, as for example, vermiculite, rotted sawdust, rice hulls, coffee husks and coconut fibre. Vermiculite deteriorates with age, because of collapse of structure.

Rooting response depends largely on the composition of the air in contact with the cut surface *(11)*. In air saturated with water vapour, a pad of callus is produced by the cambium. This greatly delays the initiation and development of root primordia if it is too thick. In air devoid of oxygen, the end of the cutting soon rots. With higher oxygen content, little callus is formed at the ends of the cuttings but rods of callus emerge from the lenticels, and root primordia are not produced. When the composition of the air is most suitable, neither pods nor callus rods are formed but the whole of the cambium for about half a centimeter from the end of the cutting swells up and root primordia rapidly appear. Prolific rooting then takes place within 13 to 15 days. It is essential for succssful rapid rooting that the air-moisture relations of the rooting medium be carefully adjusted so that optimum conditions prevail *(11)*.

The merits of different rooting media have been investigated by many different horticulturists working on cacao propagation, and varying conclusions have been reached *(15) (29)*. On the whole, the most satisfactory medium appears to be sawdust (particularly coarse balsa wood sawdust used in Ecuador) provided it is frequently renewed.

(6) *Pathogens:* Attack by fungi is generally rapid whenever the intercellular spaces in the leaves of cacao cuttings become injected (or gutted) with water (11). In order to prevent or to reduce pathogenic infection, the rooting medium should be sterilised by the application of a suitable fungicide. Certain proprietory materials, for example Zerlate and Fermate, have been found to be particularly effective in controlling cuttings bin diseases *(8)*.

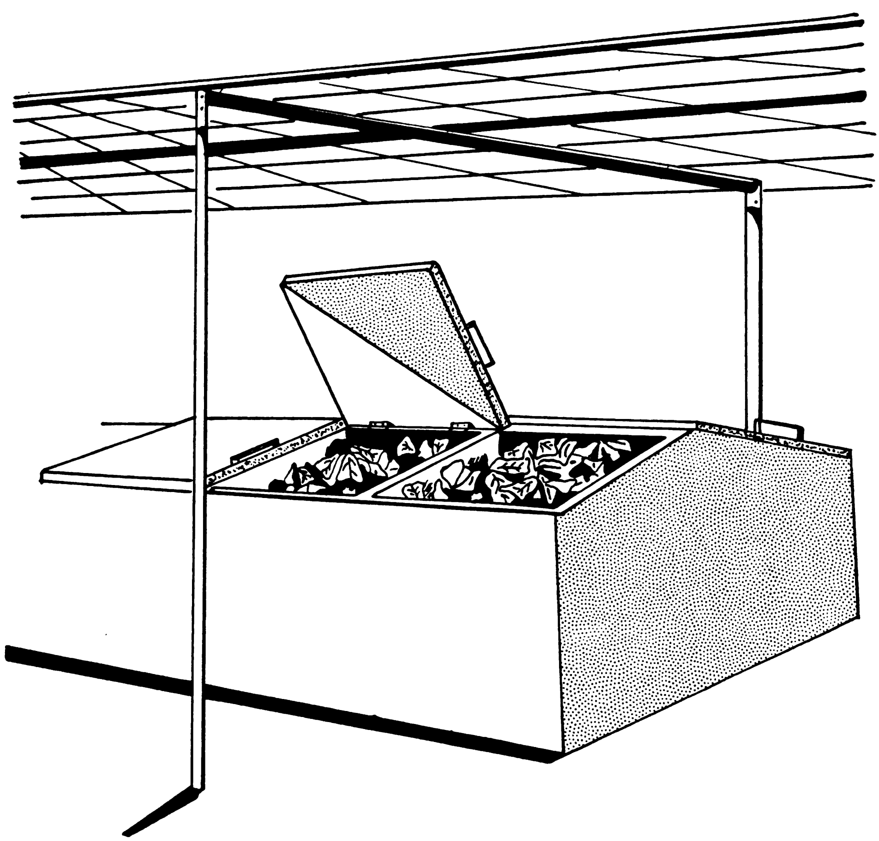
(7) *Hormone:* The application of growth-promoting substances to the ends of cacao cuttings in order to stimulate root formation has become established practice in nearly all rooting techniques. The most effective substance is a mixture in equal proportions of beta-indolyl-butyric acid and gamma-naphthlalenic acid *(11) (12)*. Aqueous solutions containing 80 to 100 mg. per litre are used in the 24 hour dip method *(7) (11)* or 8 mg. per cc. of 50

percent alcohol in the instantaneous method applied to the ends of cacao stem cuttings. *(11)*. Hormone preparations may be used in powder form with talc as the base *(3)*.

(3) EXAMPLES OF CUTTINGS BINS IN USE

The following types of cuttings bins or propagators include most of those that are in use in the cacao-growing countries of Central and South America at the present time. All of them give satisfactory results and the choice of any one of them should be decided by local circumstances *(26)*.

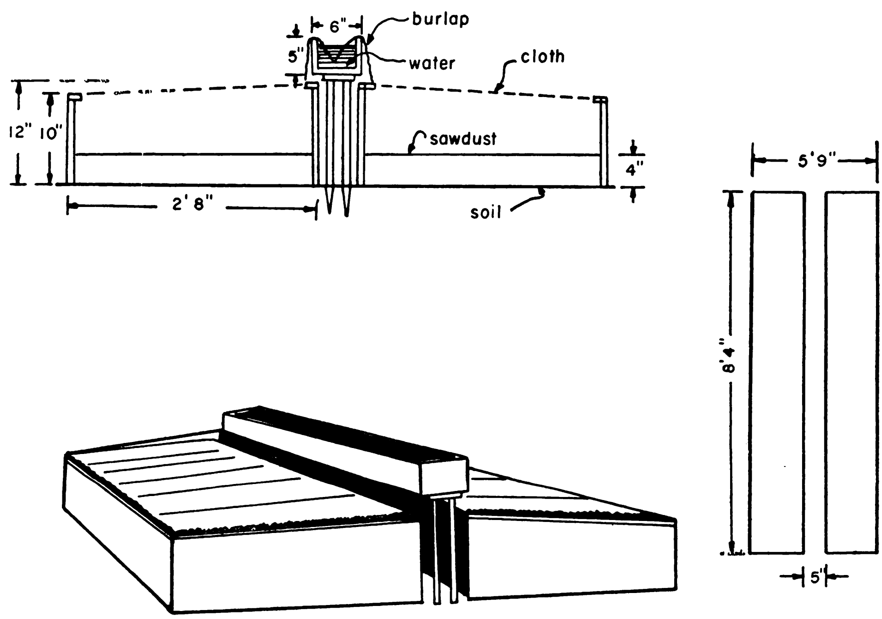
(1) *Trinidad*



Trinidad Propagator

The Trinidad type is made of concrete *(6)*. Large stones and coarse gravel are used for improving the drainage in the bins. Coarse calcareous sand is used as rooting medium. The bins are closed with frames made of calico cloth, or with glass frames covered with a double layer of cheesecloth. These covers are kept moist by hosing. Overhead shade is used. The cuttings are watered at 8 AM, noon and 4 PM, until water runs out of the drainage holes in the bottoms of the bins.

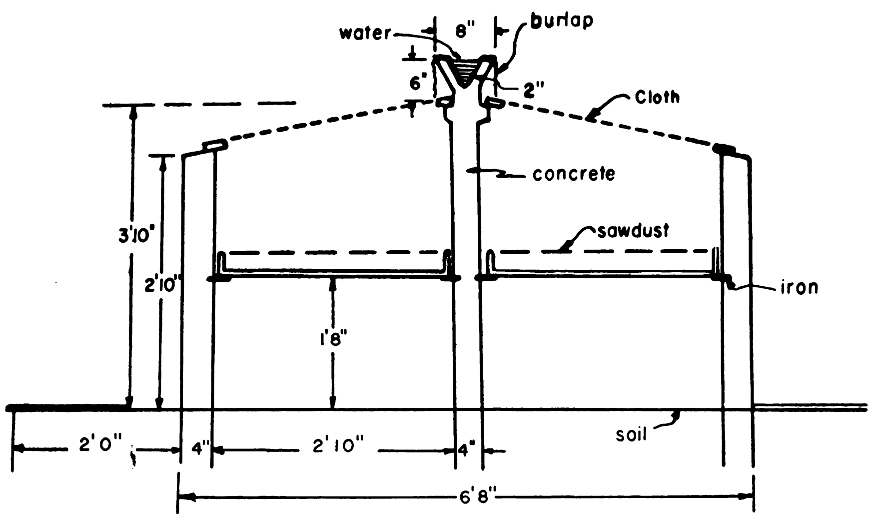
(2) *Turrialba Nº 2*



Turrialba N°2 propagator

This is a bottomless rectangular wooden box specially designed for small growers who are not able to make heavy investment in permanent structures *(1) (9)*.. The cloth covers are of coarse muslin and are maintained constantly wet by water flowing from a trough through strips of burlap acting as a wick. The water level in the trough is controlled by a float valve which is usually disconnected at night. Sawdust is used as the rooting medium.

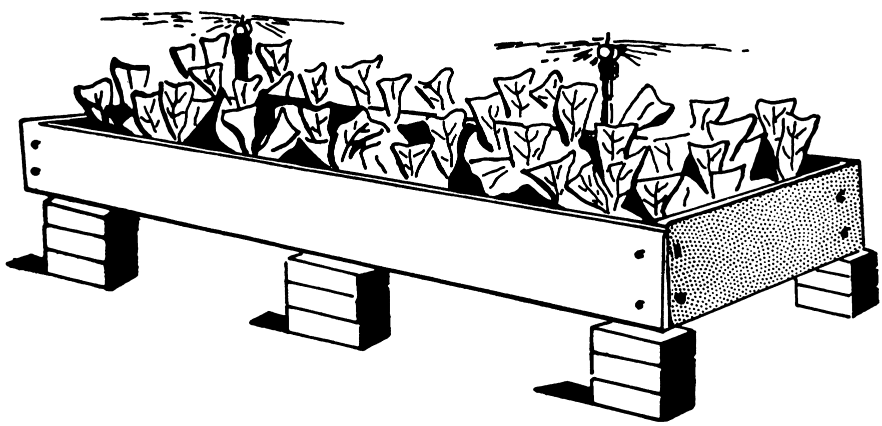
(3) *Turrialba Nº 3*



Turrialba N°3 propagator

This works on the same principle as Nº 2 but, being built of concrete, it is a more permanent type *(1)*. In both types, the cloth covers are sprayed with Bordeaux misture to protect the material from decomposition. Brass nails are also used in the construction, and the wooden frames are kept painted. Wooden trays containing the rooting medium rest on pegs 3/8" long, embedded in the cement walls. Wooden legs are also sometimes provided.

(4) *Open spray bed propagator*

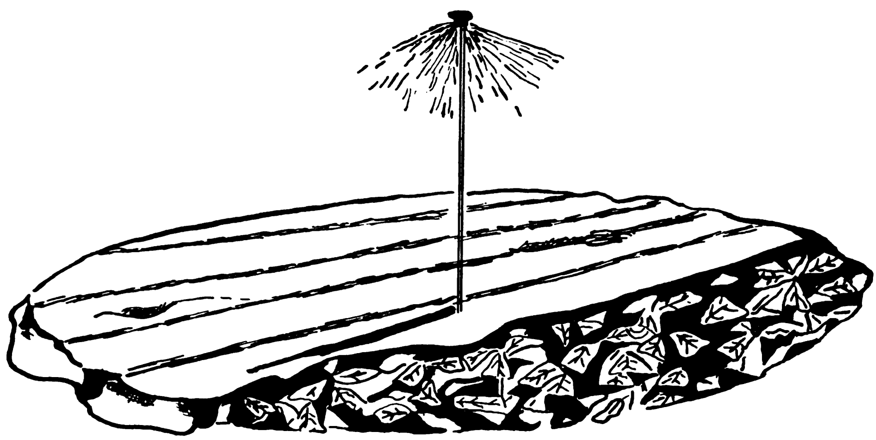


Open spray bed propagator

To ensure success with this type of propagator, a steady reliable water pressure is essential *(21)*. When the pressure drops, the water comes out in streams instead of as a mist. Cuttings in between these streams of water dry out, turn yellow and die. It has been reported that *(10)* when the water pressure drops to 5 to 10 pounds per square inch during the hottest part of the day, it is necessary to use coarse nozzles (O.C.02 Tee-jet) to ensure mist coverage. With high pressures (50 lbs.) finer tee-jet nozzles are recommended. Good drainage is essential to avoid waterlogging of the rooting medium. Quartz sand of particle size 2.5-2.0 mm. has been recommended as a satisfactory medium and is used for that purpose in Trinidad *(10)*.

This type of propagator is said to have a lower efficiency than closed bins *(31)* but it is cheaper to construct and requires less labor to operate. It consumes 5 times as much water as the closed bin and requires 50-pound pressure for the proper functioning of the nozzles. The constant mist frequently causes leaching of nutrients from the leaves.

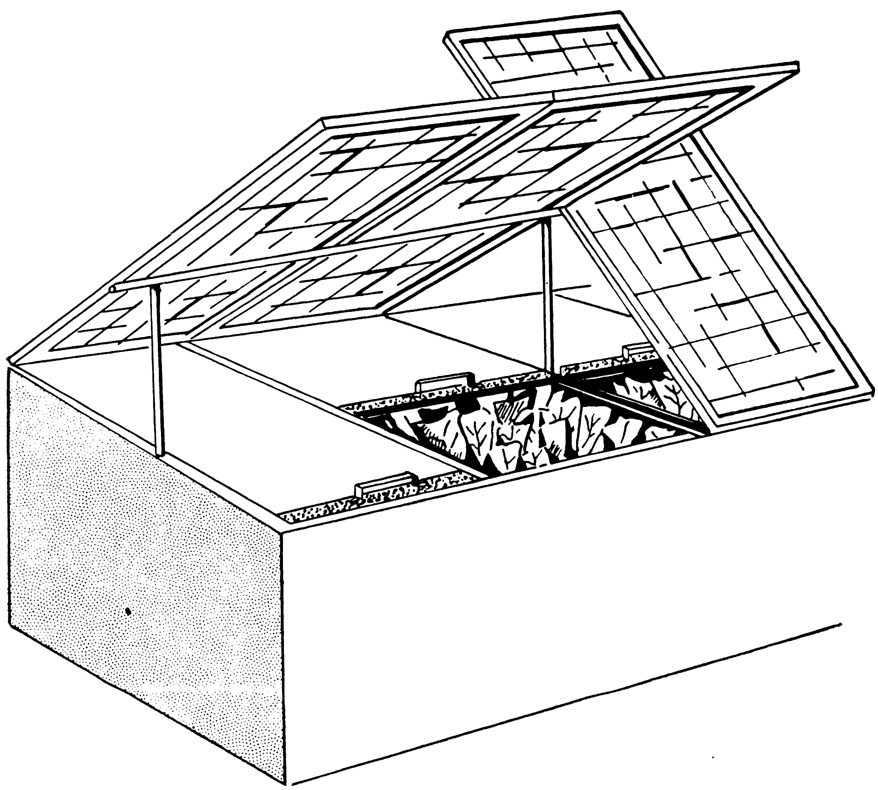
(5) *Circular pit*



Circular pit propagator

This propagator *(18)* consists of a circular pit, 22 feet in diameter and 1 foot 8 inches deep. A ditch at the bottom provides drainage. The rooting medium is sawdust and is placed on a 3 to 4 inch layer of gravel. The soil under the gravel must be free draining. The whole cavity is covered by jute cloth suspended on wires strung radially from a center post. A rotary lawn springler is mounted in the middle, 3 feet above ground level. It is turner on three times daily for a period of 20 to 25 minutes in dry periods and 10 to 15 minutes in wet periods. The sprinkler is occasionally turned on at brief intervals to keep the cloth wet. The cuttings are afterwards hardened for 30 days before being removed from the pit. This propagator is cheap and easy to construct but, during heavy rains, it is prone to waterlogging.

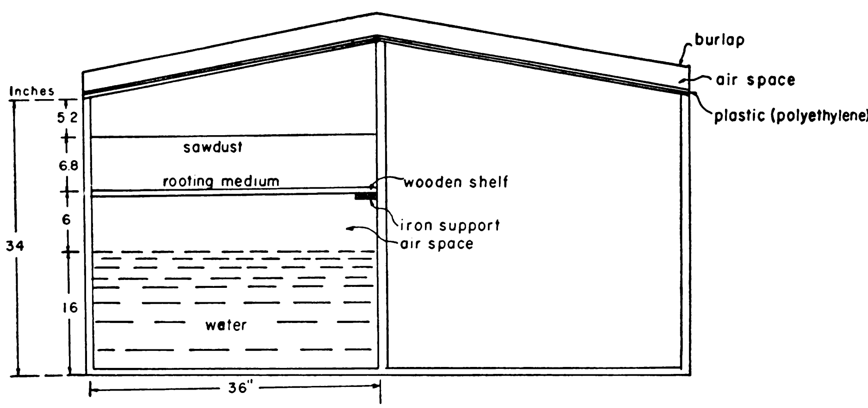
(6) *Surinam type*



Surinam propagator

The Surinam type is a larger version of the Trinidad type *(31)*. Its dimensions are $2\frac{1}{2} \times 1\frac{1}{2}$ m. (8 x 5 ft.) with no center wall. The back wall is higher than the front. The frames used as covers are fitted with clear glass. Instead of cloth covers, mesh screen, made of a reedy plant *(Ischnosiphon arouma)* is used which gives 75 percent shade. The screen is set on an axle running the length of the propagation bin and can be tilted to any angle depending on the position of the sun. These screens are removable in rainy weather. Sawdust is the rooting medium. Internal irrigation is provided. The bottom drainage material consists of stones and gravel.

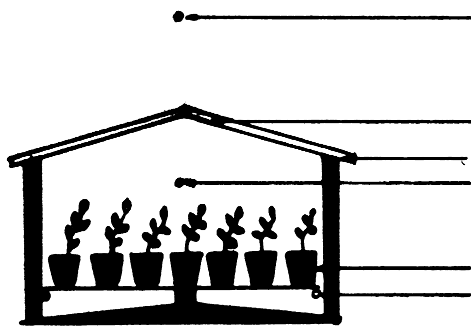
(7) *Clementina type*



Clementina propagator

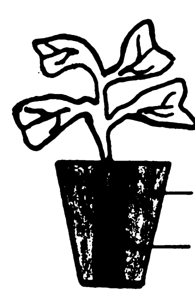
The Clementina propagator *(31)* is similar in construction to the Trinidad type but it includes Fiester's adaptation *(14)*. Here, the rooting medium is placed on wooden trays with wire mesh bottoms for free drainage. The frames are covered with polyethylene instead of glass and four inches above them there is a second covering of jute cloth. The insulating air space between the double covers maintains an even temperature inside the bins.

(8) *La Reunión (Trinidad) type*



La Reunion propagator

This propagation bin is at present being used by the Cocoa Board of Trinidad and Tobago *(31)*. It incorporates the chief features of the Surinam and the Clementina types in which the center wall and every alternate cross wall have been removed. The cuttings are rooted directly in baskets containing a core of sawdust, surrounded by soil (see diagram) *(20)*.



The covers are made either of cloth or of polyethylene depending on whether a water bath is used below. The advantages of this kind of propagator are cheaper construction, because of the absence of cross walls, and the elimination of bulky drainage and rooting media.

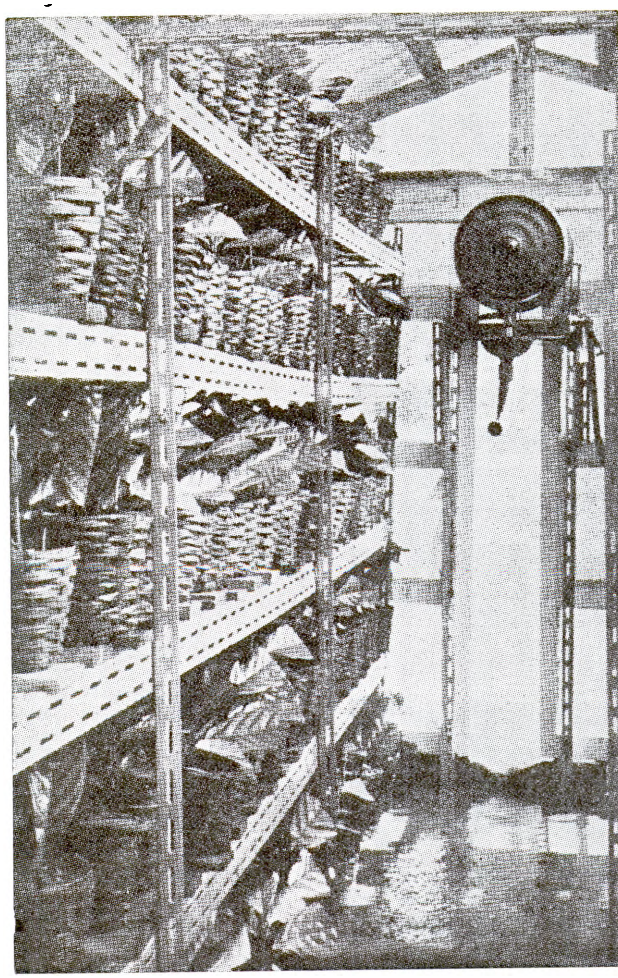
(9) *Glass house with centrifugal humidifier*

This propagating unit *(11) (22) (23)* consists of a glasshouse with a centrifugal humidifier. Its use is discussed later in connection with the hardening of cuttings. The glasshouse is 7 x 4 x 3 m. (23 x 13 x 10 ft.) dimensions and is completly enclosed but not airtight. The roof is made of "Windolite" plastic and is shaded to 25 percent of full sunlight intensity. The centrifugal humidifier is mounted high up at one end. It employs a 1/4 H. P. electric motor, and requires 30 to 35 litres of water per hour at 20 ponds per square inch pressure. There is a 50 to 60 centimeter space between the shelves. The cuttings are rooted in baskets with a core of coconut fiber residue. The humidifier is turned off in rainy weather and at night. There is a minimum amount of water used and leaching of the soil does not take place. According to the author, the cost of the glasshouse and humidifier is less than that of closed concrete bins.

A method has also been described of combining already-existing closed bin propagators with the humidifier glasshouse *(24)*. Cuttings are placed in closed bin propagators for a pre-rooting period of 15 to 18 days' duration. The cuttings are then pulled up and those showing the beginnings of root development are potted in soil-filled baskets and placed in the humidifier glasshouse. Cuttings showing no signs of rooth initiation are discarded. Root growth requires less aeration than root initiation. When once started, root growth will continue in soil and there is no need for a central core of rooting medium in the pot of soil.

(4) THE USE OF POLYETHYLENE SHEET AS COVERING FOR ROOTING CACAO CUTTINGS

An entirely different and new method for producing cacao cuttings has been discovered in which the unique properties of polyethylene (or polythene) sheet are utilised. The first successful attempt in this direction seems to have been made in Ghana at the West African Cacao Research Institute *(4)*. A nursery bed, 6 x 3 feet by 6 inches deep, is first prepared under shade provided by laths of split bamboo. It is well watered. One hundred 2-leaf cacao cuttings are set out in this bed with the stems at an oblique angle to the soil surface so that the leaves lie on it. The ends of the cuttings are first dipped in hormone solution ("quick-dip" method). A large sheet of polyethylene is then placed over the cuttings and weighted down round the edges. No further watering is done. After one month, the cuttings are lifted. In an experiment at W. A. C. R. I., Ghana, 57 percent of the cuttings were healthy and well rooted, 41 percent were healthy but not yet rooted and 2 percent only were dead. It should be noted that polyethylene sheet restricts water-vapor diffusion but, at the same time, allows gaseous diffusion.



Glass house with centrifugal humidifier

A modification of this method, also invented at W. A. C. R. I., Ghana, consists in putting hormone-treated 2-leaf cuttings, with the leaves trimmed to two-thirds their area, into 6-inch baskets containing soil surrounding a central core of sand-compost mixture *(19)*. Fifty to 100 of these baskets with cuttings are placed together on the ground, watered thoroughly and then tightly covered with polyethylene sheet weighted down at the edges. Shade is provided by bamboo slats giving 15 percent of full sunlight over the cuttings under the sheet. Rooting occurs in 3 weeks. The sheet may have to be removed and the cuttings watered once very three days. The rooted cuttings are at once hardened off by uncovering the baskets for a few hours each morning. The cost of producing cuttings by this method is less than one-third of that of producing them by the bin method. The polyethylene sheet may be used several times and lasts at least 18 months without deterioration.

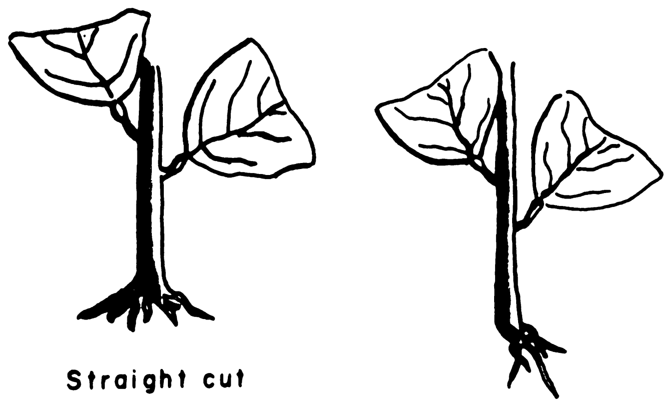
Further modifications, used in the Ivory Coast, have also been described *(5)*. Another, used in Ecuador, consists of a shallow rectangular pit under bamboo slat shade in which baskets with cuttings are placed and covered with polyethylene sheet weighted round the sides with wooden poles.

An even simpler method has recently been suggested *(27)* in which cacao cuttings are rooted entirely in polyethylene bags. A cutting carrying 4 to 6 trimmed leaves is dipped in hormone solution and its end wrapped round with wet sawdust held in coconut fibre. The cutting with its ball of sawdust is then put into the bag, a little water added, and the neck tied up with string. The bag is hung up in a shady place which allows 7 percent of the sunlight to reach the cutting. Roots appear in about 22 days' time. The rooted cutting is then planted out in the field with the bag placed over it. The bag is removed in about 5 days' time, and used again.

(5) PROCEDURE FOR PREPARING CUTTINGS FOR ROOTING

(i) *Selection of material:* Successful rooting can only be ensured if the material to be used is carefully selected. The leaves of the flush to be rooted should be green and mature, and the stem should still be green but just about to turn brown *(11)*. Some authorities prefer that the wood be a little older than this. Stems carrying flowers should not be used, as the wood is too old. The last two flushes on a branch may safely be used. The branch carrying the cutting should not be exposed to full sunlight. The best cuttings come from the inner shady parts of the tree. If there is likely to be any delay in transporting cuttings to the propagator, it is best to wrap them in damp cloth or paper. Cuttings are best taken in the early morning.

(ii) *Cutting off:* An average cutting carries 4 or 5 leaves, or up to 8 or 9 leaves if material is plentiful. It should be severed from the branch by a cut made at right angles to the stem axis with a sharp knife. If made at an angle, roots may develop only on the lower side. It does not seem to matter whether the cut is made midway between nodes or just below or just above a node, but it is recommended that it be made about one-quarter of an inch from a node *(31)*. The bottom leaf should be removed to facilitate insertion into the rooting medium. The larger leaves should be cut in half to save space in the bin and to reduce self shading. It has been demonstrated that carbohydrates are not transported from the illuminated part of a leaf to the part in the shade. At least 10 to 15 percent of the leaf surface is needed to keep the leaf alive by providing the requisite amount of carbohydrate.



(Diagram, p. 76, Manual)

(iii) *Hormone treatment:* The following instructions refer to the preparation of a suitable hormone powder containing fungicide *(3)*. Weigh out 800 mg. (0.8 g.) of indolyl-butyric acid, dissolve it in 50 cc. of absolute alcohol, mix in 70 g. of talcum powder enough to make a uniform paste, using a glass vessel, dry in air for 24 hours, and mix the powder with 30 g. of Phygon XL. Keep in a well-stoppered bottle to avoid dampness. The mixture contains 8000 parts per million of growth promoter and 30 percent of Phygon. Higher concentrations should be used for stimulating rooting in clones which produce roots with difficulty *(32)*.

Many chemical compounds used as hormones will not dissolve in cold water and must therefore be dissolved in hot water or alcohol. Hormone preparations should be stored in dark bottles in a dry cool place, and should be carefully labeled with the exact concentration. It is a good practice to prepare fresh hormone every 6 months. Some quick calculations to help those making their own preparations are as follows:

1 part per million = miligram per litre
1 gram per 100 cc. = 1 percent of solution

The safest way to apply hormones to cuttings is in liquid form, because there is then least danger of applying too much. The "quick dip" method is generally recommended in which the cuttings are dipped for a few seconds in the solution. If hormones are in powder form, the cuttings are gently tapped after dipping into the powder to remove excess adhering to the basal portion.

(6) SETTING AND CARE OF THE CUTTINGS IN THE BIN

The cuttings are inserted into the rooting medium in the bin just deep enough to prevent their falling over, say to a depth of one or two inches. In order to ensure close contact between the ends of the cuttings and the wet medium and, at the same time, to provide adequate aeration, the medium, if it is sawdust or some similar soft material, is gently pressed down around the ends of the cuttings. In the case of sand, the mere act of watering is sufficient to effect satisfactory compaction. High humidity of the air inside the bin is achieved by lightly sprinkling the cuttings with a fine spray of water three times a day on sunny days or once a day on cloudy days during the first two weeks. This spraying is essential if the bin lids are made of glass. Even if they are also provided with cloth or newspaper covers which are constantly kept moist to lower the temperature within the bin by virtue of rapid evaporation, it is still advisable to spray the cuttings frequently. Covers and lids should be kept scrupulously clean to allow light to pass through them, and the cloth should occasionally be treated with fungicide, such as Bordeaux mixture, to prevent the development of moulds which rot the fabric.

(7) HARDENING-OFF AND TRANSPLANTING

Hardening-off involves the development of an adequate root system to meet the requirements of transpiration and to acclimatize the cutting to a drier atmosphere after having been in moist air inside the propagation bin *(10)*.

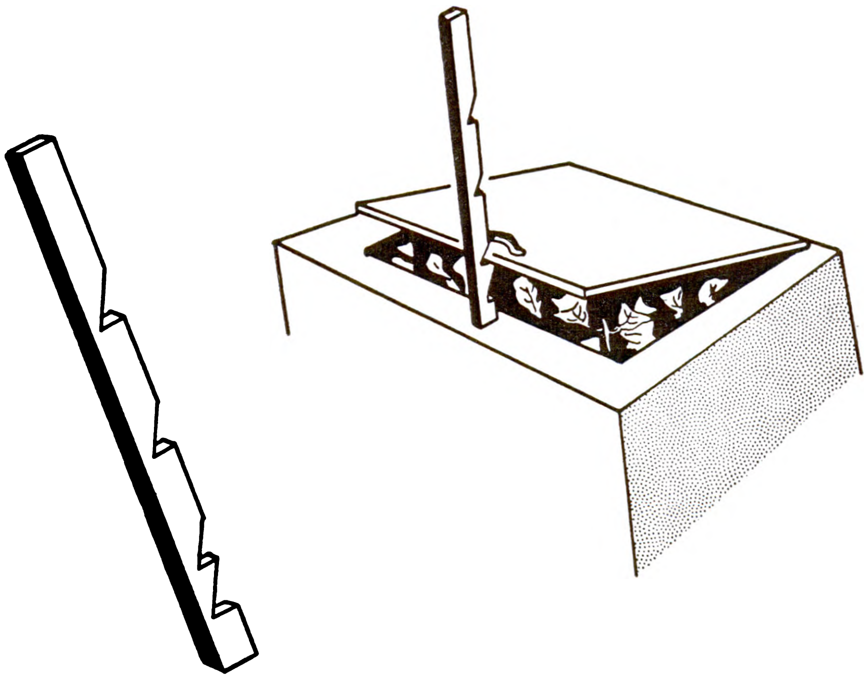
There are two possible alternative procedures that may be followed in the hardening off process, namely:

1) Keep the cuttings in the same propagator used for rooting and transplant them afterwards to pots or to a nursery bed when properly hardened.

2) Transfer the cuttings to a special bin for hardening off. The cuttings in this case are first potted and afterwards placed in the hardening-off bin from which they are later moved to a storage area (20).

In the hardening process, as practised at I. I. C. A., Turrialba, the cuttings are left in a closed bin propagator for one week. The covers are then opened gradually over a period of another week. A notched stick is used to hold the propagator covers open, as shown below. During the first week of hardening, the cuttings are sprinkled lightly with water several times daily. As the covers are gradually opened, they are sprinkled less frequently.

A method has been described *(2)* for determining whether a rooted cutting is properly hardened. The theory underlying the method is that, if the plant is in good physiological condition without any water deficit within the leaf tissues, the stomata will be wide open and a liquid of low surface tension, such as kerosene or xylol, will readily penetrate the open stomata and produce a translucent



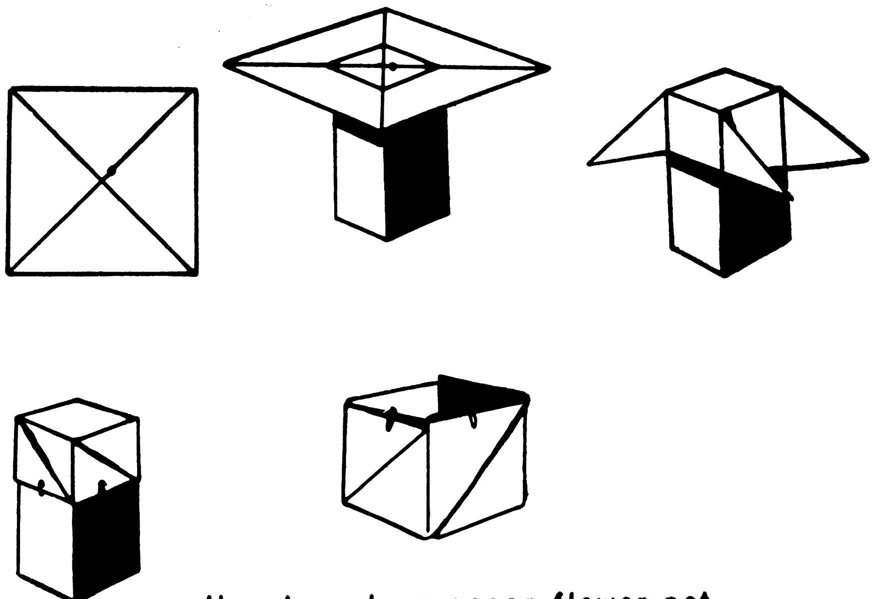
Notched stick for raising lid of hardening bin.

spot. It has been suggested that, upon completing the hardening-off process, the cuttings should best be planted in pots and stored under a glass or plastic roof rather than in an open nursery where heavy rains and splashing soil may injure the young tender leaves. At I. I. C. A., Turrialba, the rooted cuttings are transplanted to paper pots made from a 14-inch square of 6-ply asphalt paper (see diagram).

The paper lasts for 3 to 4 months which is ample time for the rooted cuttings to develop a well-hardened flush prior to being planted out in the field. The whole pot is set into the soil with the plant in it, thus avoiding disturbance of the root system. The paper pot disintegrates rapidly in the soil and the roots have no difficulty in emerging. Pots in the British West Indies and Surinam are made from *Ischnosiphon arouma* and are dipped into a preservative for longer use *(31)*. In Ecuador, pots are made of a bamboo *(Guadua spp.)* and in Mexico from abaca *(Musa textilis)* (31).

The preparation of a free-draining soil, as carried out at I. I. C. A., Turrialba, is a follows:

Three parts of soil are mixed with one part of well-decomposed manure, one part of old sawdust (discarded from the propagators) and one part of sand to improve the drainage. To this, one pound of Arasan per cubic meter of soil is added to control soil fungi. In Trinidad, the potting soil consists of two parts of slightly acid soil and one part of well-composted sawdust *(10)*. This mixture is fortified at the time of mixing with 4 ounces of ammonium sulfate, 2 ounces



How to make a paper flower pot.

of potassium sulfate or chloride, and 1 ounce of superphosfate added to each bushel of mixture. The mixture is left standing for 7 to 10 days before using. Two grams of ammonium sulfate are applied every 3 or 4 weeks to each plant to correct nitrogen deficiency, and a periodic spraying with one percent urea is also given.

The hardening of cuttings rooted under mist spray presents a somewhat different problem. Probably the best procedure in this case is to harden the cuttings in the same propagators in which they have been rooted by turning on the mist spray half an hour later each morning and shutting it off half an hour earlier in the afternoon. Toward the end of the hardening period, a little sprinkling is given only at midday. If, alternatively, the cuttings are transplanted in pots and then placed in a mist propagator, there is a tendency for the potting mixture to become waterlogged, and also for nutrients to be lost by the leaves through leaching (10). This method is thus unsatisfactory, and it is better to put the cuttings in the glasshouse, depicted previously, for hardening-off the plants rooted under mist sprayers in open bins *(12) (22) (23)*.

A suitable mist-spray glasshouse has dimensions 18 x 10 x 8½ ft. with 4 or 5 shelves, and will accomodate 3,000 plants. A shaded roof to allow 15 percent light intensity is recommended with unshaded glass sides. A humidity of 100 percent is maintained by a Bahnson centrifugal humidifier. The hardening process takes 5 to 10 days in a glasshouse of this kind *(12)*.

(8) CARE OF CUTTINGS WHILE IN STORAGE

It may be necessary to apply a solution containing 0.5 percent of urea as a foliar spray to the hardened cuttings every 15 to 30 days. If aphids and thrips become troublesome, they may be controlled with an insecticide such as 6 cc. of Malathion per gallon of water. Hydrogen cyanide and methyl bromide are effective against arthropods *(13)*. A weak solution of Bordeaux mixture (2-2-50) may be used in addition to control diseases. Weeds should be removed by hand and the plants should not be allowed to dry out.

(9) TRANSPLANTING TO THE FIELD

The plants should have at least one hardened flush before transplanting them into the field. A hole about one foot square and one foot deep should be dug and then filled in again, leaving a central hole big enough to accomodate the pot. When the young roots penetrate the paper wall of the pot, they then encounter only loose soil into which they can penetrate easily, thus avoiding a check in growth. This is not possible when the ball of roots is wrapped in banana leaves which sometimes decompose rather slowly and the plants are thus unable to absorb sufficient water for their needs *(16)*. If banana leaves are used, it is recommended that, before planting the cuttings, the leaves are either opened out or else removed.

The use of a foliar spray consisting of Goodrite VL-600 (venyl resin latex) diluted with 4 parts of water has been recommended for application to cuttings before transplanting *(28)*. This plastic material forms a thin coating over the leaf surfaces and thereby reduces transpiration. It has been used with success in Ecuador. Before transplanting, a temporary shade, such as a cover of banana plants, should be grown.

(10) SHIPMENT OF CUTTINGS

The shipping of cuttings by air is best carried out as follows *(10)*:

Place the cuttings in a small bag of jute (burlap) containing damp sterilized sawdust or pulped newspaper and tie the bag around the stems with string. Pack in cardboard cartons lined with waterproofed or waxed paper *(10)*. Under these conditions the cuttings are in complete darkness during air shipment and food reserves are exhausted only after 4 to 5 days. Ninety percent establishment may be obtained after this period, but only 40 percent may be obtained after 6 days and none after 8 to 9 days. Upon arrival, the cuttings should be placed immediately in hardening bins. For short distances, the cuttings should be packed in layers of wet newspaper and put into cardboard boxes. As previously mentioned, spraying the cuttings with Goodrite VL-600 helps them to withstand adverse conditions during shipment *(28)*.

For the shipment of cuttings, it has been recommended *(24)* that the roots should first be washed free of soil and packed in damp moss, and the whole cutting then enclosed in a plastic wrapping. The limit allowed before starvation begins is 3 days. Upon arrival, the cuttings must be potted at once and rehardened. Plants may be established much more quickly in this way than by preparing and shipping budwood.

(11) CUTTING GARDENS

As a continuous source of material for propagation purposes, it is recommended that organizations that practice propagation by cuttings on a large scale establish their own cutting gardens. The best spacing of cacao plants in the garden is 1½ x 1½ meters or 5 x 5 feet. Each time a branch is severed for making a cutting at least two buds should be left so as to encourage the growth of new shoots. At least one shoot should remain on the stock plant. Every precaution should be taken to maintain the plants in an actively growing condition. The use of a foliar spray containing one percent of urea and 0.5 percent of iron or manganese sulfate is recommended together with complete fertilizer *(11)*. It has been found that a single cacao plant 2 to 7 years old will provide 10 to 20 cuttings per year when spaced at 4 to 6 feet between the plants *(31)*. It is recommended that cuttings be not taken during the first year *(24)*.

Stock plants often appear to be growing vigorously when in reality the nutritional level of the soil is extremely low *(12)*. This is because cacao plants do not usually show deficiency symptoms under low light intensity where the slow accumulation of carbohydrates just balances the slow uptake of soil nutrients. Leaves or cuttings taken from such plants will usually not die in the propagation bins if the light intensity is reduced to 20 percent of full sunlight. If soil fertility is high, however, as much as 50 percent light may safely be allowed.

The age of stock plants should be between 1½ and 4 years *(12)* and it is generally agreed that, after 5 years, new plantings should be made in the cutting garden. Many authorities recommend a heavy pruning of stock plants in order to produce "fan" material, but pruning does not always bring about these expected results, and instead may result in the formation of chupons.

(12) ONE-LEAF CUTTINGS

Propagation of cacao by the production of one-leaf cuttings is recommended when cutting material is scarce and limited *(12)*. The temperature, light and humidity requirements for rooting are the same for one-leaf cuttings as for normal-sized cuttings. Hormones are best applied at half strength. A freely draining medium must be provided to counteract the tendency for water to accumulate at the base of one-leaf cuttings. A support, constructed of cross wires or wooden slats, is needed to sustain the weight of the leaves.

(13) EVALUATION OF PROPAGATION BY CUTTINGS

In answer to the question whether it is possible for a planter to recover his investment in propagators by planting cuttings on a commercial scale, it has been stated that, in Trinidad, a planter recovers his money by the fifth year *(25)*. In places where land is expensive, only those planters who have planted high-bearing clones produced by cuttings will be able to recover their financial investment in propagators. When cacao prices are low, only those planters owning high-producing trees will succeed, since the cost of maintaining a poor tree is the same as that of maintaining a high-producing tree. Cuttings taken from genetically high-producing trees have been repeatedly proved to develop into trees that have much greater yielding capacity than trees that develop from unselected seedlings.

Recently, the important question has been raised at to whether the use of cuttings is the best way of establishing a commercial cacao estate *(17)*. It is well known that cuttings trees have many disadvantages, for example, initial high cost, poor shape and tendency to tip over. Nowadays, with the present interest in high producing hybrid seed, the advantages of cuttings, in-so-far as commercial cacao production is concerned, seem to be somewhat lessened and the planting of hybrid seed may be more advantageous. Perhaps the only real advantage that cuttings have over seeds is that, when they are planted in really first-class soil, they are capable of extremely high production, otherwise the growing of seedlings from hybrid seed is probably more profitable. Even with high-bearing selections, it has been found that cuttings produce trees which, at the same age, give much higher yields per acre than trees produced from seedlings of the same clones. The accompanying diagram shows the average performance of cutting-trees of the three clones ICS 1, 45 and 95 compared with that of seedling trees produced by seeds taken from pods obtained by open pollination of flowers borne by these same three clones.

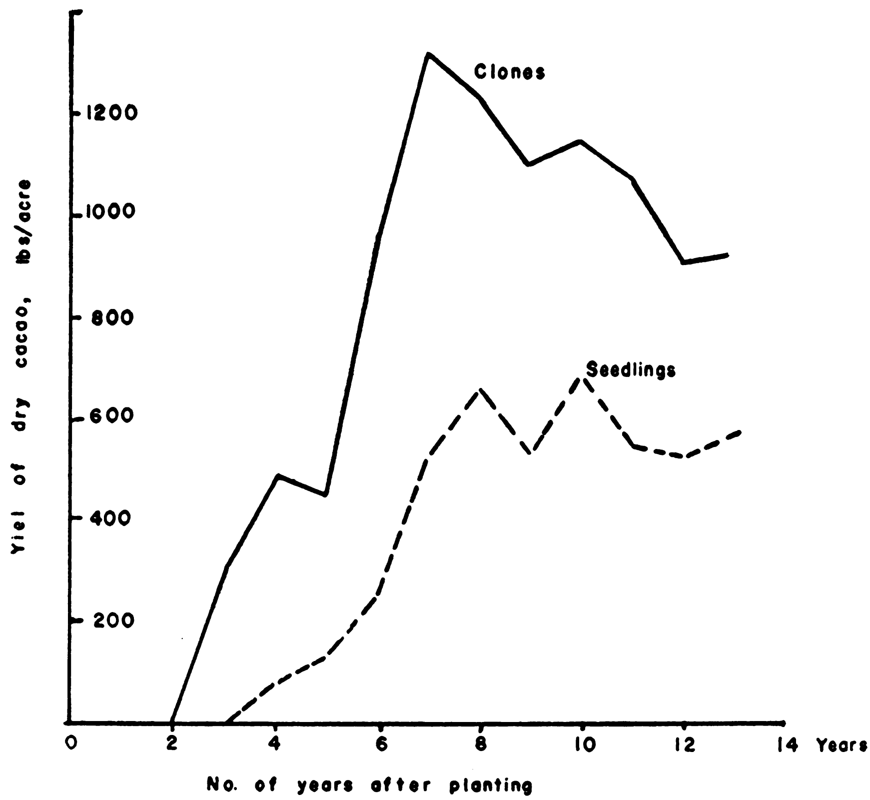
SUMMARY

1. Three main methods for rooting cacao cuttings have been devised and are described, namely, (i) the closed bin method, (ii) the open spray bed method and (iii) the centrifugal humidifier method. To these should now be added a fourth, nomely, (iv) the polyethylene sheet method.

2. Seven methods for hardening rooted cacao cuttings have been employed and are described. Three of these are carried out in the closed bin, the open spray bed and the centrifugal humidifier *in situ*, by merely altering the environmental conditions within the bin without removing the cuttings after they have rooted. Three of the four remaining methods involve the use of special hardening bins, suitably adjusted so as to give the right conditions, following the rooting of cuttings in (i) the closed bin (ii) the open spray bed and (iii) the centrifugal humidifier. The last method of all involves the use of the centrifugal humidifier, suitably adjusted, fololwing rooting in the closed bin.

3. The environmental conditions necessary for the successful rooting of cacao cuttings are discussed, and details are given to show how they may be attained in the rooting bin.

4. A comparison made in 1955 in Trinidad between these seven different techniques for rooting and establishing cacao cuttings *(26)* showed that all are capable of producing between 75 and 80 established plants ready for



SAN JUAN ESTATE, TRINIDAD

planting out in the field from every 100 cuttings set to root, provided the methods are operated efficiently. The cost of production of the established plants varies somewhat, a difference of 25 percent in cost being proved between the most and the least expensive methods.

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CHAPTER 11

PROPAGATION BY BUDDINGS, GRAFTS AND MARCOTS*

(A) BUDDINGS

(1) INTRODUCTION

Budding is one the chief methods used to propagate vegetatively clonal material, produced by selection and breeding, having highly desirable characteristics. Is has the great advantage over the cuttings method in that it is possible to produce a large quantity of plants from a limited amount of clonal material. Furthermore, it is much more economical to transport budwood from one country to another than it is to transport bulky cuttings. Compared with the cuttings method, budding requires much less space and equipment, needing only a suitably shaded nursery. The main reason why the budding method is not more widely used than it is at present is because the laborers who are employed in the budding nursery need to acquire a high degree of skill, necessitating a considerable period of carefull training before they become proficient. On the other hand, certain disadvantages attend the budding method, among which the following may be mentioned *(8)*:

(i) The techniques of budding are not sufficiently reliable always to ensure complete success.

(ii) The stock may produce unwanted chupon growths below the bud union and constant attention and supervision are needed to eliminate them.

(iii) Cacao trees that develop from fan branches do not possess an erect habit and have unsymmetrical shape.

(iv) Trees that develop from buds often do not possess strong stout trunks.

(v) Trees that develop from buds begin to produce a crop later than trees that develop from cuttings.

(vi) In many cases the bud scion and the parent stock are incompatible and union is not effected.

(vii) Occasionally a bud may be a "latent' 'type and fail to burst after budding.

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* This article is largely based on a chapter by A. L. Erickson in the Cacao Manual, First Spanish (1957) Edition, pp. 91-101.

(2) PREPARATION OF BUDSTICKS

It is debatable whether there is need of any preparation of budsticks on the tree before they are cut off for budding. Some authorities believe it necessary to girdle the selected branch, and others think it essential to cut off the leaves, leaving the petioles attached, some 7 or 8 days before cutting off the branch for use as a budstick. Others simply cut off a branch whenever buds are needed.

If the buds on a budstick are small and have not reached maturity, more time is needed for them to grow out into a stem than when they have assumed normal size and age. If they are too large or have started to sprout, they may break off during the budding operation. Some authorities consider a bud to have reached the best stage of development when the subtending leaf has just abscissed and fallen off. A bud that subtends a leaf that has been cut off too close to the main stem generally does not produce a satisfactory plant *(14)*.

A common procedure for preparing buds on a branch is to cut the leaf petioles in half, leaving a stump. This stump usually falls off after about 10 days, by which time the bud is in good condition for use. Hence it has been recommended that leaves of intended budsticks be cut off through the middle of the petiole 8 days before the buds are needed *(19)*.

Before using budsticks, it is advisable to immerse them for 3 or 4 minutes in a 0.5 percent solution of formalin *(14)*. When budsticks are to be transported from one place or country to another, they should be wrapped in slightly damp newspaper or banana leaves and then in burlap for protection.

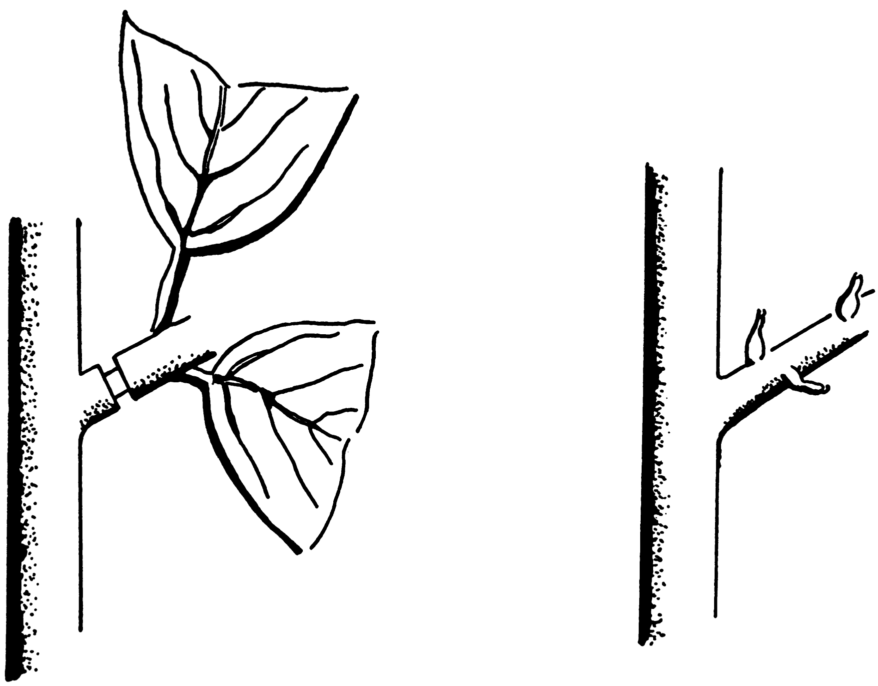
(3) STORING OF BUDSTICKS

Budsticks should be used within 24 hours of cutting off the tree, but this is not always possible. The material can be stored for several days without deterioration by wrapping it in moist cloth and putting it in moist sand or sawdust. It can also be stored for as long as one week by placing it in moist charcoal containing about 30 percent of water *(4)* and better results have been obtained by this method than by storing in sawdust. If kept longer than 6 days, the cells of budwood lose turgor and the buds are then difficult to separate cleanly from the stems. Furthermore, the longer the material is stored the longer the time subsequently needed for the bud to sprout.

(4) BUDDING TECHNIQUES

The most commonly used method for budding cacao is the patchbud method. An incision is made in the stock in the form of an inverted letter U. The procedure that follows in shown in the diagram.

It is advisable to make the cut on the stock below the scar left by the cotyledons *(1)*. This prevents chupons or branches growing out from the stock



Ring

Cut petioles

How to prepare a budstick

11

at a point below the bud. Some budders leave the tongue of the U-cut so as to form a protection to the bud when bound over it after insertion, others cut away the tongue before inserting the bud. A paste of Fermate thinly applied to the bud before wrapping will protect it against infection by fungi.

Methods other than patch budding are used in the Federated West Indies and other places. In one method, called rectangular patch budding, a "window", the size of the rectangular bud patch, is cut in the bark of the stock stem and the bud patch is fitted into it. In another method, called the T-bud method, two small cuts at right angles are made in the stock and the bud shield inserted in it under the flaps made by slightly lifting the edges. This method, in inverted form, is widely practised in Jamaica under the term "Topper inverted T-bud method" after the name of its introducer *(17) (18)*. Wrapping the bud after insertion into the stock is generally carried out either with waxed tape or rubber strip which have proved to be about equally effective *(3)*. It does not matter whether the bud is covered over by the wrapping or left exposed. For preparing waxed tape, cotton tape is dipped in a molten mixture of 2 parts paraffin and one part bees' wax. Raffia strip or black insulating tape are sometimes used as wrapping. It is advantageous to rub the upper part of the wrapping with a piece of paraffin wax in order to prevent rain water penetrating inside the wrapping. Perhaps the best kind of wrapping tape to use, and one which is rapidly gaining favor, is a transparent plastic tape manufactured by the Resinite Corporation, Santa Barbara, California, U. S. A. This resinite tape is especially recommended for the Topper inverted T-bud method which indeed may owe its success to its use.

The questions as to whether budding should be performed in the nursery or in the field, or applied to stock growing in nursery beds or in pots or baskets, are often debated by cacao propagators. The choice of procedure largely depends on local circumstances. In order to avoid the necessity for transplanting, budding onto seedling stock planted at stake out in the field is sometimes practised but, when this procedure is adopted, great care must betaken in growing the seeding stock in the first place and in tending the budded plants afterwards. It is troublesome to have repeatedly to "supply" sites where the seedlings have died before budding, or where the buds have not "taken", or where the successfully budded plants have subsequently died. It is perhaps just as hazardous to bud the seedling stock in the nursery bed and then to transplant from the bed to the field. Perhaps budding seedling stock grown in pots or baskets in the nursery and then transplanting the buddings to the planting sites out in the field may be the most preferable method in the long run.

It has already been pointed out that it is best to transplant bare rooted seedlings, whether buded or not, with the bud growth or flush cut back, when transferring plants from the nursery bed to the field. The bud growth should be allowed first to form a 2-flush branch, which usually takes about 6 months, and then this is cut back to a point just above the "crown" or "collar" of the first flush.

The curvature of the piece of bark forming the shield of the bud should be the same as that of the stem into which the bud is to be inserted *(14)*. This necessitates selecting bud sticks which have the same diameters as the stems that are to be budded.

(5) FACTORS WHICH INFLUENCE SUCCESS IN BUDDING

The age and size of the stock and of the budstick should be approximately the same. For patch budding it is recommended by one investigator that the stock plants should be 7 to 8 months of age, 1.5 to 2.0 cm. in diameter, and about 0.2 meters tall *(2)*. Another investigator found that stock plants having diameter 2.0 to 3.0 cm. gave better results than those having diameter 1.0 to 1.5 cm. *(7)*. Another claims that the diameter of the stock plant does not exert any effect on the development of the bud-scion, provided its diameter lies between 1.5 and 3.0 cm. *(12)*. Generally speaking, the larger the diameters of the stock and of the budstick, the more vigorous and quick-growing is the budded plant, In the case of cacao, good results have been reported even with stock plants having the diameter of a pencil (0.7 cm.) though the budded plants needed careful handling. It is stated that a greater proportion of "takes" occurs when budding is performed in the morning rather than in the afternoon *(3)* and that little difference is noted when budding is carried out either on sunny, cloudy or rainy days although sometimes the results are not so good on very rainy days *(3)*. Varying amounts of rain falling within a 14 days' period from the time of budding were found not to exert any significant effects on the number of successful bud unions *(7)*. Incompatibility which is sometimes found to occur between stock and scion has been attributed to physiological causes *(14)*.

(6) THE AFTER CARE OF BUDDED PLANTS; POST BUDDING TREATMENT

Whether the stock plant stem be cut off, broken off, or merely bent over to induce the bud to "take" and grow out into a branch, is a debatable subject and some authorities favor one practice and others favor another. One writer asserts that budded stock plants in pots should be cut off just above the bud union as soon as the bud has begun to sprout, and considers that, by bending the stem, its vegetative functions cease to operate *(10)*. Another advises bending down the stock-stem 15 to 20 days after budding and later, when the bud shoot has grown out 20 to 25 cm., cutting back the stem to 0.5 cm. above the pud *(2)*. Another advises "topping" the stock 14 days after budding *(7)* and states that bending gives similar results. On the other hand, ringing the stock stem above the bud, and leaving the stem untouched was stated to exert deleterious effects on the subsequent growth of the bud shoot *(7)*. Best results were obtained by yet another investigator by cutting back the stem plant 14 days after budding, leaving about 5 cm. of stem above the bud, as compared with cutting back immediately after budding and leaving 15 cm. of stem above the bud *(12)*. This result differs from that of another investigator who recommends topping off the stock stem immediately after budding, leaving 10 cm. of stem above the bud *(13)*.

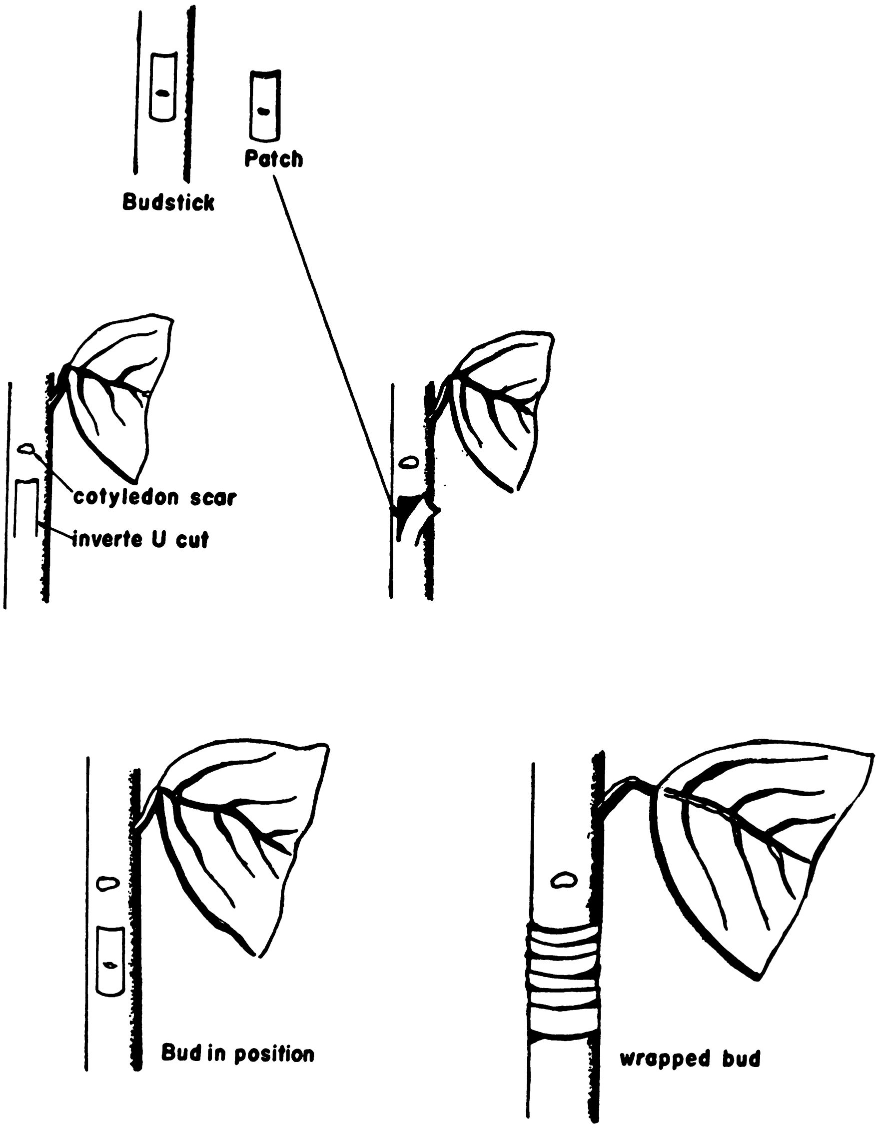
These different findings are greatly at variance one with another, and it is difficult to decide which procedure is best to adopt. At I. I. C. A., Turrialba, the plan followed is to leave the bud covered with wrapping tape for 15 days after bud insertion and afterwards to remove the tape and bend down the stock stem and fix it with a hook pushed into the ground as shown in the diagram, taking care not to damage the bud union.

Pests and diseases that affect the young budded plants should be controlled. An application of urea in the form of foliar spray, having a concentration of 0.5 percent, should be made. When transplanting budded plants from nursery beds to the field, it must be remembered that they possess long tap roots and the greatest care must therefore be exercised not to break them off and to excavate them deep enough not to injure the growing tips.

(7) GROWTH AND DEVELOPMENT OF BUDDED PLANTS

The vigor of a budding is closely related to that of the stock plant *(16)*. If buds taken from chupon stems are used, the bud shoot takes the form of a seedling plant, but if buds are taken from fan branches, the budding will have the same fan shape. At first the fan bud shoot will grow at an inclined angle but, after about 2 years, it will grow more-or-less erect and its lateral branches will form a symetrical tree.. Thus, after 3 years' growth, it is usually difficult to distinguish between budded plants that have developed from chupon buds and those that have grown from fan buds. In order to stimulate branching, it is advisable to cut off the terminal buds of budded plants.

The yields given by cacao trees that have grown from budded plants of the best clones have been found to be less than those given by trees that have developed from cuttings *(5)* but the difference between them gradually diminishes with age. In the case of poor, less vigorous clones, budded trees often give higher yields than cuttings. Thus, at I. I. C. A., Turrialba, cacao trees produced by budding with buds taken from six different clones showed considerable differences in vigor and yielding capacity, and one of them was particularly outstanding in the first few years. It is difficult to determine which begin to bear pods earlier, buddings or cuttings, and great variability in this feature is shown by different clones. The effect of site and soil is also noticeable in determining early bearing. There is evidence that some clones exert much more influence on growth when used as scion than when used as stock *(6) (9)*. Some clones used as stock possibly exert a dwarfing effect on the scion which accordingly should produce a tree having low stature *(15)*. So far, however, outstanding examples of such behaviour have not been discovered among cacao clones. It is nevertheless interesting to speculate on the advantages of using dwarfing stock, in that their employment would greatly reduce the cost of pruning, harvesting and spraying caaco fields.



How to make a bud union.

(B) GRAFTS

Grafting employed for the propagation of selected clonal cacao has not proved to be generally successful and the results obtained have been variable in different countries. Thus, whereas considerable success with grafts has been experienced in Ecuador, results obtained in Costa Rica have been unsatisfactory. The procedure in grafting is to insert a wedge, cut from the stem of the scion plant, into a cleft made in the end of a severed branch or stem of the stock so that the cambium layers of each come into close contact. Cleft grafting needs a large amount of material for propagation as compared with budding. Nevertheless, successful grafts have been reported in which 75 percent of the attempts proved to be satisfactory with 50 percent success in transplanting the grafts in the field (11). A recommended procedure for grafting cacao consists in cutting back 6 to 12 months' old nursery seedlings just below the level of the cotyledon scars, digging them out and taking them to a grafting bench where a slit is made in the cut end of each seedling stock. Wedges of stem, carrying 2 to 4 buds, are then fashioned and inserted into the slits. The leaves should first be removed down to the beginning of the petioles. The grafts are protected by applying semi-molten wax at 50º to 60º C. temperature. Wrapping tape is not required The grafts are then placed in the nursery until the union is formed and the buds of the scion have unfolded.

(C) MARCOTS

Cacao may be propagated by marcotting which takes place quite readily as a rule, though it is usually difficult to establish the marcotted plants in the field afterwards. For successful marcotting, stems having diameter from 1.5 to 2.5 cm. should be used *(15)*. A ring of bark about 4 cm. long is removed and the stem is wrapped with an absorbent material such as Sphagnum moss which is wetted and tied around the ringed area. When roots emerge, the stem is cut off from the tree below the ring and planted in a pot or basket of soil or in a nursery bed *(15)*.

Difficulty in establishing the rooted marcot has been the main drawback to the wider employment of this simple method of cacao propagation. The actual rooting of the marcot is generally easily accomplished in the case of cacao, especially if growth hormone is applied to the cut edges of the ring, preferably as paste*. The employment of polyethylene bags for faciliting the difficult hardening-off process after the marcot has been made promises to provide a solution to the problem ,according to results obtained at I. I. C. A., Turrialba*. The marcot is prepared in the usual way by ringing a stem of convenient thickness carrying between 4 and 10 leaves. The ring is one inch long and it is treated with growth promoter (Hormodin Nº 3 powder). Damp moss (or sawdust or friable soil) is applied and held in position by means of a piece of polyethylene sheet tied round with string. Roots appear and penetrate the wrapping after 7

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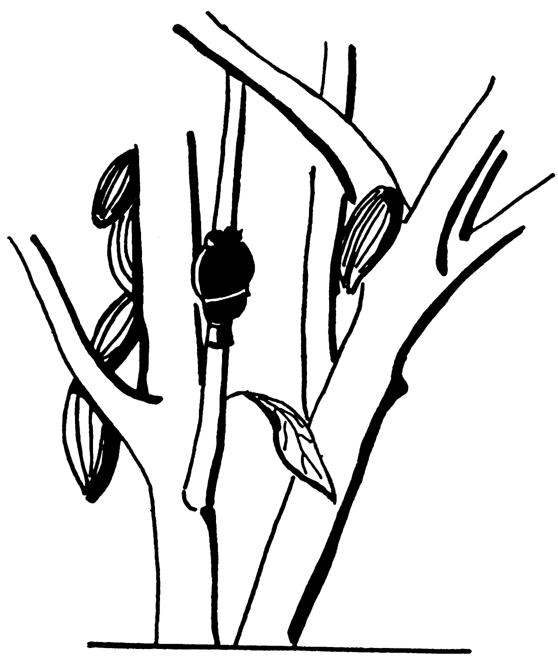
* E. Camacho; private communication.



Marcot

or 8 weeks. The marcot is then cut off low enough to leave about 3 to 4 ins. of stem which acts as a peg when the marcot is planted in soft moist soil or compost contained in a polyethylene pot provided with drainage holes.

A large bag made of polyethylene plastic sheet is then placed around the plant so as completely to enclose it and tied to the stem at its base at soil level. The plant is then placed in the nursery or under a tree and left for 7 to 11 days to harden. The plastic bag is then removed. The plant it left in the shade for a further period of about 7 days. Thus the total time taken to produce a hardened marcot cacao plant ready for the field is about 9 to 11 weeks in all. The cost of a polyethylene bag is only about 3 cents. U. S. and the bag may be used several times over without deteriorating. The polyethylene pot, which costs about 2 cents U. S., may be replaced by a cheaper kind of pot that can be put straight into the planting hole in the field.

It is possible that the marcot may be planted, with its cover of polyethylene bag, directly into the field, provided the planting site is suitably protected by temporary shade provided by plants such as banana, *Crotalaria* or cassava, previously established near the site. Strong sunlight should be rigorously avoided so as not to "cook" the bagged plant. After about 2 weeks, the bag may be removed and the overhead shade gradually reduced.

SUMMARY

1. The chief disadvantages of budding as a means of propagating cacao vegetatively are: (i) constant vigilance is needed to prevent chupon growths developing below the bud union and producing a tree of the same kind as the stock, (ii) incompatability between stock and scion may occur, producing unsatisfactory growth of the budded scion, (iii) replacement of a scion tree which has been damaged (by disease or accidental injury) by rebudding, either onto the old stock or onto a shoot that has grown out from it, is usually unsatisfactory.

2. The chief advantages of budding are: (i) all cacao clones or varieties can be budded with equal success, in contrast to rooting cuttings which present great difficulty in some cases, (ii) budding is highly economical in propagating material. For example, ten budded plants can be obtained to every single cutting, (iii) the production of propagating material does not require special nurseries or gardens as is the case with cuttings; budding material may be obtained from prunings, (iv) budwood can be kept for 4 days before use if properly stored, whereas cuttings must be set in the propagating medium on the same day when they are cut off the nursery tree, (v) budded seedlings develop into seedling type plants and have tap roots. By earthing up the bud union, if the bud has been inserted low enough to permit this to be accomplished, adventitious roots develop in addition and help to nourish the tree.

3. The preparation and storage of budwood and the techniques used in budding are described.

4. Factors which control success in budding are discussed.

5. The after-care of budded plants and their growth and development are described.

6. Grafting is considered as a means of vegetative propagation of cacao.

7. Marcotting is also considered and a new method is described in which polyethylene bags are used to prevent undue transpiration during rooting in soil after the marcot has been cut off from the tree, and during the subsequent growth of the marcot until it is ready for hardening-off.

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CHAPTER 12

PRUNING*

(1) INTRODUCTION

There are three main objectives to be aimed at in pruning a cacao tree (2) namely, (i) to shape or form the young tree, (ii) to maintain the shape or form of the tree subsequently ,and (iii) to renovate or rehabilitate a cacao tree after it has been allowed to lose its shape by unrestricted growth. The immediate operations are carried out (i) to remove diseased and dead wood, (ii) to remove undesired chupons, "water-shoots", "suckers" or "gormandisers", (iii) to open up the tree so as to facilitate spraying and harvesting, (iv) to produce a not-too-dense canopy and (v) to developed a tree of upright stature.

Diseases and pests, such as Black Pod *(Phytophthora)* and thrips, multiply more rapidly in unpruned cacao trees with dense canopies than in trees that have been opened up by pruning and possess well-aired canopies. Less pruning need be practised in plantations where the permanent shade is light or sparse or where it is absent, than in plantations provided with dense shade. In well-shaded plantations, pruning should be more severe so as to allow greater illumination of the cacao foliage.

(2) FORMATION PRUNING

The procedure differs in formation pruning of young cacao trees according as the tree is a seedling (or chupon-budding) or a cutting.

Seedling trees: A seedling cacao tree normally grows to a certain height and then branches out at the top into a whorl of 3 to 5 branches known as the "horquette" *(5).* The terminal bud then disappears. Growth in height is latter resumed by a bud which grows out from below the horquete, the resulting shoot turning upwards to produce another main vertical stem. This in due course also produces a horquette consisting of 3 to 5 branches and then stops growing. Another bud grows out from below the second horquette and carries on the vertical growth a stage further. The horquetting is usually repeated, at least for a third time, resulting in the production of a three-layered tree consisting of a compound trunk

* This article is largely based on a chapter by A. L. Erickson in the Cacao Manual, First Spanish (1957) Edition pp. 127-132.

and three whorls of lateral branches. These laterals subsequently produce side-branches that carry leaves arranged in two ranks giving a fan-like appearance to the branches in contrast to the spirally arranged leaves of the original seedling stem or of a chupon growth *(5)*. The lengths of the trunk sections between the horquettes, the lengths of the side branches, and the number and vigor of the successive sections vary among different varieties or clones of *Theobroma cacao*. The differing growth habits have been insufficiently studied, although it is well known that the Amelonado kind of cacao, widely grown in West Africa, is taller, possesses longer trunk sections, and is not so spreading in its side branches, as Trinitario cacao.

In pruning seedling trees ,all basal chupons should be removed as soon as they appear. When the horquette is formed, all the side branches may be allowed to grow, or only 3 or 2 of them, the rest being removed, depending partly on the closeness of the spacing. Extra branches that are unwanted are cut out so as to attain a balanced framework which will bear abundant pods. Pruning should be systematically and regularly carried out and should never be excessive, otherwise the set-back to growth may encourage the formation of numerous basal chupons as well as reduce the size of the crop.

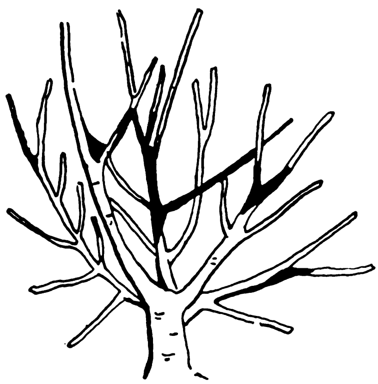
Cutting trees: The habit of a cacao tree developed from a cutting is altogether different from that of a seedling tree. The side branches of a cutting tree originate near to the ground and the basal ones tend to droop; they should be cut out and the more upward-trending branches should be encouraged to grow. If the thickest fan branch of a cutting be firmly tied to a stout stake driven deep into the ground, an upright habit may develop and the shape of the young tree may come to resemble that of a seedling. Not only the lowermost trailing branches but also weak spindly branches of the cutting tree should be pruned away, as well as some of the central branches, so as to open up the canopy. Two or three main vertical branches should be chosen to provide the future framework of the tree, and certain of the symmetrically-spaced side branches should be allowed to develop so as to fill in the spaces between adjacent trees.

A great deal of attention should be afforded cutting trees during the first two years of their growth in order to impart good shape and form. The first formation pruning should be given after the trees have been in the ground for 9 months *(6)*. A second pruning should be given at 18 months, and a third at 2½ to 3 years when all deformed branches are eliminated *(6)*. The accompanying diagram indicates the effects of proper pruning applied to cutting and seedling cacao trees.

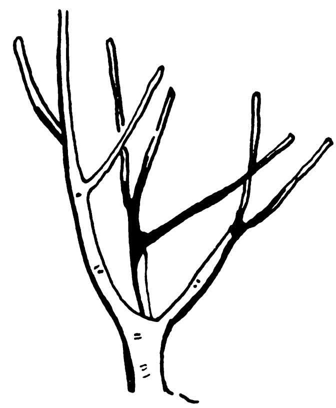
(3) MAINTENANCE PRUNING

Maintenance pruning, both of cutting and of seedling trees, consists in a light pruning given from time to time to keep the trees in good shape. Diseased and dead wood is cut out, twisted and broken branches and branches that cross others are sawn off. If the canopy is too dense, smaller branches are topped off so as to lighten the shade. The pruning operations should preferably be carried out during the latter part of the dry season, if there is any, so as to allow full benefit of the

Pruning cacao trees from cuttings

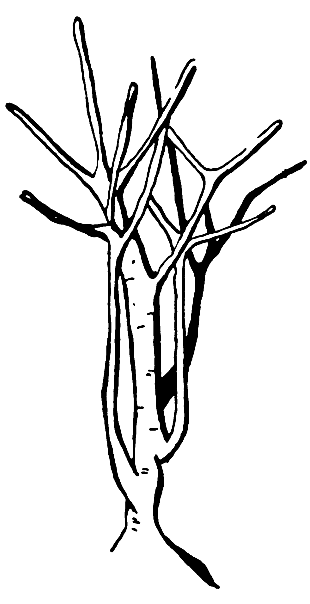


Before pruning



After pruning

Pruning cacao trees from seedlings



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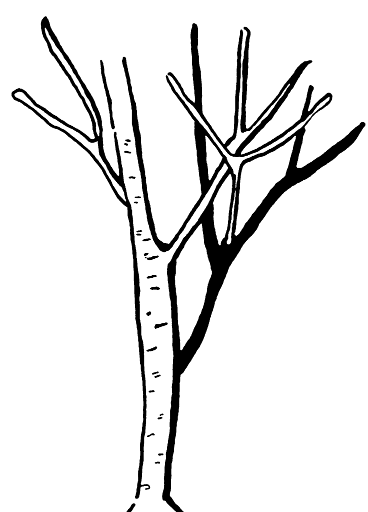

After pruning

growing season that is ushered in by the rains. The pruning is repeated at 2-yearly intervals by some planters whilst others advocate an annual light pruning with heavy pruning only once or twice in the lifetime of the tree. Chupons should be removed as soon as they appear.

The intensity and frequency of maintenance pruning should be controlled according to local circumstances, for example, rapidity of growth as determined by environmental conditions, spacing distance, habit of the variety, strain or clone, prevalence of diseases such as Witches' Broom *(Barasmius perniciosus)* which incidentally may be controlled by sufficiently frequent light pruning, cost of labour, accessibility of the fields and the trees, and finally, topography. It is perhaps unwarranted to attempt to lay down hard and fast rules.

In regard to the effect of pruning on the development and size of the cacao crop, it should be borne in mind that the chief materials of which cacao beans are composed consist of carbohydrates, fats and proteins which are mainly manufactured by the leaves. It has been estimated that between 6 and 10 mature healthy cacao leaves are required to provide the organic materials contained in one ripe cacao pod *(1)*. In order to produce a crop of 500 lb. dry cacao per acre, about 3500 ripe pods are needed. If there are 300 trees per acre, then each tree should ripen at least 12 pods which would need between 70 and 120 mature healthy cacao leaves. There are probably an equal number of young unhardened leaves and an equal number of old leaves which have ceased to function, or a total of 210 to 360 leaves on each cacao tree required to ensure a crop of 500 lb./ac. of beans. In maintenance pruning, it is therefore advisable not to remove too many leafy branches so as to ensure an adequate leaf population.

Chupons from fan cuttings: Sooner or later, a fan cutting produces a chupon or chupons. Some planters take advantage of this fact in order to establish seedling-type trees from rooted cuttings trees (fan-type) by gradually pruning away the branches from the cuttings trees as the chupons develop. Care should be taken to ensure that only the basal chupons are encouraged to grow up because these soon put down their own taproot systems, particularly if the lower parts of the chupons are earthed up. Various procedures have been tried to force an established cutting tree to produce a basal chupon but none has proved to be reliable and satisfactory *(5)*. Nicking the bottom of the stem with a cutlass or machete sometimes is effective, and occasionally a severe pruning of the branches may cause the tree to throw out one or more chupons. Partial or complete ringing is often effective also but should be practised with caution. When the chupon has grown into a fair-sized tree, the remainder of the cutting-tree should be cut away.

(4) REHABILITATION PRUNING

This consists in severely pruning old trees so as to stimulate the growth of strong basal chupons, either to serve as the framework of new trees or to provide stock for budding. The procedure to be followed by budding is first to map the tree population and to mark each tree according to its productive potentiality, into one of three categories, A, B, C, denoting high, medium and low yielding capacity *(2)*. The trees that are to be rehabilitated, say class C, are then cut back, leaving a suitable chupon which is then budded with a bud or buds taken from a desirable clone.

Whilst this method is often successful, depending on the proportionate number of budded and unbudded original trees and on various other environmental circumstances, there is always the risk of new chupons arising from below the bud unions and producing trees of undesirable type, that is, trees of the same kind as the pruned remants. This eventuality may be evaded by low budding onto basal chupons arising near ground level and afterwards earthing up so that new root systems develop from the chupons which are completely independent of the original trees. The old original trees are subsequently removed by pruning and the old root systems are either allowed to die out and decay or else they are dug out, taking care not to injure the new chupon roots.

(5) PRUNING TECHNIQUE

When pruning off a branch of a cacao tree, it is advisable to make an incision with the saw below the branch that is to be severed so that a large piece of bark will not be torn off as the branch falls away. Branches should preferably be cut flush with the supporting branch or trunk without leaving a stub or stump.

After sawing or cutting off a branch, the exposed fresh surface should at once be painted with a disinfectant or fungicide. Several suitable substances are available, for example, Fermate paste or a paste made of Bordeaux mixture.

Some planters prefer to leave a short stub when pruning large branches, with the idea that, when the woody tissue dies back, it sloughs off and leaves a calloused wound flush with the surface, whereas, when the branch is cut off flush, and tissue die-back ensues, a calloused cavity remains.

For pruning small branches and twigs, pruning shears should be used, but for thick branches, a pruning saw is preferable. A cutlass or machete should never be used unless it is very sharp and unless the user has had considerable experience in handling it.

When pruning or cutting down diseased cacao trees, for example, trees affected by *Ceratostomella,* the cutting tools (axes, saws, cutlasses, machetes, shears) should be thoroughly disinfected with some suitable liquid such as formalin so as to prevent the spread of the disease to healthy trees when they in turn are pruned.

(6) REACTION TO PRUNING

The first noticeable response to pruning is the appearance of new growths upon or near to the exposed cut surfaces. It is advisable to cut these out at an early stage unless there is a special reason for leaving them, as for example, to replace a dead or dying branch, or to fill a gap in the canopy. In a pruning trial *(4)* it was found that buds appear earlier and grow out quicker on pruned branches having diameter 2.5 cm. than on branches of diameter 5 cm., and earlier and quicker on 5 cm. branches than on those having diameter 10 cm. The new outgrowths were well dispersed on the 2.5 cm. branches whilst they were clustered around the cut ends of the 10 cm. branches. In this last case, many of the new shoots were chupons, but in the case of the thinner branches, all the new shoots were fan-branches. The branches which developed in strong light were less vigorous than those which developed in shade.

In another pruning trial *(3)* cut branches having diameter 3 cm. developed fan shoots whereas those of diameters 6 cm. and 10 cm. produced chupons. The largest number of new growths were situated upon the first 50 cm. of branch surface below the cut end. The new growths produced by branches having diamter 3 cm. were better developed after 6 months' time than those produced by the thicker branches but, after 11 to 13 months' time, growth and development was better on the thicker branches having diameters 6 cm. and 10 cm. In all three cases, the chupon growths developed the quickest. Best development on the whole was shown by shoots arising from the 10 cm. branches subsequent to pruning. In every case where the branches had been thinned out by pruning, the new shoots mainly arose from basal axillary buds, in contrast to trees whose branch system had not been thinned. Furthermore, terminal buds grew out more vigorously in the case of the thinned trees, and the subsequent growth of the shoots and stems that followed was better.

SUMMARY

1. Formation pruning, maintenance pruning and rehabilitation pruning are described in turn, both for seedling-type and for cutting-type cacao trees.

2. The formation of chupon (or seedling)-type trees from fan (or cutting)-type trees is described.

3. Pruning techniques are discussed and the reaction of the cacao tree to pruning is described.

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CHAPTER 13

WEEDS AND THEIR CONTROL*

INTRODUCTION

Preliminary considerations: In a properly managed cacao plantation, newly established on forest land, weeds ought not to occur, because the ground should be too densely shaded to permit any but a few species of shade plants to survive. When weeds, particularly grasses, gain access to a cacao field in which shade is being controlled, their presence is usually an indication that light is too intense. When a cacao plantation is being developed on land on which the previous vegetation was not forest but some agricultural crop such as sugar-cane or pasture grass, weeds usually become abundant during the period of conversion into cacao (the establishment phase) and great trouble and expense are often incurred in removing them *(18)*. If the cacao is being grown with complete artificial shade, however, the weeds disappear as the shade plants grow up and their canopies gradually cover the ground.

Cacao without shade: In certain cases when soil conditions warrant the procedure, cacao is planted without overhead shade of any kind, except that which the cacao trees themselves provide as they develop to maturity and their leafy canopies close in. During the establishment phase in this case, weeds multiply rapidly under the incidence of strong sunlight and to such an extent that they compete severely with the young cacao trees; accordingly an attempt must be made to control them.

Roads, paths and traces: A common source of weeds which invade cacao plantations as seeds are the weeds that grow alongside roads, paths, field traces and tram lines. These wayside weeds must be eradicated if possible in order to prevent further spread, as well as to remove obstruction to the free passage of laborers, pack-animals and machines along the roads and paths.

Definition of weed control: Whether used for cleaning cacao fields or waysides, and by whatever method, weed control is an expensive process because it requires much labor, if performed by hand, or it involves the use of costly

* This article is mainly based on unpublished lecture notes prepared by L. A. Montoya for the 1959 Cacao Course.

implements and apparatus and expensive chemical substances, if performed by other means. *(14).* Consequently, weed control should aim at reducing and keeping in check all weed growths that are likely to compete with the growing cacao trees, or to interfere with operations being carried out on the plantation. It does not necessarily imply complete eradication or elimination which would be prohibitive in cost, but its objects must be attained with the minimum expenditure (11).

Damage caused by weeds: Generally speaking, weeds are plants having great vegetative vigor and capable of absorbing water and nutrients at a faster rate than crop plants *(2) (22).* Many possess broad leaves which overshadow crop seedlings and compete with them for light and carbon dioxide. They are for this reason particularly undesirable in the early establishment phase of cacao-growing, that is, before the young cacao plants have become fully grown. Some weeds of the cacao field are creepers and entangle the seedling leaves, thus preventing them from unfolding.

Factors affecting weed growth in the cacao field: The kind and quantity or density of weeds present in a cacao field depend on many environmental factors, including climate (rainfall and temperature) age and condition of the cacao trees, planting distance, presence or absence of overhead shade and features of the soil and topography *(22).* The amount of light incident on the soil surface is especially important in determining the rapidity of weed growth and the density of the weed population.

Weed reproduction: Weeds are spread and naturally propagated in many different ways *(10).* Some weeds are spread by seeds which are disseminated by the wind, by birds or by animals to whose hairy coats the seeds adhere. Tillage implements also spread weeds, either seeds or stolons, which become attached to them when in use. Weeds that reproduce themselves by underground stolons or rhizomes are particularly difficult to control *(1) (9).*

Biological weed forms: There are three biological forms of weeds, namely: (i) *Annuals* which reproduce themselves solely by seeds and can be easily controlled by destroying them before the seeds are formed, (ii) *Biennials* which propagate themselves by bulbs or other stem or root modifications, as well as by seeds. These grow vegetatively during the first year and in the second year produce seeds. They are therefore best controlled by destroying them before they are over a year old, (iii) *Perennials* which produce seeds during the first year but mainly propagate themselves by stolons, rhizomes or bits of stem, and are best controlled by destroying the vegetative organs by constantly cutting back the stem growths so that their food reserves are quicly used up *(9).*

Examples of cacao weed annuals are *Alternanthera sessilis* and *Drymaria cordata;* of biennials, species of *Amaranthus,* and of perennials, various grass species, for example, *Paspalum conjugatum* and *Panicum laxum (7).*

METHODS OF WEED CONTROL

There are five main methods used for combatting weeds in the cacao plantation, namely: (i) by the use of shade, (ii) by the application of mulches, (iii) by the growing of cover crops, (iv) by cultivation, either by hand or by mechanical implements *(10)*, and (v) by the application of chemical weed-killers or herbicides.

(1) SHADE

The continuous provision of shade in cacao fields, from the time the forest is felled or the previous crop is removed, is essential for the successful establishment of young cacao. Not only do the young cacao plants need protection against excessive light, but shade is needed to prevent weeds from spreading rapidly, particular grasses. Shade is usually provided at first by the growing of groundshade plants such as *Crotalaria, Tephrosia,* pigeon pea, banana, and plantain, or of cultivated cash-crops such as cassava, tannia, maize and beans. Permanent shade is provided at suitable spacing by planting certain tree species, preferably leguminous species. Gaps in the overhead shade frequently arise in old cacao plantations through the death and collapse of the shade trees. This permits sunlight to enter and to illuminate the soil whereupon weeds soon appear and grow rapidly in the open places. They should at once be suppressed by planting temporary shade *(22)* or by applying weed killers.

(2) MULCHES

Covering the surface of the ground is a highly effective means of destroying weeds and preventing weed seeds from sprouting, because it completely cuts off the light. Various materials have been used as mulch. These are classified into two groups, namely, vegetable mulches and artificial mulches.

Vegetable mulches: These comprise plant residues, such as cut-grass, cut-bush, banana leaves, plantain leaves, sugar-cane trash, sugar-cane bagasse, rice-hulls, sawdust and any other cheap crop refuse. Grass and bush are sometimes grown specially for producing mulching materials on waste ground or in the traces between the cacao fields or alongside roads and paths.

Artificial mulches: These include aluminum foil, zinc foil, roofing sheet, white or black polyethylene sheet and certain specially-fabricated kinds of paper made from various fibre plants. These materials are expensive and are profitably used only for covering the ground in the immediate vicinity of young cacao plants recently put out into the field. Not only do these materials completely shade the soil surface, but they also oppose physical resistance to penetration by the weed sprouts. Their period of usefulness varies greatly and depends partly on the care exercised in handling and laying the materials on the ground around the trees. It also depends on the degree of exposure to the climatic elements to which they are subjected, because they deteriorate rapidly when exposed to the action of moisture and heat. The temperature of the soil under a mulch sheet exposed to direct sunlight rises to high values which cause injury to young cacao roots. In order to prevent undue heating, it is advisable to cover the artificial mulching material with a thin layer of vegetable mulch where exposure to sunlight is unavoidable. This, however, further increases the cost of the mulching operation often to a prohibitive degree.

(3) COVER CROPS

Few kinds of cover crops will grow satisfactorily in the dense shade of a well established cacao field *(19)* but where gaps occur in the canopy, the growth of weeds in the sunlit areas can often be prevented by planting a suitable cover-crop, such as one or other of the well-known leguminous creepers or small bush plants, for example, some species of *Indigofera (22).* Occasionally, tall clump grasses, such as *Tripsacum laxum* (Guatemala Grass) or sugar-cane are planted in gaps in cacao fields as a temporary measure. Cover crops are also grown in cacao fields that are being formed out of old pasture for the purpose of suppressing the grass and weeds but, when they possess a creeping habit, care must be taken to prevent their growing over and smothering the young cacao trees.

(4) CULTIVATION

Weeds growing close to young cacao trees can be removed, either by (i) cutting them down by hand with a cutlass or machete, (ii) tilling the ground by handhoeing or light forking, (iii) mowing by small machines drawn by animals or tractors and (iv) cultivating the soil to shallow depth with implements drawn by animals or tractors.

(i) *Weed cutting:* The operation of cutting back weeds in a ring around the trees by the use of the cutlass or machete is commonly practised on most cacao plantations. It is called "arondiering" in Trinidad. The practice is exce-edingly dangerous as a means of weed control, especially in young cacao fields, because of the risk of injuring the stems or trunks. Cutlass wounds provide ready ingress for certain fungi and some wood-boring insects which eventually kill the trees. Indeed wound damage caused in this way is one of the chief reasons why cacao yields often decline long before the trees have reached the age of full bearing. In order to eliminate the risk of injury to the cacao trees when weeds are being removed by cutlassing around them, special wooden cutlasses or sharp-edged pieces of cane or slips of bamboo stem are sometimes employed for weeding but these are not generally satisfactory, being difficult to wield.

(ii) *Costs of weed cutting:* Cutlassing is generally applied three or four times a year in cacao plantations. It is an exceedingly slow and costly method of weed control and requires much labor. In Costa Rica, the operation, involving four slashings, costs between $ 12 and $ 20 US per hectare per year, or $ 5 to $ 8 per acre per year for complete weed control in old cacao plantations. A survey of 20 cacao farms in Bahia in 1950 proved that the average cost of cutlass weeding was greater than the combined cost of harvesting, transporting and curing the crop. At "La Lola" in Costa Rica, the cost of cutlass weedling in 1951-52 was about 6 percent of the total production costs.

(iii) *Weed control by hand hoeing or forking:* The use of the hoe for weeding cacao fields, and the practice of forking around the trees for eradicating weeds, are not generally advocated because of the risk incurred of damaging the surface -feeding cacao roots. In the case of cacao which is growing on heavy clay soil that has become compacted by over exposure to beating rain, or has lost its cover of litter and organic debris, a light "prick" forking without inverting the soil is favored by some planters, but the main object is not to destroy weeds so much as to aerate the soil and to improve its surface infiltrability to water.

(iv) *Mowing weeds:* Small power machines are available for mowing down weeds in cacao fields. They are especially useful where cacao is being grown without shade and the cacao trees are suitably wide-spaced between the rows to allow the mowing machine to pass. Two main types of mower are used, namely, the "sickle-bar" mower and the "rotary" mower. They can only be used satisfactorily on fairly level ground free from stones and boulders. Maintenance is usually costly but the rate of work is high.

(v) *Cultivating for weed control:* Cultivating implements, drawn by animals or tractors, are sometimes used for weed eradication where cacao is grown in wide-spaced rows without shade trees, or where shade trees have been planted in the cacao rows. Care must be taken not to cultivate too deeply so as not to damage the superficial cacao roots, nor too near to the trunks of the trees so as not to injure them *(18)*. In most cases where tillage is applied to old well-established cacao fields, the damage done to the cacao roots is disastrous.

(5) WEED KILLERS

In recent years, the use of chemical weed killers or herbicides has been advocated as a means of controlling weeds in general *(22)* and the method has ben applied with some success to cacao plantations. When properly applied in the right amounts, weed killers considerably reduce the cost of weed control in young cacao fields but, when not skilfully used, they cause much more damage to the surface roots of the cacao trees than a massive growth of weeds *(18)*. The killing of weeds by chemical substances entails much less expenditure on labor than cutlassing or hoeing. Success in the employment of weed killers in agriculture dates from the time of the discovery of 2,4-D (2,4-dichlorophenoxy-acetic acid) and the development of the herbicide chemical industry was most rapid after the beginning of the Second World War.

History of weed killers: The earliest weed willers to be successfully employed were copper salts, first used in 1896, and later iron sulfate *(22)*. Sulfuric acid was also found in 1897 to be effective in the control of broad-leaved weeds.

The discovery was also made that certain salts used as fertilisers, for example, potassium sulfate (kainite) ammonium sulfate and calcium cyanamide, were effective weed killers when used where cereals were grown in northern Europe. Sodium arsenite was found in 1914 to be a powerful weed killer in sugar-cane fields, but its use was prohibited by law in U. S. A. in 1956. The famous herbicide, 2,4-D, was first used during the last world war. During 1950, about 17 million pounds weight of this substance were used in agriculture, and during the year following, the amount used rose to 25 million pounds weight. Since 1944, some 10 new chemical weed killers have been put on the market, some of which are derivatives of 2,4-D though differing from it considerably in effectiveness for combatting weeds.

Classification of weed killers: The following classes of weed killers differ in their effect on weeds *(10)*:

(i) *Contact:* These cause rapid death of plant cells with which they come into direct contact. They are ineffective when applied to stoloniferous weeds. Examples are pentachlorophenol (PCP), dinitro-compounds and Diesel oil.

(ii) *Translocatable:* These are translocated from the leaves to which they are applied into the stems and roots which they kill *(5)*. They are used to control perennial weeds having deep root systems. Examples are 2,4-D, 2,4-5-T, sodium arsenite and amino-triazol.

(iii) *Pre-emergent:* These are applied to the soil surface *(9)*. They prevent seed germination and destroy young seedlings. Examples are PCP, CMU and CIPC.

(iv) *Selective:* These are more toxic to certain weeds than they are to crop plants *(10)*. Their selectivity depends on the properties of the leaf surface or epidermis, as well as on the physiological resistance of the tissues and the susceptibility of their cells to plasmolysis *(28)*. They are useful for killing weeds in a rapidly growing crop *(4) (6)*. Examples are 2,4-D and dinitro compounds.

(v) *Non-selective:* These act equally on weeds and on crop plants *(27)*. Their effectiveness in killing weeds depends on the particular form in which they are applied. Examples are PCP and sodium arsenite.

(vi) *Inorganic:* These include (besides sodium arsenite) ammonium sulfate, sulfuric acid and calcium cyanamide *(21)*.

(vii) *Organic:* These are more selective than the inorganic weed killers. They include 2,4-D, TCA, CMP and IPC *(21)*.

Factors that determine the effectiveness of weed killers: The following are the chief:

(i) Kind of weed, (ii) size and age of weed *(26)*, (iii) environmental conditions before and after the application *(3) (10) (25) (26)*, (iv) concentration and degree of subdivision of the substance as applied *(15) (18)*. For the control of weeds in the cacao plantation, greatest success is obtained when weed killers are applied 15 to 30 days after cutlassing or slashing when the new growths are tender, particularly when the application is repeated several times *(18)*.

Weed killers suitable for cacao plantations: The following weed killers, made up into solutions or emulsions, are suitable for controlling cacao weeds:

(i) *Contact weed killers:* (a) *Oil emulsions:* The oils used are by-products of the petroleum industry and include aromatic compounds having low surface tension and good spreading capacity *(2)*. Their high cost precludes the use of these oils directly. They are therefore usually mixed with activators such as pentachlorophenol (PCP) or dinitrophenol or its derivates. These reduce the amount of oil required and increase its toxicity. In order to stabilize the oil emulsions, emulsifiers are used, for example, detergents. Stability depends chiefly on the specific gravity of the oil and on the size of the droplets comprising the emulsion. Thorough homogenization assures stability over long periods but it is advisable to stir the emulsion continually before putting it into the spraying apparatus and during application in the field.

Preparation of oil emulsion:

(a) *Mother solution:* Add 12 to 18 lbs. of pentachlorophenol (PCP, to 50 gallons of Diesel oil contained in a barrel. If possible, heat the mixture to ensure admixture.

To make 50 gallons of weed killer: Add sufficient water to a 50 gallon tank to fill one-third of its volume. Add 1/5 gallon of 2,4-D or preferably one of its esters having low volatility. Add 150 cc. of Triton B-1956 emulsifier, previously dissolved in water. Add 8 gallons of mother solution (containing PCP) and make up the volume to 50 gallons with water. Stir throughly. The quantities of the different ingredients of this mixture that should be applied per hectare of land are:

Pentachlorophenol (PCP)	2 to 4	kg.
2, 4-D	1	kg.
Diesel oil	200	litres

It is advised not to apply this oil emulsion weed killer too near to the cacao trunks but directly onto the weed surfaces or to the soil surface. When portable spray pumps are used for applying this weed killer, it is best to agitate the mixture before putting it into the container and to shake it up from time to time afterwards. The most suitable pump is a knapsack sprayer provided with an agitator and pump lever for maintaining the air pressure inside the container.

Preparation of dinitro emulsion:

For making 50 gallons of this emulsion, the following ingredients are required:

(1)	Dinitro-ortho-cresylate ammonium salt (DNOC)	0.5	litre
(2)	Triton B-1956 emulsifier	2 to 4	fluid oz.
(3)	Diesel oil	4 to 6	gallons

Add water to make up to 50 gallons. The amount of Diesel oil to be used depends on the condition of the weeds. If sparse, 4 gallons of oil are enough.

Dinitro-phenolic compounds exert lasting residual effects and are extremely toxic to weeds, but their effectiveness partly depends on climatic and soil conditions and on the concentrations used. When the weeds are young and tender, a mixture of 1.5 litres of dinitro-phenolic compound with 50 gallons of water provides an effective weed killer.

(b) *Other contact weed killers:* The following additional mixtures are recommended as direct contact weed killers:

(1) 2,4-D plus DNOC in commercial dosages, mixed with 50 gallons of water (18).
(2) "Weedone", 1 litre, plus DNOC, 2 to 3 kg. in 50 gallons of water.
(3) DNOC plus 2,4-D or MCPA in minimal dosages recommended by the manufacturers (11) (12) (16).

The above weed killer mixtures are used chiefly for controlling *Mirabilis jalapa* (Nictaginacaeae) and *Sida carpinifolia* (Malvaceae).

(ii) *Translocatable weed killers:*

(a) *2,4-D derivatives:* Only the less volatile of these substances are used, for example, butoxy-ethanol ester and its sodium salt, 1/4 to 1/5 gallon per 50 gallons of water. The rates of application are based on the amount of "free acid" in the 2,4-D derivative. The recommended concentration is 1 lb. of free acid to 50 gallons of water.

Weed killers containing 2,4-D are used mostly for controlling broad-leaved weeds that are resistant to contact weed killers (8) (10) (14) (20). They are highly toxic to cacao; a solution of concentration equal to 100 parts per million of 2,4-D will defoliate a cacao tree if sprayed onto it.

(b) *TCA (sodium) 90 percent:* (This is the sodium salt of tri-chloroacetic acid). The commercial product contains 3/4 lb. free acid per pound. Dissolved in water, it is used as a selective weed killer and its employed primarily for destroying grass weeds. It is effective also against many broad-leaved weeds and Cactaceae. It has a marked residual effect. It may be mixed with 2,4-D or its phenolic derivatives to give a weed killer which is effective in the control of a large number of weeds.

Conditions of application of TCA: The best mixture is 8 to 12 lbs. of TCA to 50 gallons of water (14) (17). It is most effective when applied as spray in full sunlight and when the soil is moist. Best results are obtained with two sprayings separated by 4 or 5 weeks' time. It should not be applied near to cacao trunks nor to exposed superficial roots. It may be mixed with oil emulsions.

(c) *Amino-triazol:* At dosages of $1/2$ to 4 lbs. per 50 gallons of water, this weed killer exercises good control of perennial weeds if applied at 30 to 40 day intervals. Its residual effects last 3 or 4 months.

(d) *Delapon:* This controls grass weeds when applied at lower concentrations in aqueous solution than those used for TCA (24). The recommended strength is 3 lb. per 50 gallons of water. It should be applied at intervals of 4 or 5 weeks. At higher concentrations it injures cacao and shade trees.

(e) *Karmex W:* This is a derivative of urea. It exercises complete control of grass and broad-leaf weeds. It should be applied at concentrations of 1 to 2 lb. per 50 gallons of water, 30 to 40 days after cutlassing or slashing. A second application should be made after 3 or 4 months, particularly if the first was not particularly effective. Karmex costs $ 4.50 US. per pound, and 2 to lb. should be sufficient to control the weeds on a hectare of land for a period of 6 months.

Some practical suggestions for the application of weed killers in cacao plantations.

(i) *Machines:* The best equipment is the knapsack sprayer of 3 gallons' capacity, with air compressor and agitator. Some sprayers are provided with a small motor (10) (24). Stationary pumps ,holding 50 to 100 gallons of weed killer liquid and provided with a motor and a moveable pipe-line system, have given good results. The jets used for spraying weed killers have an angle of spread of 110 degrees and deliver 2 gallons per minute.

(ii) *Application cycle:* This depends largely on the density and rate of growth of the weeds and on the cost of materials and application. *(14).* It varies according to (a) the closeness of the spacing of the cacao trees, (b) the density of the shade, (c) the kinds of weeds present, (d) the particular kinds of weed killers used and (e) the method of application. If it is found necessary to cutlass the weeds on the cacao plantation four times a year in order to achieve full control, then not more than this number of applications of weed killer would be sufficient to obtain equally good economic results.

(iii) *Danger in the use of weed killers:* To avoid accidents to laborers applying weed killers, certain precautions must be followed, for example *(26):*

(a) Read the instructions on the containers, (b) keep the weed killers out of reach of children and animals, (c) do not store weed killers in the vicinity of food, (d) wash hands and face after using weed killers.

Control of epiphytes on cacao trees: Cacao trees often carry large quantities of epiphytes on their trunks and branches. Among them are lichens, mosses, "old man's beard" *(Tillandsia)* and other species of Bromeliaceae *(23).* These do not necessarily cause danage to the cacao trees except when they interfere with the development of flowers and fruits on the cushions. They can effectively be controlled by spraying with dinitro-ortho-cresol (DNOC) (0.1 to 0.05 percent solution) or cuprous oxide (0.1 percent suspension) or copper oxychloride (0.5 percent suspension). The use of these weed killers is less damaging to the cacao trees than mechanical methods of removal that were used in the past *(13) (23)*.

SUMMARY

1. The conditions occuring in cacao plantations which favor the growth and success of weeds are enumerated and discussed.

2. The damage caused by weeds, the natural means of propagation and the chief biological forms of weeds are described.

3. The main methods employed for controlling weeds, namely (i) the use of shade, (ii) the application of mulches, both vegetable and artificial, (iii) the growing of cover crops, (iv) cultivation by hand or by implements and (v) the application of chemical weed killers, are severally considered and described.

4. Special attention is given to weed killers as used in cacao plantations, since this method of weed control, when properly applied, is the cheapest and most effective of all the methods now in use.

5. Weed killers are classified as (i) contact, (ii) translocatable, (iii) pre-emergent, (iv) selective, (v) non-selective, or as (vi) inorganic and (vii) organic. These are defined and examples of each are given.

6. The factors that determine the effectiveness of weed killers are briefly considered.

7. Weed killers that are suitable for use in cacao plantations are mentioned and the mode of preparation, the concentration used and the method of application of each are stated. They comprise three contact weed killers, namely (i) PCP activated oil emulsion, (ii) dinistro oil emulsion and (iii) aqueous solutions containing 2,4-D, DNOC or MCPA, and five translocatable weed killers in aqueous solutions, namely, (iv) 2,4-— derivatives, (v) TCA sodium salt, (vi) amino-triazol, (vii) Delapon and (viii) Karmex (a urea derivative).

8. Suitable apparatus for applying weed killers, the best time for applying weed killers and precautions to be taken in using and storing weed killers are described.

9. The elimination of epiphytes (lichens, mosses, *Tillandsia* and other bromeliads) by the use of weed killers and copper compounds is mentioned.

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PART V:

DECLINE IN CACAO PRODUCTION: REHABILITATION

CHAPTER 14

DECLINE IN CACAO PRODUCTION AND DETERIORATION OF CACAO SOILS

Decline in cacao production. A cacao field which has been established on virgin forest land usually begins to decline in yield after a number of years, depending on the efficacy of certain operative factors, the chief of which are:

(1) Diminishing productivity of the site and soil
(2) Increasing age of the original tree population
(3) Poor management
(4) Unsuitable cacao varieties initially planted.

These factors will be considered in turn.

(1) DIMINISHING PRODUCTIVITY

By productivity of a cacao field or site is meant, not merely soil fertility (which is a chemical feature of the soil) but *physical condition* considered together with soil fertility. The physical condition of a soil depends on soil structure and texture which determine rootroom and water and air-supply, as has already been explained. There are several subfactors which operate to cause diminishing productivity. The most important of these are:

(1) Too much or too little shade
(2) Damage to the cacao trees by cutlass wounds
(3) Poor canopy partly caused by falling shade trees
(4) Diseases and pests
(5) Other causes, such as:

(i) Poor drainage
(ii) Invasion by weeds, particularly grass
(iii) Poor tree-sites, for example, drain-edges and stream-banics
(iv) Reduction in amount of leaf-litter
(v) Lack of nutrient balance, for example, too much or too little nitrogen.
(vi) Deficiencies of minor nutrient elements
(vii) Soil erosion (surface wash, sheet erosion, landslide).

Not all of these productivity sub-factors directly concern the soil. Many of them are "casualty" factors, for example, cutlass wounds and damage by falling shade-trees; also damage done by diseases and pests. The direct soil factors are poor drainage, due to unsatisfactory soil structure or shallow depth, unbalanced nutrition and shortage of minor nutrient elements. These direct soil factors tend to deteriorate as time goes on because of continuous cropping, lack of fertilizer additions, or improper use of fortilisers, and bad management that fails to correct these adverse tendencies and allows soil erosion to remove the nutrient-rich and well-structured humic surface soil.

Poor drainage: An indisturbed forest soil has high infiltrability because of the presence over its surface of leaf-litter and crumb soil. Rain water which reaches the floor of the forest is readily absorbed and percolates rapidly downwards if the permeability of the subsoil is high. When the permeable soil is deep, much water can be stored in the soil-colum and run-off is reduced to a minimum or entirely prevented. If, however, the amount of litter has gradually diminished after the forest war replaced by cacao and uncontrolled surface erosion has removed much of the crumb layer and the humic soil immediately below it, then surface infiltration, penetration, absorption and water storage will have diminished also and a large proportion of the rain water will run away over the surface and accumulate in depressions where it may cause water-logging or start the formation of erosion gullies .

Soil deterioration: There are three main causes of soil deterioration in forest soils that have been utilised for growing cacao *(1)*. They are:

(1) Reduction in the supply of litter
(2) Nitrogen accretion
(3) Soil erosion.

These will e considered in turn.

(1) *Reduction in litter-supply:* Forest soils that have been converted into cacao soils are almost certain to deteriorate when constantly cropped, unless the reserves of nutrients that are slowly released by the minerals comprising the parent rock are sufficient in quentity to replace those that are removed in the crop* and also are delivered to the cacao tree roots at a fast enough rate to permit regular absorption. If not, then the growth of the tree will be retarded and supply of litter will diminish. This will ultimately lead to a lowering of the organic status of the soil because the rate of decomposition of the litter may exceed the rate of its accumulation. Loss of organic material will reduce the carbon content of the decomposing litter more quickly than the content of nitrogen which will mostly be fixed as microbial protein. This differential action will result in a lowering of the C/N ratio. It will also be accompanied by an increased rate of release of inorganic

* It has been estimated that a 500 lb. crop of dry cacao beans removes 22 lb. nitrogen, 9.5 lb. phosphate (P_2O_5) and 38.5 lb. potash (K_2O) if the pod husks are included, or 12 lb. nitrogen, 7 lb. phosphate and 12 lb. potash if the husks are left to rot on the ground.

nutrients, notably phosphate and potash. These important changes will tend to upset the nutrient balance to the further detriment of the cacao tree and to the magnitude of the crop.

The differences in chemical composition between a forest soil and a cacao soil derived from it and developed over the same kind of parent rock *(1)* are well shown by the data presented in Table I.

TABLE I

COMPARISON OF FOREST AND CACAO SOILS

Profile layers	FOREST SOIL						CACAO SOIL					
	pH	O. M. %	N %	C/N	P_2O_5 p.p.m.	K_2O p.p.m.	pH	O. M. %	N %	C/N	P_2O_5 p.p.m.	K_2O p.p.m.
Organic detritus												
1. Litter and root-mat (AOO)	—	—	—	—	—	—		—	—	—	—	—
2. Crumb (Al)	5.0	20.9	.83	14.4	62	329	4.7	11.7	.56	12.1	28	230
*Soil**												
3. Humic soil (Al)	5.1	6.4	.34	10.7	19	129	4.5	7.3	.41	10.3	18	201
4. Sub-humic (A2)	5.1	5.1	.30	9.8	21	99	4.6	4.6	.29	9.2	18	144
5. Ditto.	5.0	4.2	.26	9.3	10	84	4.6	2.7	.23	6.9	18	104
6. Ditto.	5.0	3.2	.21	8.5	16	96	4.7	1.6	.17	5.3	12	114
7. Non-humic (B)	5.0	1.8	.16	6.7	8	—	4.9	0.8	.13	3.6	10	—
Weighted means	5.0	2.9	.20	8.0	12	95	4.6	1.5	.18	5.4	12	118

* Thickness of layers: (3) 0 - ½ (4) ½ - 1½ (5) 1½ - 3 (6) 3 - 6 (7) 6 - 12 ins.

Discussion: The data in Table I clearly show the marked superiority in the organic matter and nitrogen status of the forest soil. The C/N ratio of the cacao soil is much less than that of the forest soil, not only in the crumb layer but also in the humic soil beneath. The mineral nutrient status of the crumb is higher in the forest soil than in the cacao soil, but that of the soil beneath is about the same. Not only is the organic status and the kind of organic matter, as indicated by the value of the C/N ratio, different between forest and cacao soils but it is different between high-yielding (good) and low-yielding (bad) cacao soils of the West Indies and West Africa *(3)* as shown by the results given in Table II.

TABLE II

COMPARISON OF "GOOD" AND "BAD" CACAO SOILS

(Top 6-inch layer)

	"GOOD" CACAO SOILS						"BAD" CACAO SOILS					
	pH	O. M. %	N %	C/N	P_2O_5 p.p.m.	K_2O p.p.m.	pH	O. M. %	N %	C/N	P_2O_5 p.p.m.	K_2O p.p.m.
WEST INDIES												
Trinidad	6.6	4.8	.28	9.8	42	250	5.6	3.3	.25	7.7	25	110
Tobago	6.7	4.7	.24	11.1	63	100	6.6	3.4	.21	9.1	24	64
Grenada	6.9	3.9	.21	10.7	75	306	6.6	3.8	.23	9.4	45	289
WEST AFRICA												
Ghana	6.4	2.8	.14	11.1	25	97	5.8	1.5	.09	9.7	18	58
Nigeria	6.5	2.4	.13	10.7	23	147	4.8	1.6	.07	—	14	70

Discussion: Although good cacao soils contain greater amounts of organic matter and nitrogen than bad, the chief difference is shown by the much lower C/N ratio of the bad cacao soils, presumably due to soil deterioration. Marked differences also occur in available phosfate and potash contents which are higher in the good soils.

(2) *Nitrogen Accretion:* Shade trees that are planted with caaco usually comprise genera of Leguminoseae, such as *Erythrina, Inga* and *Gliricidia* whose root -nodules contain nitrogen-fixing bacteria whose symbotic activity enriches the leaves and flowers in nitrogen. Thus it has been estimated that 1150 lb. weight of flowers and leaves that collect on the soil surface of one acre of shaded cacao, containing 50 leguminous shade trees, contribute, per year, about 40 lb. of nitrogen, equivalent to 200 lb. of ammonium sulfate *(1)*. Nevertheless this amount of extra nitrogen added to the soil, although theoretically it should lower the magnitude of the C/N ratio of the soil, would increase its total nitrogen content by only 0.002 percent per year. It would therefore take a great many years before nitrogen accretion would have lowered the C/N ratio by, say, one unit, assuming that the total carbon content remained unchanged.

(3) *Soil Erosion:* Since C/N ratio diminishes in magnitude with depth (Table I) profile truncation brought about by soil erosion will progressively remove layers of humic soil having lower and lower C/N ratio. This would readily account for the lower C/N ratio of bad cacao soils as compared with good *(1)*. Nevertheless, in theory, soil erosion should not occur to appreciable extent in mature cacao fields in which the ground is completely covered with vegetation for, under these circumstances, rain does not impinge directly on the soil surface but is decanted down the tree-trunks and enters the soil without disturbing the surface. Once the cacao canopy is discrupted and rain gains direct access to the soil, heavy rain showers wash away the litter and crumb, especially on sloping land, and soil erosion inevitably results.

Conclusion: It may be concluded that the reason for diminishing C/N ratio in cacao soils that are undergoing deterioration may be any or all of the three reasons that have been suggested above, although it is probably mainly the first, namely, diminution in the amount of litter. This is brought about by retarded growth occurring on soils of unsatisfactory nutrient status and having inadequate root-room because of impediments to root-penetration. It is accelerated by continuous cropping and failure to make good the nutrient losses by manuring or mulching or by the application of fertilizers and amendments.

(2) INCREASING AGE OF THE FIELD

Soon after a young cacao field has been planted up and the shade trees are growing satisfactorily, the various accidents and casualties begin to affect the tree population and the soil deteriorates at a rate depending on its original inherent properties. As an example of the effects of deterioration factors on the yield and composition of the cacao-tree population, actual data for two old cacao fields (50 years old) in Trinidad, planted respectively on good and bad soil, are given below in Table III.

TABLE III

COMPOSITION AND YIELDS OF THE CACAO TREE POPULATION IN OLD CACAO FIELDS IN TRINIDAD

(Fields 50 years old)

(A) COMPOSITION OF TREE POPULATION

	GOOD SOIL	BAD SOIL
Number of trees producing cacao	64	50
Number of non-producing trees	36	50
	100	100
Non-producing trees composed of:		
(i) Blanks (no trees)	5	10
(ii) Supplies (replants)	6	6
(iii) Trees less than 5 years old	8	8
(iv) Trees more than 5 years old	17	26
	36	50
Trees older than 5 years damaged by:		
(a) Excessive shade	5	1
(b) Cutlass wounds	2	8
(c) Poor canopy	3	8
(d) Diseases and pests	1	2
(e) Other accidents	6	7
	17	26

(B) YIELD CONTRIBUTIONS OF DIFFERENT TREE-CLASSES

	GOOD SOIL		BAD SOIL	
Total yield (lb.)	290		90	
Yield of cacao per tree (lb.)	1.3		0.4	
	Percentage of yield	Percentage of pickets	Percentage of yield	Percentage of pickets
Age classes				
Blanks	0	0	0	16
11 — 4 years	0	30	0	13
5 — 10 years	4	13	3	11
1 — 4 years	31	24	72	51
Original trees	65	31	25	9
Total mature trees (over 10 years old)	96	55	97	60
Yield classes (lb. per tree)				
— 0 lb. ("Blanks")	0	42	0	64
0 — 1 lb.	7	16	29	25
1 — 2 lb.	19	16	22	5
2 — 3 lb.	21	11	20	3
3 — 4 lb.	18	6	17	2
4 —	35	9	12	1
Profitable trees (over 1 lb. per tree)	93	42	71	11

Discussion: The first part of the table (A) indicates that only about two-thirds of the total number of cacao trees in a field of comparatively suitable soil bear an appreciable crop and only half of the number of trees in a field of less suitable soil. About half of the non-producing trees in each case are less than 5 years old. They represent supplies that have been planted annually to replace dead or non-bearing trees but which have failed to grow. Non-producing trees more than 5 years old are half again as numerous in the bad soil field, but their poor performance is only partly due to adverse soil conditions (for example, poor canopy). It is largely owing to accidents.

The second part of the table (B) indicates the following facts: (i) that nearly all the total yield is produced by 55 and 60 percent of the mature trees in the good and bad soil fields respectively. These trees are all over 11 years old. (ii) that the rest of the trees (45 and 40 percent) produce only 4 and 3 percent of the yield, (iii) that most of the high-producing trees (31 percent of the total population) in the good soil field are original trees 50 years old, whereas only 9 percent of the high-producing trees in the bad soil field are originals, (iv) that the greatest yield contribution in the good soil field (35 percent) is made by a few (9 percent) trees in the over 4 lb. per tree class, whereas in the bad soil field it is made by trees in the 3-4, 2-3 and 1-2 lb. per tree classes, and finally (v) that there are nearly four times as many profitable trees (each producing over 1 lb. of dry cacao) in the good soil field than in the bad soil field. Presumably the length of life of the cacao trees in the good soil field is much greater than that of the trees in the bad soil field.

(3) POOR MANAGEMENT

This human factor varies greatly in importance as a cause of decline in yields of cacao fields. In many cases it is probably the most important cause of all. The reason for its variation lies in the power of incentive and this in turn usually depends on probable profits. When "times are bad" the cacao fields are neglected. Pruning, draining, reaping, supplying, disease and pest control and general orchard sanitation do not receive the attention that should be given to them. There is need in certain instances for financial assistance and long-term credit to enable planters to tide over the difficult periods. In many cases economic circumstances exceed all others as a factor in declining yields. These cases have been discussed in another place. Their importance as a cause of declining yields can scarcely be over-estimated.

It must have been the general experience of many cacao planters that certain trees in every field are outstanding in growth and yield. In some cases the cause can be attributed to exceptionally favorable environmental conditions, for example, a "good pocket of soil" but, in many instances, a simple explanation may not so readily be forthcoming. Evidence has been obtained by a consideration of the individual yields of the trees comprising certain field experiments being conducted in Trinidad that the important factor whose effect in many cases quite outweighs the effects of environmental circumstances, including those experimently imposed, is field management *(2)*. The experimental evidence referred to is as follows.

The mean yields over three consecutive cropping seasons of experimental trees whose girths at ground level had been measured at the beginning of the period when the trees were 3½ yars old showed a highly significant degree of positive correlation with the girth measurements. This clearly implies that cacao plants which have been carefully produced and carefully established, so that they have early reached large size, are likely subsequently to produce high yields of cacao, under continued good management (2). An assurance of high yields puts a premium on horticultural skill, manipulative care and efficient field management which sometimes may exceed in importance the natural factors of the environment.

(4) UNSUITABLE CACAO VARIETIES

This factor has been exaggerated in recent years. High-bearing strains of cacao exist which out-yield other strain, even on marginal or unsuitable land. Many presumed high-bearing varieties have been wrongly selected, however, because they were growing on exceptionally favorable sites of good soil. New varieties of cacao, believed to be high-bearing, should be compared with tested varieties under a wide range of environmental conditions before they are accepted as outstanding. Similar arguments apply to varieties believed to be resistant to diseases and pests.

SUMMARY

Decline in cacao production is attributed to deterioration of site and of soil, as well as to increasing age of field, poor management and unsuitable varieties. Site deterioration includes vicissitudes such as tree damage by cutlass wounds, diseases and pests, weeds and falling shade trees. Soil deterioration includes unsatisfactory drainage, reduction in amount of fallen litter, unbalanced nutrition, deficiency of minor elements and surface erosion. These factors are cumulative. As the age of the field increases, their effects are greatly enhanced under poor management.

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CHAPTER 15

REHABILITATION OF CACAO FIELDS

INTRODUCTION

By rehabilitation is meant the transformation of an old plantation whose yields have declined so as no longer to be profitable, either (i) by removing the existing trees (ii) by introducing new trees as partial replacements or (iii) by removing all the old trees and replacing them by new trees. Experience with these three methods has shown that, under present-day circumstances, the third method (complete replacement) is the best in the long run.

It is now well known that cacao trees exist which are naturally low-bearers and that this is a genetic characteristic, whereas other trees exist which are naturally high-bearers, even when grown under identical environmental conditions as those under which low-bearers are grown. Thus the tree population of a cacao field may consist of a large proportion of naturally low-bearing trees and its yield might therefore in theory be increased merely by replacing trees of low-bearing genetic strains by trees that are known to comprise high-bearing strains which are also resistant to diseases and pests and which produce high quality cacao.

Heterogeneity of tree population in old cacao fields: In discussing the causes of decline in production of old cacao fields in the last chapter, an actual example was given of a 50-year old field of good soil in which 36 percent of the trees produced hardly any crop. These low-bearers comprised 19 percent that were yet either too young (under 5 years of age) to bear pods, being recent supplies (replacements) or had died and had not been replaced. The remaining 17 percent, consisting of non-bearers over 5 years of age, comprised trees that had suffered damage from excess of shade, cutlass wounds, diseases and pests and other accidents, or that possessed poor canopies. Another 50-year old cacao field of bad soil in which 50 percent of the trees were low-bearers contained 24 percent of replacements under 5 years of age, the remaining 26 percent of older trees not producing any crop because of accidental damage, over-shading or poor canopies. Had it not been necessary to replace the large percentage of trees that had died, and had not any accidental damage occurred, the yields of these two fields would have been approximately twice as large as they actually were. Even then, however, the yield of the field on good soil would have been very much less than the theoretically possible maximum production which is nowadays accepted as 2,000 lb. dry cacao bean per acre.

Another example of the yield distribution between high-bearing and low-bearing trees in a cacao field is given in *Figure 1* *(3)*. In this field, less than one-quarter of the total number of trees produce 3 lb. or more of dry cacao per tree and would thus be regarded as high bearers. The remaining three-quarters produce less than 3 lb. per tree and would be regarded as low bearers.

The fact has been demonstrated that old fields, no matter on what kind of soil they occur, yield less than young fields. On good soil, decline in yield sets in, on the average, at about 30 years and on bad soil at about 20 years *(3)*. The rate of decline on good soil is much slower than that on bad soil, namely, one percent per annum as compared with 6 percent per annum *(3)*. Original trees on good soil begin to decline at about 70 years of age, although the cause of decline is not necessarily old age but usually accidental circumstances such as damage by fallen shade trees. By contrast, original trees on bad soil begin to decline at about 20 years of age *(3)* largely because of soil deficiencies or soil deterioration. In either case, the original old trees produce more than the young ones because these latter mainly consist of supplies (replacements). Supplies seldom grow satisfactorily nor produce good crops because (a) they have to complete for light, water, air and nutrients with the well established trees that surround them, (b) the site where a supply has been planted may have coincided with that where an old tree died because of unsatisfactory soil conditions or some other unsuitable environmental circumstance, and (c) supervision may have been inadequate; supplies rarely receive the attention given to compact blocks of young trees planted as a pure stand *(3)*.

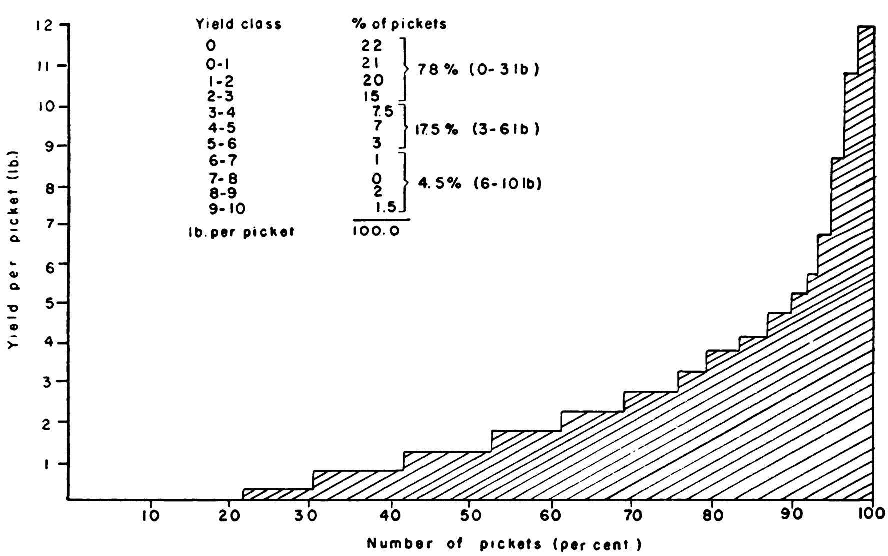
Supplying: It has been the unfortunate experience among cacao planters every-where that supplies are difficult to establish successfully in cacao fields whose age is over five years and whose trees have reached the stage when their canopies have closed in and are touching one another. By this time, the shade is too dense to permit rapid growth of newly-introduced young trees and, even when the shade is suitably reduced by severely pruning the adjacent cacao trees or thinning out the artificial overhead shade, the general environmental conditions are not satisfactory for the growth of the supplies, quite apart from the expense and trouble involved in pruning, coupled with the serious loss of crop that may be sustained by the pruned trees. Supplying should therefore be regarded as an altogether unsatisfactory means of resuscitating old cacao fields.

The procedure first suggested in 1938 in Trinidad for rehabilitation was the replacement of blanks and poor bearers, yielding one pound or less of dry cacao beans, by new seedling plants. (Clonal cuttings and buddings were not at that time available in quantity) *(5)*. Usually these poor trees and blank sites amounted to between 30 and 40 percent of the total number of trees in an old dilapidated field, so that the supplying was confined generally to a few large areas, not merely to scattered spots. This greatly reduced the cost of rehabilitation, as well as increased the chance of success of the procedure. The loss of yield incurred by such replacement was generally less than 10 percent of the total yield of the field, so that it was considered that the method was economically sound *(3)*. Consequently it was adopted by the Cocoa Board of Trinidad and Tobago under its Subsidy Scheme launched in 1945 (see below) though not until considerable progress had been made in the large-scale production of clonal cacao cuttings (6).

FIGURE N°1

DISTRIBUTION OF YIELD PER PICKET PER YEAR

Seedlings
Age: 41 years
Yield: 540 lb. per acre



The chief drawback to the method of rehabilitation described above, apart from the cost of labor, the need for continued supervision, and the skill and care required, is actually the loss of crop caused by the heavy pruning of the remaining trees which, in some cases, is as high as 30 percent of the former yield in the year following the rehabilitation pruning, and is still appreciable in the year after that *(3)*. Another, nearly as important, drawback to the method of rehabilitation by partial replacement, in comparison with rehabilitation by complete or entire replanting, is a loss of revenue owing to the fact that, when a field is replanted, temporary shade is needed and this (at least in the West Indies) usually consists of an edible and marketable species or variety of banana that is sold locally or exported in cases where an established banana industry already exists. The value of a catch crop such as banana often amounts to as much as 65 percent of the cost of replanting *(3)*. *Although* banana also is often used a shade when rehabilitation by partial replanting is practiced, the quantity of shade plants needed is proportionately much less.

Certain cacao clones, planted as cuttings, come into bearing much earlier than seedlings of the ordinary low yielding strains. They often give substantial yields even when only four years old. It should be possible, by rehabilitating old cacao fields solely by complete replanting, to adopt a policy of rotational planting in which each field of the plantation is replanted say once every 25 years, which means that four percent of the total area is replanted every year with the very best planting material available, obtained from the best possible selections of proven clonal cacao possessing potentially high yielding capacity, high degree of resistance to diseases and pests and capable of producing dry cured cacao of the most desirable quality, commanding the highest market price.

Cocoa Subsidy Scheme in Trinidad: An example of financial assistance: In Trinidad, according to the rules drawn up under the Cocoa Subsidy Scheme of 1940 *(4)* partial replanting of 35 percent of the total number of tree sites in old cacao fields to be rehabilitated was at first permitted and encouraged. An allowance of free plants, a cash subsidy, which varied with the amount of intended replacement, and free gifts of fertilizers were provided from government funds. Two large propagating stations were established for producing clonal cuttings of specially selected high-yielding strains of cacao. These propagators gave an outturn of nearly 900,000 clonal caaco cuttings in 1958 and a further increase was expected for future years. Assistance was also offered to estate owners who wished to construct their own propagators, provided the need for clonal plants exceeded 10,000 per year for not less than 5 years. The cost of construction, as well as the cost of upkeep and operation, of these private ly-owned propagators were also met from government funds.

Since the cacao rehabilitation scheme was actually inaugurated in Trinidad in 1944, some 8,500 acres of land have been completely replanted with select clonal cacao cuttings and 19,000 acres have been partially replanted out of an estimated total area of 150,000 acres suited to cacao growing. Thus, 18 percent re-establishment had been achieved by the end of 1958. It is estimated that, at present, about 10 percent of the total number of pickets are occupied by clonal plants. It will take 40 years more to replant all.

Replacement by cuttings or buddings: This is the method most generally practiced at the present time. It is strongly advised that a mixture of clones of different strains be planted rather than all of one strain. Certain clones are compatible while others are incompatible, and it is likely that the beans produced by them possess differing qualities so that, by suitably mixing the clones, a regular high yield of standard quality cacao may be ensured.

Replacement by chupon buddings: A recent development in the practice of rehabilitation consists in budding onto basal shoots (chupons) arising from the old trees, using budwood from nursery trees comprising selected clones. If chupons are not present on the old trees, their growth can be induced by severe pruning or by chopping down the trees just above ground level. The budding procedure should be systematically followed, the ultimate aim being total replacement. This method has the advantages that time is saved and that it is cheaper than the process of rebabilitation by planting with cuttings, buddings or seedlings. It has the disadvantages that incompatibility between scion and stock may exist, and that the root-system of the old tree may be unsatisfactory. This latter drawback is said to be eliminated, however, if the bud graft is made low down on the basal chupon and the junction earthed up so as to induce the formation and development of a new root system in the midst of the old. Assuming adequate soil aeration, the old root system should rapidly decay after the parent tree has died and thus make room for new roots.

Replacement by hybrid seedlings: In recent years, increasing attention has been given to the propagation of cacao by open pollinated seed produced by high bearing clones, or by single cross hybrid seed obtained by hand pollination among individual clones of disease-resistant Upper Amazon parentage *(1)* and also between these Amazon clones and other clones, such as Trinitario strains in Trinidad or West African Amelonado cacao in Ghana. Seed obtained in Trinidad by crossing SCA selections (Upper Amazon) that are highly resistant to Witches' Broom disease with ICS selections (Trinitario) which are high yielding, has produced plants that show a marked progeny precocity in that they have given when only 6 years of age phenomenally high yields of the order of 2000 lb per acre or more, as well as being markedly resistant to disease *(1)*. This important discovery has suggested that it is highly advantageous to use hybrid seedlings or cuttings derived from trees grown from hybrid seed, for rehabilitation cacao plantations in the future.

Difficulties involved in re-establishment: It has unfortunately been the common experience of cacao planters that attempts to re-establish cacao on land that had previously grown the crop for many years are generally unsuccessful unless special precautions are taken. The problem is being especially investigated in Ghana in areas that have been devastated by the Swollen Shoot disease and by capsids *(2)*. It has been found that the most successful reestablishment is achieved in Ghana where the damaged land had previously reverted to second-growth bush. Where it had been used for food farming, the results were unsatisfactory. Much soil organic matter had been lost, and invasion by grasses and other weeds had occurred. Weeds and grass could easily be suppressed, however, by close-planting vigorously-growing trees such as *Gliricidia* or Tree-Cassava *(2)*. In fact, it is nowadays generally conceded that the bush fallow is the only practicable method that has yet been discovered for rapidly renovating worn-out land which has previously been growing a cacao crop.

The yields of cacao obtained in all re-planted areas have so far generally been much below expectations, even when recommended clonal planting material has been consistently used. Thus, in Trinidad, it appears that, with the planting material now available, yields of only 500 to 600 lb. per acre of dry cacao per year can be expected from fields that have been completely replanted, and yields of only 150 to 250 lb. per acre from partial replanting. The reasons advanced for these low yields are (i) bad management during establishment (unsuitable shade, inadequate planting holes, irregular weed control) (ii) unsuitable varieties of cacao and (iii) competition from other cacao trees in the case of partial replanting*. The use of fertilizers in establishing new plantings so far has not proved beneficial in Trinidad. How far deteriorated soil is responsible for the low yields has not yet been ascertained. Undoubtedly, however, failure to protect the soil from wastage of organic matter through exposure to direct insolation and from surface erosion by beating rain, because of over-long delay in replanting old caaco land that has been cleared or felled must have greatly affected its productivity. It is recommended that temporary shade be planted before the derelict cacao trees are cut down. This is not difficult when banana and cassava are employed as ground shade.

REHABILITATION BY CULTIVATION AND MANURING:

In discussing the preparation of the land for planting cacao, the case of old pasture land was considered, and it was indicated that cultivation by mechanical implements and the application of manures, fertilizers and soil amendments might be the best way to impart high productivity. It was also hinted that best results could be expected only if the soil possesses favorable physical properties. By this is meant a stable porous aggregate structure built up from assorted mineral particles of different sizes cemented by colloidal clay or humus or by ferric oxide in the case of Latosols. Under suitable circumstances, and as the result of much greater experience than has so far been gained, it seems reasonable to expect that, under a system of replanting every 20 or 30 years, involving the use of the best available planting material and the application of balanced fertilizers and minor elements, it should be possible with deep mechanical cultivation and the construction, if necessary, of combered beds and drains, to ensure continued high yields of much greater magnitude than those which have heretofore been obtained.

SUMMARY

1. Rehabilitation or resuscitation of old cacao fields in declining production by (i) supplying (partial replacement) and (ii) replanting (total replacement) are described. The second method is favored because of the practical difficulty of establishing supplies in old fields.

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* E. Moll, private communication, Feb. 1959.

2. The history and development of a subsidy scheme for rehabilitating old cacao plantations are described in which cuttings or buddings or hybrid seedlings of high-yielding, disease-resisting clonal selections are used.

3. The advantages of rotational replanting of entire cacao fields are considered. This system could be combined with mechanical cultivation and the application of manures and fertilizers.

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CHAPTER 16

FERTILIZER USAGE IN CACAO GROWING*

The choice of kinds and quantities of suitable manures and fertilizers for application to cacao at the present state of knowledge is an arbitrary procedure. A large number of factors must be considered whose effects vary greatly according to local circumstances. Sufficient experimental evidence has not been assembled regarding the responses of cacao to manures and fertilizers under widely-varying environmental conditions to warrant generalized statements. The planter is therefore advised to proceed cautiously and to experiment for himself from first principles. The most satisfactory results from manuring are obtained only with uniform well-managed cacao plantings which have been created and developed with manures and fertilizers from the time of the initial planting.

The first question to decide is whether or not permanent shade trees are required after the young trees have passed the establishment phase, that is, have reached the age of 4 or 5 years, by which time their canopies should have closed. If the soil's physical features are satisfactory, particularly root-room and water and air relations, then permanent shade can be dispensed with altogether. The use of fertilizers in this case will be essential for satisfactory growth and production in all soils, except those that are naturally exceptionally fertile, and in all climates, except those with constantly low light intensity owing, for example, to dense and continuous cloud. Provided the right kinds and amounts of fertilizers are employed and that they are applied in the correct manner, the yields given by unshaded fertilized cacao should greatly exceed those given by shaded cacao whether fertilized or not, assuming, of course, that diseases and pests are fully controlled. Where the physical conditions are not adequate, shade is essential for satisfactory growth and production, although lower yields must be expected and accepted. Permanent shade should always be provided when there is any doubt that the environmental factors other than enhanced nutrient supply provided by added fertilizers, are entirely suitable. Shade that is too dense may easily be thinned or removed by poisoning where evidence is forthcoming to prove that better results can be obtained with less shade or with no shade at all when fertilizers are applied. Under permanent shade, the use of fertilizers is generally beneficial during the establishment phase though not necessarily economically advantageous during the productive phase of the cacao crop. Whether permanent shade is planted or not, the provision of temporary shade,

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* This chapter was written by G. Havord mainly from notes used in lectures to the Cacao Course.

for example, banana plants, leguminous shrubs or palm leaves, is essential up to the time when the cacao trees are large enough to become self-shading.

The following suggestions are offered regarding the quantities of fertilizers that might be used, with the proviso that they should be altered at any time if evidence is obtained that the amounts are too large, as indicated by leaf scorching, or are unbalanced, as indicated by the appearance of leaf symtoms that denote specific nutrient deficiencies. The suggested fertilizer treatments differ according to the phase of growth or age or the cacao trees and whether or no permanent shade trees are present.

(A) ESTABLISHMENT PHASE (First 4 or 5 years)

1. The seeds, seedlings, clonal cuttings or clonal buddings should be planted in holes of suitable size in which the excavated soil, before returning to the hole, has been mixed with one basket (15 lb.) of well-rotted pen manure or compost, if available, together with ½ lb. of the following fertilizer mixture:

Ammonium sulfate	5 parts (or urea 2½ parts)
Single superphosphate	5 parts
Potassium sulfate (*not* chloride)	2 parts
Magnesium sulfate (anhydrous)	1 part

A small amount (about one percent) of a mixture of compounds (preferably chelates) of minor elements should also be added, to include iron, aluminum, zinc, manganese, copper, molybdenum and boron, unless it is known previously, from chemical analysis or pot tests, that the soil contains adequate amounts of these essential minor elements. A stock supply of this mixture should be made up with fine sand or soil for use when required.

2. During the first year, assuming that the young plants are growing satisfactorily, a dosage of ½ lb. of the same fertilizer mixture should be applied, fortified by one percent of the minor element mixture, to each tree.

3. During the second, third and fourth years, the quantity of the fertilizers mixture should be increased to 1½ lb. and 2 lb. per tree respectively, but the minor element mixture could be omitted. If there is any trace of leaf scorch (as there might be if the soil is sandy) this fertilizer treatment should be reduced or divided and applied in two, three or more doses at different times of the year. It is advisable to apply the fertilizer in not less than two doses in most cases, one of them just before the beginning and the other later in the rainy season.

4. The fertilizers can be applied ready-mixed or else an approximately equivalent compound fertilizer, for example, 15-15-15-5, N-P-K-Mg fertilizer, but the quantities required in this case would be about one-half of those given above. The advantage of separate fertilizers is that, when single superphosfate is included, sufficient calcium is provided by it to satisfy the needs of the cacao plant in cases where the soil is highly acid and possibly deficient in this essential nutrient. Complete compound fertilizers often do not contain calcium.

(B) PRODUCTIVE PHASE (5th. or 6th. year and after)

The composition of the fertilizer mixture should be altered in the productive phase and the amounts regulated by the magnitude of the crop and the presence or absence of shade. It should now be based partly on the quantities of nitrogen, phosfate and potash that are removed by the pods from a normal productive soil. The quantities given below may provisionally be accepted for these removals in the case of a 100 lb. per acre crop of dried beans, given by a population of 300 cacao trees per acre. It is assumed that the pod husks are *not* removed but are left in heaps in the field to rot and then spread uniformly over the ground. Discarded pods should be treated with freshly-slaked lime or with some suitable sterilizing agent in order to prevent the spread of diseases. The figure, 1000 lb. per acre, is suggested as basis because, unless yields of this or of greater magnitude can be obtained, the use of expensive fertilizers is likely to be uneconomical and unremunerative.

The following total amounts of nutrients are removed by 1000 lb. ac. crop of cured dry beans.*

Nitrogen (N)	24 lb., equivalent to 120 lb.	sulfate of ammonia
Phosphate (P_2O_5)	14 lb., equivalent to 80 lb.	single superphosphate
Potash (K_2O)	24 lb., equivalent to 50 lb.	potassium sulfate

The following total amounts of nutrients are removed by the *husks* of a 1000 lb. ac. crop of dry beans, when the whole pods are taken off the land.

Nitrogen (N)	20 lb., equivalent to 100 lb.	sulfate of ammonia
Phosphate (P_2O_5)	5 lb., equivalent to 28 lb.	single superphosphate
Potash (K_2O)	53 lb., equivalent to 110 lb.	potassium sulfate

Considerable quantities of fertilizer apparently must be used to compensate for the removal of nutrients from the soil by the crop. At the same time, the supply of available nutrients in the soil is constantly being augmented and replenished by the natural processes of mineral weathering and atmospheric nitrogen fixation. The nutrient supply is also constantly being reduced by leaching to a degree depending on the magnitude and distribution of the rainfall. Added fertilizer similarly is prone to loss by leaching and by fixation by clay minerals. Taking all these processes into consideration, the following quantities are recommended for application to cacao in the productive phase, in pounds per acre of the individual standard fertilizers, assuming that the husks are left on the ground.

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* These figures were adapted by S. N. Adams and A. D. McKelvie (Rept. on Cocoa Conference, 1955, Cocoa, Chocolate and Confectionery Alliance, p. 25) from data published by E. C. Humphries (Ann. Bot. 1944, N. S. VIII, p. 57). They differ from figures published by other investigators, as would be expected, particularly in the ratio of weight of husk to weight of beans which varies greatly between different cacao varieties. Cacao husk is particularly rich in potash and its removal from the field more that doubles the loss in potash which might be serious in in the case of some sandy soils that are deficient in this nutrient, necessitating the application of large quantities of potash fertilizers to compensate for the loss.

(I) UNSHADED CACAO

	For a 1000 lb. crop
Ammonium sulfate	500 lb. or N 100 lb. per acre per year
Single superphosphate	300 lb. or P_2O_5 55 lb. per acre per year
Potassium sulfate	200 lb. or K_2O 100 lb. per acre per year
Magnesium sulfate (anhydrous)	75 lb. or MgO 25 lb. per acre per year

Note: (i) Magnesium sulfate is used here as fertilizer because it is nowadays regarded as particularly important as a cacao nutrient and is often deficient in the soil, especially if it is a sandy sort. Magnesium sulfate contains about 33 percent of magnesia (MgO).

(ii) Calcium, which is also an important nutrient for cacao, is supplied by the superphosphate. Single superphosphate contains about 27 percent of lime (CaO). Thus the dressings of lime and magnesia combined in these divalent-base dressings occur in the ratio of about 4 to 1, which is thought to be the best ratio for these two nutrients for cacao.

(iii) There may not be need for further additions of minor elements in the productive phase.

(iv) Any one of the nutrient ingredients should be reduced in amount or omitted from the mixture if it becomes evident that the soil contains adequate quantities of it.

This fertilizer mixture should be applied twice a year in two equal portions, where possible, but if not all of it, then at least the nitrogenous part. Ready-mixed or compound fertilizer having equivalent composition, as before, might be substituted for it. A suitable and cheaper procedure would be to apply 400 lb. per acre of a 15-15-25-5 mixture in one application and to follow it by an application of 100 lb. ac. urea six months later. This would satisfy the requirements and also split the nitrogenous component into two parts.

(II) SHADED CACAO

	For a 1000 lb. crop
Ammonium sulfate	300 lb., or N 60 lb. per acre per year
Single superphosphate	300 lb., or P_2O_5 55 lb. per acre per year
Potassium sulfate	200 lb., or K_2O 100 lb. per acre per year
Magnesium sulfate (Anhydrous).	75 lb., or MgO 25 lb. per acre per year

Note: The amount of nitrogenous fertiliser recommended for shaded cacao is here diminished in view of the facts that (a) light intensity is reduced and (b) leguminous shade trees supply a considerable amount of nitrogen by the fixation of atmospheric nitrogen.

Should a mixed commercial fertilizer be prefered, an application of 400 lb. of the same 15-15-25-5 mixture, per acre per year, would provide approximately equivalent quantities of nutrients.

Liming: The question might be asked why, in order to supply calcium and magnesium as important plant nutrients for cacao, magnesian limestone (dolomite) is not recommended, assuming that it is readily procurable and cheap? The reason is the great risk involved in applying limestone (especially in the case of sandy soils) of inducing chlorosis through the suppression of iron, as well as zinc, manganese and copper. The risk is considerable with soils on the borderline of neutrality, but it is not so great with highly acid clayey cacao soils which often benefit markedly by judicious liming, say up to 2000 lb. per acre of ground limestone, applied broadcast.

Method of fertilizer application: In the establishment phase, fertilizers should be applied in a broad ring around each tree but at a safe distance from it. In the productive phase, they should be applied in wide bands in directions at right angles midway between the rows of trees. For sandy soils, and particularly under wet climates, they should be applied in two, three or more fractional dosages rather than in one dosage only.

Alleviation of minor nutrient deficiencies: Minor elements need not be applied in the productive phase after the major nutrients have induced vigorous growth of the cacao trees and have caused the root systems to explore a large volume of soil. If symptoms of minor nutrient deficiencies develop later, they can best be dealt with by spraying the foliage with solutions of the chelates or, less effectively, with solutions of simple salts containing the minor elements. Nitrogen is sometimes also applied in this way, being added to the spray liquid in the form of urea which contains about 46 percent of nitrogen and does not cause leaf scorch as would ammonium sulfate or other simple salt. The quantity that can be applied in this manner, however, is usually far too small to satisfy the nitrogen requirements of vigorously-growing cacao trees and needs to be augmented by adequate dressings of nitrogenous fertilizer applied to the soil. When applied to the foliage in solution by spraying, urea should not be used in concentrations exceeding 1½ percent. In order to conform with this restriction, only high volume spraying can therefore be employed.

SUMMARY

1. The use of fertilizers in the growing of cacao is discussed and recommendations are made regarding the kinds and quantities of fertilizers required, including minor nutrients, both for unshaded and for shaded cacao.

2. The fertilizer requirements of the cacao tree are separately considered for (A) the establishment phase (first 4 or 5 years) and (B) the productive phase.

3. The recommended quantities are partly based on the average contents of nitrogen, phosphate and potash removed by a 1000 lb. ac. crop of cured dried beans, assuming that the pod husks are left on the ground to rot and then spread around the trees.

4. The dressing of nitrogen recommended for cacao growing under shade is less in magnitude than that for cacao grown without shade; the quantities of phosphate and potash are the same.

5. Equivalent amounts of mixed or compounds fertilizers corresponding to the recommended simple standard fertilizers are given.

6. The method of fertilizer application, the use of sprays for supplying minor nutrients and nitrogen (as urea) and the need for liming are severally discussed.

PART VI:

PLANTATION MANAGEMENT

CHAPTER 17

MANAGEMENT OF THE CACAO PLANTATION *

Characteristics of the cacao industry: Management includes control of labor, business finance, adjustment of the different branches of activity that comprise the business and the application of new technological developments accruing from research. The planter should not allow himself to become obsessed, however, with any one of these branches. Good management consists in the recognition of the main problems that concern a particular plantation and their satisfactory solution.

Although the management problems of individual farms vary according to such factors as size, situation and soils, as well as financial, labor and material resources, the opportunities on all farms follow a general pattern owing to certain characteristics that are typical of the cacao planting industry in general. There are seven characteristics that determine the broad lines of cacao farm management, as follows:

(1) The cacao-planting industry primarily concerns a monoculture. Some cacao farms include cultivations other than cacao, for example, food crops and coffee, but these are usually subsidiary to the main cultivation.

(2) Cacao cultivations are run under private ownership, seldom if ever under public companies. The chief reasons for this are that expensive machinery is not at present needed for preparing the final product, that technical knowledge of the crop has not reached the same advanced stage as it has reached in other crop industries, and that the marketing of the product presents peculiarities that prevail from the past. The financial outcome of a cacao-planting venture is seldom sufficiently predictable to attract public investment.

(3) The average life of a cacao plantation is relatively long, about the same as that of a man, but it is not everlasting. Consequently, its management must be conducted with the inevitability of replanting or abandoning it when the trees have become senile.

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* This article is based on a series of lectures given by A. L. Jolly, Lecturer in Economics, I. C. T. A., Trinidad, to the Cacao Course at I. I. C. A., Turrialba, and published in the *Jour. Agric. Soc.* of Trinidad and Tobago, LVI, 1956, pp. 309-349. *See* summary (in Spanish) in Manual del Curso de Cacao, I. I. C. A., Turrialba, 1957, pp. 205-211.

(4) Cacao has earned the reputation of being a difficult crop to grow and to require extremely exacting ecological conditions for its successful development. It is generally believed to succeed only when planted on virgin forest land. These opinions may merely have arisen, however, from ignorance of the exact environmental circumstances required for high production and of the means of creating them.

(5) The growing of the cacao tree and the production of marketable beans require a regular supply of labor throughout the year. This feature differentiates cacao from many other monocultural crops such as sugar cane which demand more labor during certain times of the year than at other periods. The distribution of wages paid out in a typical cacao estate in Trinidad is shown in *Fig. 1* for each consecutive fortnight of the year, starting on Ist July and ending 30th June. A vigorous improvement program is being carried out on this estate and this makes a large demand on labor in the wet season. The small seasonal difference that appears on the diagram is caused by migration of some of the labor to sugar estates during the cane-cutting season.

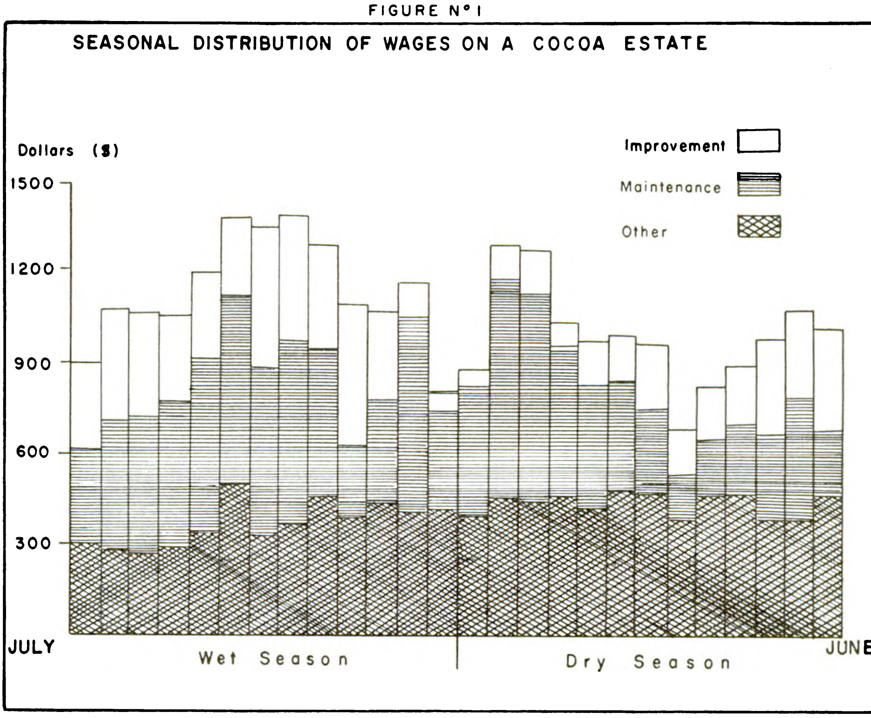
(6) A cacao plantation is heavily capitalised but most of the investment is in the cacao trees and not in elaborate buildings or expensive machinery. Moreover, the original cost of establishment was much less than the cost of replacing the old trees and rehabilitating the fields at present-day prices for labor and materials. In Trinidad, the cost of replanting an acre of cacao land lies between $ 700 and $ 1000, which is about three times the cost of replanting an acre of sugar cane land and six times that of planting most annual crops. The need for better housing on cacao estates has also become more urgent in recent years. The minimum investment for building laborers' dwellings in Trinidad is about $ 200 per acre of estate land. The capital required on an adequately financed cacao estate in Trinidad at the present time lies between $ 1,200 and $ 2,000 per acre or between $ 6,000 and $ 10,000 per unit of labor which is commensurate with that required in urban industries.

(7) The movements of the cacao market are described as "long cyclical" in regard to prices. This aspect will be more fully discussed later.

The unique conditions of the cacao industry described above offer the following opportunities for good management, based on some of these characteristic features of the cacao industry.

(1) The fact that cacao is grown as a monoculture enables the planter to concentrate all his attention on the improvement of a single crop and to apply to it the new technological knowledge that has become available from research. On the other hand, a monoculture is more vulnerable than mixed cultivations to the ravages of diseases and pests and to fluctuations of the market. The growing and processing of the cacao crop need so much careful attention, however, that the advantages of large-scale production, which are so obvious for other tropical crops such as sugar cane and sisal, do not apply, and the industry does not favor mass production by a central

FIGURE N° I


SEASONAL DISTRIBUTION OF WAGES ON A COCOA ESTATE
Dollars ($)
1500
1200
900
600
300
Improvement
Maintenance
Other
JULY
Wet Season
Dry Season
JUNE

management of ten thousand acre units| The features of small units of monocultural planting encourage the achievement of a standard of technical management in the case of cacao comparable with that of modern orchard industries of temperate regions, although at present the standard attained in most existing cacao plantations falls far below this ideal.

(2) Private ownership allows of more stability of production during periods of low prices than is possible in enterprises run with public funds, but the willingness of private proprietors to bear losses for a time is, in the long run, a disadvantage in that the continuance of overful production depresses prices further and for a longer time.

(3) The long life of the cacao crop creates difficulties in its financial management under private ownership. The planter establishes his cacao plantation in his youth and reaps the reward of his enterprise in middle age without having to contend with many difficulties but, when the plantation has begun to deteriorate during his old age, he no longer may possess the energy or desire to undertake its resuscitation, nor are his sons able to replant the fields so cheaply and easily as their father planted up the plantation in the first place. A farsighted manager should always bear in mind the importance of conserving his assets and should plan a regular replanting of his fields so as to maintain production. This aspect of management has so far been overlooked and greater attention given to it in the future would impart greater stability to the cacao industry and reduce the cyclic swing in prices.

(4) Because of the exacting demand of the cacao crop on the factors of the environment, the amount of land really suitable for cacao growing is strictly limited. Other circumstances besides environmental conditions are also important in deciding the suitability of an area for cacao production, as has already been stressed. Among these are the need of a sufficiently high density of population in order to supply the necessary labor required to establish and to maintain the plantation and the importance of the right state of economic development of the available labor and the nature of the social and political structure of the country.

(5) The regular seasonal demand for labor on a cacao plantation permits the creation of a permanent well-trained labor force and relieves the manager of the necessity of employing inefficient casual labor.

The characteristics of the cacao industry outlined and discussed above indicate opportunities for much more intensive and efficient management than has in the past been applied, and it may not be an exaggeration to claim that the future of the cacao industry depends largely on the creation of a highly-qualified body of plantation owners and managers who are able to take full advantage of the rapid progress that is being made in the different technological branches of the industry. It would appear that the cacao industry has been singularly conservative in the past and has failed to realise the possibilities that attend good management.

Long-term problems: The reasons for the conservative lack of enterprise among cacao planters in the past can be traced to the unique fact that the demand for cacao, in contrast to other tropical products, for many years was greatly in excess of the supply, particularly during the period when the earnings of labor in Europe were rising rapidly as a result of the Industrial Revolution, that is, between the years 1870 and 1920. Little economic effort and the minimum of managerial efficiency were necessary to obtain a comfortable living from cacao. Those years of prosperity provided the worst possible foundation for the future development of the cacao industry, because they suppressed the need of innovations and the desirability of introducing better planting material and more efficient methods of production and processing. Thus, in Trinidad, after cacao prices fell in 1920, production declined rapidly but the plantations were then too old to respond readily to treatments such as manuring. In ten years it declined by 30 percent, and in 15 years by 75 percent below the 1920 rate of production.

An important result of the depression in the early 1920's was the disappearance of experienced educated managers who turned to other occupations for their livelihood. Conditions in Trinidad were different from those in West Africa where the cacao industry was much younger and the problems of crop decline had not become important.

The peculiar history of the cacao industry is responsible for certain management problems that are difficult to solve. Firstly, the long cyclical change in prices, described as "50 years up and 20 years down", has undermined the whole credit system on which the industry was based. Secondly, in the prosperous period in Trinidad, credit was plentiful and easy to obtain but, when the decline set in, the mortgagors were encumbered with large areas of unprofitable land. It is unlikely that credit will again become so plentiful. Thirdly, shortage of capital will become a serious hindrance to future development of the cacao industry, not only in Trinidad, but also in other countries. Large expediture and a vast amount of capital would be necessary to resuscitate the industry. The real problem, however, is the creation of a body of highly educated, well trained, competent managers who would be capable of applying the best methods of rehabilitation to worn out cacao lands, and of adequately dealing with, not only the technical problems of their profession, but more especially with the problems concerning labor and finance.

Subsidy schemes: Governments in many countries are aiding the cacao industry by initiating subsidy schemes involving considerable financial expenditure on propagating stations from which high bearing and disease resisting planting material is being distributed, and on free gifts to help to meet the costs of rehabilitation. These schemes depend upon public funds which are being raised by taxation and otherwise, so as to overcome the present shortage of capital. Many of them fail to bring results because of the scarcity of efficient managers needed to render them effective in the field. In West Africa, Government-sponsored marketing boards have been created to stabilise the cyclical changes in prices. The large amounts of capital which these boards accumulated during periods of high prices are being used to finance development plans which, when put into full effect, should make the cacao industry more profitable in the future, as well as to confer other benefits to the country.

Need for good managers: Scarcity of managers, the instability of prices, the lack of credit and the need for capital constitute adverse factors that must result only in high costs and a tendency to high prices. The reaction of the consumer will be to curtail his demands for the products of the industry and the steady decline will continue. The ultimate solution of this dilemma lies solely in the improvement of the technical and managerial aspects of cacao growing and the encouragement of high efficiency in the running of the cacao plantations, coupled with the provision of the best advice and assistance to peasant producers in those countries where the industry is in the hands of small holders.

Cost accounting: An accurate and simple system of book keeping is the chief means whereby the progressive manager is able to determine the distribution of capital and technological effort within the different parts of his organization, particularly that which concerns field expenditure. The failure of most accounting systems applied to cacao management can be traced to either (i) confusion between accounts and records, (ii) technical difficulties of accounting and (iii) lack of flexibility of the standard system.

The essential difference between record keeping and cost accounting is that a record is simply an entry of the planter's best estimate of a quantity under consideration, whereas the object of an accounting system is to prove whether an estimate is correct or not. Thus there is a tendency in keeping field records of yields to use the same conversion factors for calculating weights of dry beans from weights of wet beans and for calculating weights of dry beans from weights of wet beans and of assessing monetary values from these quantities, whereas, in cost accounting, the actual weights obtained and the money realised would be accurately entered and apportioned out to the fields according to their production of wet beans. High yields from certain fields are not objectives in themselves but are important only in-so-far as high yields are related to profits.

The only successful system of accounting that has yet been invented is double entry, but this is not suitable for the cacao plantation because it is difficult to apply without expert training. The use of *punch cards* however, has greatly reduced the difficulty of accounting and has rendered it much more flexible.

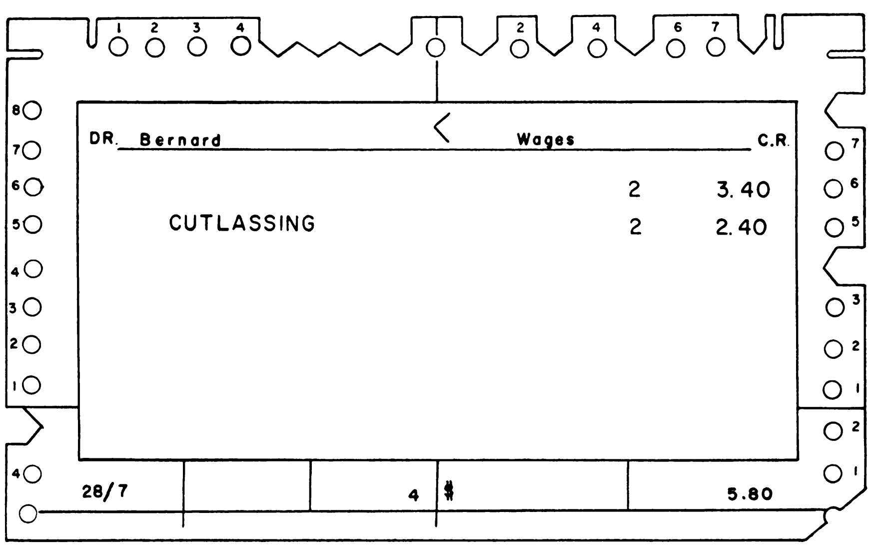
A form of punch card, termed the clip card, has been invented for application to cacao accountancy.* *Fig. 2* is an example of a clip card showing a wage allocation made to a particular cacao field. Clip cards can be sorted in two ways, one for the debit aspect of a transaction and the other for the credit. That illustrated in the diagram shows an expense of field operation as debit and a claim on wages payment as credit. Any transaction can be entered on clip cards when the details have been set up. The card is arranged with the coding of the two accounts along the top and provision for subdivision of accounts into detailed items along the sides. In this particular example, all the fields are represented by separate accounts but they could have been sub-

* (1) JOLLY, A. L. Clip card accounting on the farm. Publications Dept., Imperial College of Tropical Agriculture, Trinidad, $ 1.20 B. W. I. or $ 0.72 U. S.

(2) JOLLY, A. L. Progress report on clip card accounting. Tropical Agriculture (Trinidad) 33, 1956, pp. 278-286.

FIGURE N°2

CLIP CARD ACCOUNTS: WAGE ALLOCATION CARD



divided by details. The wages account in the diagram *(Figure 2)* is so divided for the operational classification of the work, 765 being the code number for field maintenance. The card is also coded for the month in which the transaction falls, so that totals similar to trial balances can be prepared monthly. The first requirement of cacao plantation accounts is to assess the value of the fields which comprise the most important asset. The assessment should indicate their expected individual performance throughout their lifetime. The second, requirement is the subdivision of the plantation into sections based on differences in topography, soil type, system of cultivation, age of trees, distance from processing plant and so on, but the sections need not remain fixed and certain of them can be merged together as interest in one diminishes, so that it can be absorbed by another section receiving similar treatment. The division of the plantation into sections allows better internal management and this is essential if new methods of cultural treatment which scientific research is providing are to be applied intelligently.

Conclusions: In order that the latest discoveries in advanced technology may be utilized successfully and profitably in the cacao industry, at least four important conditions must be observed:* (i) basic investigations should be carried out in order to assess their efficacy in terms of actual cacao production. (ii) Capital must be made available in sufficient amount and at a rate which will relieve the cacao grower of anxiety and want during the interim period following planting and before crop production begins. (iii) Any tendency towards the inflation of the currency must be controlled and (iv) efficient management must be assured.

SUMMARY

1. The characteristics of the caaco industry are (i) it concerns a monoculture, (ii) it is run under private ownership, (iii) the crop is long lived, (iv) it is sensitive to environmental changes, (v) it requires a regular supply of labor, (vi) its establishment involves heavy capital expenditure, (vii) market trends are "long-cyclical".

2. Hence (i) specialized knowledge is essential, (ii) production stability is possible under private ownership, (iii) long life imposes difficulties in financing, (iv) suitable land is limited, (v) labor can be trained, (vi) good cacao management requires unique ability, (vii) Government subsidy helps to overcome marketing troubles.

3. Cost accountancy by means of clip cards has proved to be useful in cacao estate management; its main features are explained.

* KYLE, L. An economist's view of the cacao situation in Colombia. Seventh Inter-American Cacao Conference, Palmira, Colombia. July. 1958.

CHAPTER 18

CACAO RESEARCH

Agricultural research consists in the application of fundamental sciences to the problems of crop production and crop improvement. It aims at discovering methods for increasing both the amount of crop produced per unit of human effort expended and the amount of produce per unit of land area used. The application of agricultural research has resulted in such a large increase in efficiency in crop growing that the majority of individuals in a community need no longer concern themselves directly with food production but can give their attention wholly to other matters such as the manufacture of domestic commodities, machinery and fertilizers. Perhaps the most spectacular advances in agricultural production are those contributed by the science of genetics and plant breeding, although important contributions have also been made through the control of insect pests and fungal and bacterial diseases, and through a better knowledge of plant physiology especially concerning the use of fertilizers and soil amendments. Furthermore, the study of water relations of plants has led to a better understanding of the practice of irrigation. Recent advances in organic chemistry have produced a wide range of insecticides and herbicides and of plant growth stimulants used by the horticulturist in the vegetative propagation of plants and for reducing flower shedding and fruit drop.

Research on a single-crop industry, such as cacao growing, at least in its early stages, must be "aplied" research rather than fundamental research. The chief aim of research in cacao is to increase the efficiency of the industry but this involves, not only increase in yield, but also decrease in costs of production *(2)*. Until recently, little success had been achieved in the case of commercially-grown cacao by the application of conventional practices such as spraying with insecticides and fungicides, applying fertilizers, draining and irrigating, either because the increase in yield obtained was generally insignficant, or because the cost of the operations was too high to be remunerative, or because, owing to poor management and inefficient labour, the methods were not properly applied. Thus the strong incentive was lacking to encourage the planter to persevere in their use and, in consequence, the state of the industry, in-so-far as the particular techniques employed in the production of the crop were concerned, has scarcely changed since cacao growing was first started some four hundred years ago.

The main discovery which has, in recent years, opened up the prospect of vastly increased crop production in the case of cacao is undoubtedly the success achieved by improved methods of vegetative propagation *(2)*. Until the year 1930, the correct technique for the large-scale production of rooted cuttings had not been discovered. As a result of the researches started at the Imperial College of Tropical Agriculture in Trinidad, followed by investigations carried out at other institutes in Latin America and West Africa, it has been found possible to multiply high-yielding and disease-resisting cacao varieties by vegetative means and to grow them successfully on a field scale within a wide range of soil-types and differing climates. Under experimental conditions, it was early found that cuttings prepared from certain selected varieties, at least during the first few years of growth, often greatly out-yielded seedlings from the same parent trees *(2)*. The results obtained in one such comparative trial are depicted in the accompanying diagram *Fig. 1* which shows that cuttings of ICS 1 and ICS 95 varieties gave about 2½ times the yield of their seedlings *(2)*. This was apparently not the case, however, with the variety ICS 45 in this experiment.

By propagating and planting rooted cuttings of cacao varieties selected for high-yielding capacity, the yield of a cacao plantation should be very much greater than that of a plantation planted haphazard with plants produced by seeds of unknown parentage *(4)*. Consequently, it should be much more profitable to use insecticides and fungicides and to apply fertilizers to such superior cacao trees than to a heterogeneous mixture of different types, and any extra care taken in their management should be immediately followed by still greater increases in yield.

There are obvious limitations, however, to the degree of improvement of planting material which can be obtained by selection from among existing cacao tree populations. Perhaps the chief limitation is imposed by the difficulty in assessing the effect of external environmental conditions, such as high soil fertility, on the yield of a cacao tree growing at any particular site. It is well known that the soil comprising a cacao field is often extremely heterogeneous, in that its physical and chemical properties vary between wide limits within a short distance *(1)*. This doubtless accounts for the fact that, out of the large number of supposed high-yielding clones that have been selected in different cacao-growing countries,* only a few have actually been proved to possess the true inherent character of high-yielding capacity transmissible to their offspring when grown under variable environmental conditions.

An entirely different method of producing superior cacao planting material other than by random selection and vegetative propagation is the method involving controlled crossing or hybridisation *(4)*. This is effected either by artificial self-pollination of selected clones or by artificial cross pollination between selected clones, the pollination being performed by hand *(4)*. The resulting seeds are planted out in nursery beds in progeny rows and the seedlings are grown under the best possible environmental conditions. Selection is subsequently made among the seedling population and the most promising seedlings are then propagated vegetatively as cuttings, buddings, grafts or marcots. The results which have been obtained in Trinidad since 1956, as well as in West Africa and elsewhere, by crossing widely-differing cacao genotypes have demonstrated that certain of the crosses possess remarkable hybrid vigor, notably crosses between ICS varieties and SCA varieties from Ecuador *(2)*. This discovery will be fully discussed in the

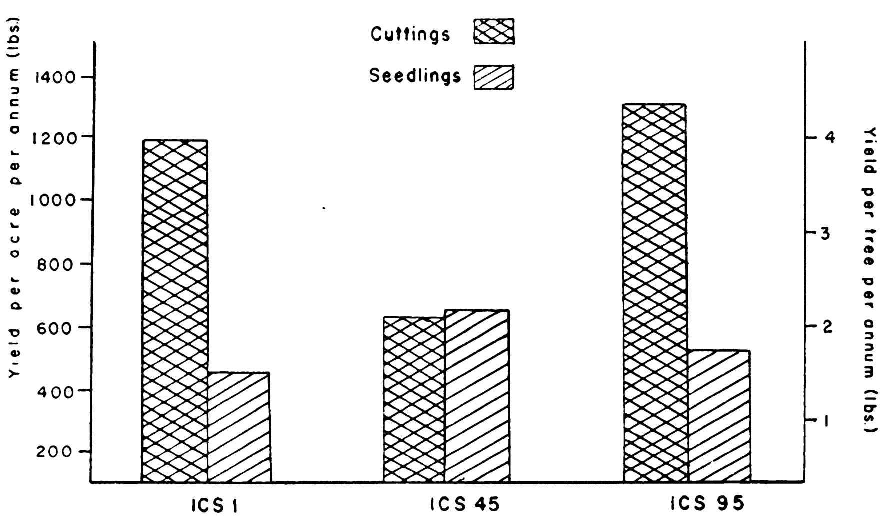
* For example, out of the 100 selections that were made by the late F. J. Pound in Trinidad in 1930-1932, only about four have proved to be capable of maintaing high yields in comparison with their original parents.

FIGURE N° I

YIELDS OF DIFFERENT PLANTING MATERIAL

(ICS CACAO CLONES)

(3-13 Years)



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chapter on cacao breeding and its implications will be mentioned. Without doubt it has opened the way for great improvement in planting material, at least where yielding capacity is the main desirable feature that is sought, though much more research work will be necessary, for example, regarding the incorporation of disease resistance, before the "ideal" or "perfect" cacao tree can be evolved.

Whether or not cacao planters of the future will prefer to employ seeds or seedlings as planting material, rather than vegetatively-propagated plants, vegetative propagation by improved methods that may supercede, or that have already superceded, the original cuttings-bin method will still have to be used to perpetuate the different well-known varieties of cacao whose specific qualities have been thoroughly tested, as well as others that will be selected and approved during the coming years. "Museums" and "clonal gardens", comprising the most desirable of the selections and hybrids, will need to be established in most cacao-growing countries. Their multiplication and extension will still necessitate the application of the techniques of vegetative propagation. Nevertheless, some authorities continue to recommend the use of cuttings or other vegetative planting materials in preference to seeds or seedlings for the commercial establishment of cacao plantations, no matter whether they have been produced from superior hybrids or otherwise. The main reason given for this choice is that the genetical characters of vegetatively-propagated clones are fixed and invariable, whereas the characters of the seedling progeny of a single cross are variable and not necessarily the same as the best of those of the parent or parents *(2) (4)*. Thus, when hybrid seedlings are used as planting material, there is a risk of producing a widely variable tree population. One of the objects of future research in the genetics of cacao will be to discover means of determining which of the hybrid progeny of a cross it would be safe to eliminate in the nursery bed or in the field because of the absence of desirable characters in its genetic composition. Only when hybridisation has been carried far enough to produce a pure-line strain can the planter expect little or no tree-to-tree variation in a field planted with hybrid seedling progeny.

The possibility of the plant breeder being able to supply the cacao planter with uniform high-yielding, disease-resisting, good quality planting material in unlimited amount greatly increases the chances of his being able to obtain still higher yields through the use of manures, fertilizers and soil ammendments. In the past, the marked heterogeneity of the tree population of old cacao fields, and the great variability in yield from one tree to another because of the operation of certain adverse environmental factors, has completely masked the effects of added manures and response to them has generally been insignificant *(1)*. Moreover, because of lack of root vigor or of inadequate root-spread, a positive response to manurial treatment obtained in the year of application has generally not been sustained in the years following, even when the manurial treatment has been repeated. Nor has the magnitude of the response usually been proportionate to the amount of manure applied. These irregularities and failures can usually be explained by the heterogeneity of the plant population superimposed on the heterogeneity of the soil *(1)*. When plant heterogeneity is eliminated by the use of uniform planting material having high-yielding propensity, response to manurial treatment should be appreciable if the soil lacks one or more of the nutrient elements, and fertilizer experiments should consequently give significant results. They should therefore enable the planter greatly to increase crop production with least expenditure on manurial substances. Thus researches on the manurial requirements of cacao soils are much more likely to yield important practical results when only uniform high grade planting material is employed in the field experiments, particularly where the manures are added from the date of planting the young cacao trees. When exact knowledge has been acquired concerning the nutrient needs of different kinds of soil on which cacao is grown, then it may be possible to decide whether the provision of permanent shade is necessary, or whether shade trees can altogether be eliminated, assuming that deep cultivation, coupled with suitable manuring, is practised. Thus, the possibility arises of growing cacao on manured soil that has first been cultivated by modern mechanical equipment and maintained in good tilth by periodic inter-row cultivation from the time of planting. Research is therefore needed on the possibility of growing improved varieties of cacao without shade under a large-scale system of mechanical cultivation with appropriate manuring and, where necessary, with the aid of supplementary irrigation, either by surface trenches or overhead sprinklers, and of deep and thorough drainage.

Besides breeding and propagation, shading and manuring, cultivating, irrigating and draining, several other lines of research await attention in the cacao industry as the level of commercial production rises. Among these are investigations on the more efficient use of insecticides, fungicides and herbicides and the possibility of applying them in a more highly mechanised manner, or by spraying them onto cacao trees grown without shade in suitably-spaced rows from aeroplanes or helicopters. It may be possible and feasible to combine the spraying operation with the application of fertilizers such as urea which might be mixed with the spray liquid in suitable quantities. Preliminary trials of some or all of the new procedures above-mentioned have already been made at several research centers and on some commercial plantations, but there is urgent need for their expansion and duplication in different areas where conditions of climate and soil vary *(3)*.

Other lines of research concern the curing of cacao beans, especially the possibility of improving the product by modifying the curing process when applied to beans produced by different varieties of cacao. Improvements in the method of drying the fermented beans through the invention of new apparatus or machinery is also necessary, particularly in countries where the dry season has short duration.

The effects of these innovations on the organisation and management of the cacao plantation are likely to be profound *(3)*. In order to put them into operation and to control their systematic application so as not to waste materials and labor, highly-skilled technicians and managers will be needed such as are not generally associated with the cacao industry in its present primitive state of development. This requirement of well-trained supervisors constitutes perhaps the most difficult problem confronting the cacao industry *(3)*. Before any progress can be made along the lines of these possible new developments, directors and owners of capital must first be convinced that the long-term prospects of cacao growing are good. To achieve this end, much further research of a kind that has not heretofore been attempted must be undertaken *(2)*. This might involve the creation of experimental plantations of differing dimensions in which mechanical methods for carrying out the various operations involved in cacao growing, as suggested above, can be tested and costed under controlled conditions by teams of qualified men who have been suitably trained in their performance *(3)*.

One possible result that might follow, if ever it be found possible and profitable to "mechanise" the cacao plantation completely along the lines indicated, would be greatly to increase the size of the cacao plantation, necessitating the establishment of a central office run on modern business lines (2). On the other hand, if the number and variety of techniques that have to be invented and applied in order to cope with the diverse problems of production should increase greatly, then the efficient cacao plantation might preferably have small dimensions so as to allow adequate supervision and to retain elasticity of operation.

SUMMARY

1. The contributions which fundamental scientific research can make to crop production are enumerated.
2. The aims of "applied" research as related to cacao growing are stated.
3. Recent advances in the technology of cacao growing are reviewed. Of these, the perfection of methods for propagating cacao vegetatively has been the most important.
4. The vegetative propagation of cacao varieties, selected on the basis of high yield, disease resistance and quality, has greatly increased the usefulnness and reliability of field experiments designed to test the effects of manures and fertilizers.
5. Vegetatively-propagated high-yielding cacao varieties have frequently out-yielding seedlings of the same parents and are often therefore more profitable to grow.
6. The spectacular results obtained by crossing certain cacao varieties that produce progeny showing hybrid vigor are referred to, and the possibility of hybrid seedlings replacing clonal cuttings as material for populating cacao plantations is discussed.
7. The prospects of increasing production by "mechanising" the cacao plantation are considered and the possible effects of this on management is debated.

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PART VII:

DISEASES AND PESTS; POLLINATION

CHAPTER 19

(A) FUNGUS DISEASES OF CACAO AND THEIR CONTROL*

INTRODUCTION

Many factors contribute to low cacao production, even when a plantation is located in a zone that, because of favorable soil and climate, is quite suitable for the growing of this crop. In the majority of the cacao-producing countries, one of the most important of these factors responsible for low yields is the presence of destructive diseases that are not controlled. A general improvement in farm management and the planting of clones or hybrids specially selected for high production can contribute in any country to an increase in cacao production. Nevertheless, the gravest and most widespread problem in all these countries is how to reduce the high percentage of loss of crop caused by the attack of various diseases.

Under present conditions the planting of high-producing clones on a large scale would be insufficient in the majority of cases if the more important diseases were not first controlled. Every cacao-producing zone has at least one disease that can be controlled by chemical compounds applied in solution by spraying. Any program of cacao improvement should therefore emphasize the importance of disease control.

(I) WITCHES' BROOM DISEASE

Witches' Broom, which is a disease caused by the fungus *Marasmius perniciosus* Stahel (*Crinipellis perniciosa* (Stahel) Singer) occurs in all the cacao- producing countries of South America and also the Caribbean islands, Trinidad, Tobago and Grenada. It does not occur at present north of the Isthmus of Panama. Witches' Broom first appeared in Surinam in 1895 and soon after in British Guiana. It was noted in Ecuador in 1922, in Trinidad in 1928, in Tobago in 1939 and in Grenada in 1948. It has also been found in Venezuela, in southern Colombia adjoining Ecuador, and in Peru. At first it was thought that Witches' Broom originated in Surinam and that it was taken to Ecuador by a plant collector, but

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Pound's explorations *(56)* indicate that the disease originated in the Amazon Valley where it had been present for a long time, and that the outbreaks of the disease in Surinam and in Ecuador simply represent outposts on the periphery of its continental distribution. Witches' Broom has not yet been found in the Cauca Valley of Colombia nor in the cacao area of Bahia, Brazil, which is the area of greatest production in Latin America. The disease does not occur outside of the Western Hemisphere.

The present distribution of Witches' Broom indicates that, having originated in the Amazon Valley, the disease has now spread to all the cacao producing countries of South America and is in the process of passing from one island to another in the Caribbean. It is therefore probable that eventually Witches' Broom will appear in Central America, Bahia and in the Cauca Valley of Colombia.

Economic importance: Witches' Broom is considered to be the most serious disease of cacao in the countries where it is found, although the degree of severity varies according to climatic conditions. The infection of the pods and the flower cushions may result in the loss of up to 50 percent of the fruits under extreme conditions. In addition, infection of the vegetative tissue can occur, resulting in the formation of broom-like outgrowths and a heavy loss of foliage. This tends to reduce pod production still further so that the total effect is difficult to assess. The disease does not kill the trees with the exception of young plants which may be killed by the destruction of the growing points. Nevertheless, mature trees are greatly weakened by the attack. The effect of Witches' Broom on cacao production after it appeared in Ecuador is indicated in Table 1.

TABLE 1.

EFFECT OF THE INCIDENCE OF WITCHES' BROOM IN 1922 ON CACAO PRODUCTION IN THE ZONE OF BALAO, ECUADOR

(After J. B. Rorer, 1926 *(61)*)

YEAR	100 POUNDS OF DRY CACAO
1918	67,411
1919	56,341
1920	73,722
1921	85,455
1922	77,817
1923	37,668
1924	18,480
1925	1,987

Symptoms and signs: The fungus causing Witches' Broom attacks the vegetative shoots, the flower cushions and the fruits. Only the meristematic tissues in an active state of development are susceptible to attack. The infection of the new vegetative shoots, the flower custions and the young pods stimulates them to abnormal and gigantic growth. This phenomenon suggests that the activity of the fungus results in the accumulation of hormones in the affected parts.

(a) *Shoots:* The infected vegetative shoots are transformed into characteristic witches' brooms. These typically possess a much larger diameter than the healthy tissue from which they originated and show a proliferation of lateral branches. Witches' brooms vary in size from a few centimeters to more than a meter in length. Generally the brooms die after four to six weeks, although they remain attached to the trees for a long time after dying. They are easily broken off when completely dry. The characteristics of short life and easy breakage distinguish Witches' Broom from similar symptoms of die-back caused by poor nutrition, Anthracnosis and insect attack.

(b) *Flower cushions:* The infected flower cushions put out small witches' brooms composed of vegetative tissue on whose branches the flowers develop. This type of growth is completely abnormal since usually the flower cushions do not produce vegetative outgrowths. These small cushion brooms die in the same way as those produced in the vegetative shoots.

(c) *Pods:* The majority of the infected pods are attacked when they are quite young and they therefore never reach maturity *(9)*. These are the dwarf pods, having the shape of a carrot or strawberry, which are commonly known as "chirimoya" pods, and which dry up and rot, remaining attached to the branches for a long time. Occasionally pods occur that have been infected when mature and have become hard and woody. These are known as "stone" pods. Their internal tissues are frequently affected and sometimes destroyed by a dry brown rot.

The sources of new infection are the sporophores produced by the fungus. These are small pink mushrooms and appear during the rainy season on the surfaces of the tissues killed by the fungus. The spores produced by these sporophores are disseminated by the millions and are carried freely by air currents. The dead brooms and the pods destroyed by the disease stay on the trees for one or two years and provide a source of recurrent infection. When the brooms are dry, a period of 20-25 weeks ensues before sporophores appear but when they begin to form, their production and liberation continue during the whole time the brooms are on the tree. In artificial inoculation work carried out in Ecuador, sporophores could be collected from certain brooms for periods varying from a few months up to a year. The brooms were eventually destroyed by rots brought about by secondary organisms stimulated by the humid atmosphere and the constant wetting which is necessary in order to maintain conditions favorable for the production of sporophores. Under normal conditions, the brooms are capable of producing sporophores for a much longer period than one year.

Control: The fact that Witches' Broom affects only the meristematic tissues makes control a difficult problem, since it is hard to maintain a covering of a fungicide over rapidly-growing tissues so as to ensure constant protection against the disease. This difficulty, combined with the high cost of applying fungicide at high volume, reduced the probability of ever achieving economic control by spraying. Although Witches' Broom has been known for a long time, few attempts have been made to control the disease with fungicides. Nevertheless, good results have been obtained in Trinidad with Bordeaux mixture and other copper fungicides applied monthly to the pods over a period of seven months *(34) (5)*. The reports on this work give the impression that such applications would be economic only in plantations producing large crops of cacao, and in which disease incidence is high *(5)*.

In Ecuador tests were carried out in which fungicides were applied to cacao trees with the object of killing the fungus mycelium occurring within the dry brooms, thus avoiding the formation of sporophores and reducing the amount of new infection *(10)*. Good results were obtained in the control of sporophore formation on dry brooms in the field by applying di-nitro-ortho-cresol and sodium penta-chloro-phenate in dilute solution during the dry season, but this method has not yet been attempted on a commercial scale.

The recent development of low volume spraying which greatly reduces the cost of fungicide applications should encourage further attemps to be made to control Witches' Broom by means of chemical substances. An experiment carried out in Ecuador, designed principally to control *Monilia* disease by an appropriate fungicide, demonstrated a significant reduction in the amount of Witches' Broom infection of cacao pods. The fungicide consisted of ½ lb. per gallon of Zineb dispersed either in water or an emulsion of 60 percent concentration of orchard spray-oil applied at the rate of 12 gallons per hectare *(75)*. The degree of control was equal to or better than that obtained by spraying at high volume or by dusting with fungicides. Nevertheless, the fungicide treatments, although applied to the entire tree and not solely to the pods, did not bring about significant reduction in the number of vegetative brooms which appeared on the twigs but, since the same applications effected good control of *Monilia,* it can be assumed that an efficient method for controlling the two diseases by the same low-volume application of fungicide might possibly be developed.

The most commonly used technique for controlling Witches' Broom is the removal and destruction of dry brooms. This operation is best carried out in the dry season because, during this period, least formation of new brooms occurs and it should be possible to collect and destroy most of the recently-formed brooms. Broom collection could be combined with pruning. In collecting the brooms, it is important, not only to break them off, but also to cut away a few centimeters of the stems on which they have been produced. This is advisable since the fungus causing the disease may have penetrated a certain distance into the apparently healthy tissues and, after the broom has been removed, the next bud to open might already be infected. The collected brooms should be taken away from the plantation and at once burned or buried. Brooms left on the ground produce sporophores and the spores formed may be carried by air currents to susceptible tissues and begin new infections.

Perhaps the most promising method for controlling Witches' Broom disease is through the use of resistant clones. During his explorations within the Amazon Valley, F. J. Pound discovered natural populations of Forastero cacao which were highly resistant or immune to Witches' Broom disease *(56) (57)*. Unfortunately, the most resistant varieties collected and propagated by Pound do not have much commercial value. A considerable variation in susceptibility to Witches' Broom has been noted among the Trinitario cacao population which is considered by some authorities to be a population of segregants resulting from natural hybridization between Forastero cacao and Criollo cacao. Programs of selection and hybridization have been carried out in order to obtain varieties, not only resistant to Witches' Broom, but also having commercially-acceptable production propensity and high quality. Such programs have given promising results in Trinidad and also in Ecuador *(33) (36) (3) (11) (12).*

The methods described above can be combined together in a general program for the control of Witches' Broom in the cacao plantation as follows.

1. Remove all brooms and infected pods and destroy them by burning or burying as a normal part of the pruning program of the plantation.
2. Spray for the control of *Phytophthora* and *Monilia* which may give a certain degree of control of Witches' Broom at the same time.
3. In planting new fields or rehabilitating old fields by approved methods, employ only planting material produced by clones, varieties or hybrids recommended as resistant by the experiment stations in the vicinity.

Note: Resistance to Witches' Broom should be included among the desirable characteristics of new clones or hybrids that are being developed in countries where the disease has not yet shown itself, in order to be prepared when the disease does appear.

(II) BLACK POD DISEASE

Black Pod, Black Rot or Phytophthora, caused by the fungus *Phytophthora palmivora,* Butl., has probably been known for a longer time than any other cacao disease. It is possible that the disaster that affected the caaco industry in Trinidad in 1727 was caused by *Phytophthora (32).* The cacao industry of Trinidad before this time was based on the cultivation of a Criollo type of cacao having high quality. To reestablish the industry after 1727, varieties having greater disease resistance (probably mainly Forastero) were introduced from Venezuela and it is believed that this resulted, through natural hybridization between the Criollo remmants and the newly introduced Forastero variety, in the formation of the Trinitario cacao that now occurs in many parts of Latin America. Criollo cacao is known today to be much more susceptible to attack by *Phytophthora* than Forastero cacao or Trinitario cacao.

Economic importance: At present, Black Pod is the most widely distributed of the more important cacao diseases. Before Witches' Broom appeared in South America and the complex of viruses known as Swollen Shoot appeared in West Africa, Black Pod was regarded as the most serious cacao disease in the cacao producing countries of the world. Even now this disease is undoubtedly responsible for more losses of crop than any other disease, although the severity of the infection varies from one country to another according to climatic conditions and other factors. *Phytophthora* infection does not occur to any extent in the Riverine Belt of Ecuador and only between 10 and 20 percent infection occurs in Trinidad. Some 47 percent infection occurs in Costa Rica and up to 80 percent in Mexico *(21).*

Figure 1. Phytophthora palmivora in cacao.

Symptoms and signs: *Phytophthora palmivora* is the cause, not only of pod rot, but also of a canker of the trunks and branches and of a withering or wilt of the chupons. J. B. Rorer was the first investigator to prove in 1910 that these three symptoms are caused by the same fungus *(59)*. Chupon wilt results from the infection of the young tissues of the stem which causes the withering and death of the leaves. This symptom sometimes affects nursery plants. The infection of the leaves of cacao trees by *Phytophthora* has aroused more interest in Costa Rica than in any other country and artificial inoculation of the leaves of young plants has been used in fungicide tests in this country for many years *(62)*. The symptoms produced by artificial inoculation of the leaves varies from isolated spots to the destruction of the greater part of the leaf or of the whole leaf by a blight similar to late blight in potatoes caused by *Phytophthora infestans*.

The infection of pods might occur at any stage of development and at any point of their surface. A characteristic form of the infection is one which begins at either end of the pod and spreads towards the middle. These typical infections are caused by the germination of spores present in drops of water clinging either to the end of the pod or trapped in the depression around the peduncle. The disease is frequently spread by means of spores carried by rain water that trickles down from diseased pods to healthy pods situated lower down the same trunk so that a chain of infected pods occurs starting from only one source of infection. Damaged tissues are brown in color and the line of demarcation between healthy and affected tissue is abrupt. The infection spreads rapidly and can destroy the entire pod in a few days. Under humid misty conditions, a weak growth of fungus mycelium occurs on the surface of the infected parts dotted with sparkling drops of water that contain large numbers of zoosporangia or conidia of the fungus. The contents of the pod eventually are destroyed either partially or totally by a brown-colored rot.

The development of *Phytophthora* canker on the bark of the cacao tree trunk or branch appears first as a moist darkening and splitting of the bark and the extrusion of a reddish-brown ooze. The fungus spreads rapidly until it encircles and kills the affected branch or trunk. This type of infection sometimes develops from the peduncle of a pod that is infected but which has not been harvested. A high incidence of trunk and branch infection is usually associated with the occurrence of Criollo cacao. Forastero and Trinitario varieties normally show greater resistance to this kind of infection.

Conditions that favor the disease: 1. Climatic conditions: Among the most important factors that affect the incidence of Black Pod are the quantity and distribution of rainfall and the relative humidity. The sporangia form zoospores when immersed in water but, in an atmosphere of high relative humidity without water, they germinate directly as conidia *(67)*. Apparently sporangia do not germinate under conditions of relative humidity less than 95 percent. By lowering the relative humidity for 11 hours and then raising it again to 98 — 100 percent, a delay of 24 hours occurs before the spores begin to germinate. Lowering the relative humidity to 80 percent causes a delay of only 12 hours in germination. The dispersal and distribution of the sporangia take place more readily during rainy weather than in the absence of rain *(67)*.

Temperature also seems to play an important part in determining the incidence of Black Pod disease. A negative correlation between the percentages of pods infected and mean temperature has been demonstrated in Brazil *(38)*. The incidence of the disease increased up to 34.3 percent as the temperature fell to 20.5º C (69º F). Similar results were obtained in Ceylon *(54)*. A close correlation between disease incidence and air temperature would naturally be expected with all species of *Phytophthora*. It may be explained by the fact that maximum efficiency of production of zoospores apparently requires a temperature lying between 18º and 20º C (64.5º and 68º F) *(28)*. The formation of zoospores by the sporangia must play an important part in the development of the disease to epiphytotic proportions. The facts that the presence of water is necessary for the formation of zoospores, and that these are formed with greater efficiency at a low temperature, are important in planning a program for the control of this disease by spraying with fungicides. When the planter is furnished with the necessary information regarding temperature, relative humidity and rainfall for his area, he can then confidently decide when he should spray with greater frequency or when he might reasonably lengthen the intervals between applications, or when he might suspend spraying altogether.

2. Number of pods per tree: A positive correlation between the number of pods per tree and the incidence of Black Pod disease has been demonstrated in Nigeria *(65)*. This relationship implies that the greater the magnitude of the crop the greater will be the amount of infection by *Phytophthora*. This can be explained by the fact that there are more possibilities of the initiation of infection when a large number of fruits are set. A negative correlation was also found to occur between the annual rainfall and the size of the cacao crop *(65)*. For this reason, although one can expect more *Phytopthora* with greater rainfall, since an excessive amount of the rain can reduce the crop, it is possible to find greater incidence of the disease with less rainfall, simply as a consequence of the increased number of pods produced *(65)*. It was assumed that the unfavorable effect of high rainfall is due to the rainfall itself and not to secondary factors *(65)*. In Ecuador, a negative correlation was also found to occur between the size of the crop and the magnitude of the rainfall but, in this case, the effect was explained as a direct consequence of the high rainfall on drainage and on other inherent factors of the area *(26)*.

Control: At present the recommended methods for the control of Black Pod disease include (i) the removal of infected pods, (ii) harvesting at shorter intervals and (iii) spraying, preferably with Bordeaux mixture. Spraying has mostly been carried out with Bordeaux mixture applied at high volume and at regular intervals during the year without reference to the fluctuations of either rainfall, temperature or humidity. A noteworthy tendency has been to spread out the intervals between applications to the absolute limit, but still to maintain a regular cycle of spraying during the year. A series of fungicidal tests carried out in Costa Rica *(44) (53) (63)* has indicated that Bordeaux mixture is superior to other fungicides when applied at high volume, although copper oxide applied together with certain stickers has given indications of being highly effective *(7)*. Recent studies on copper oxide and other copper products, applied at low volume, have given promising results *(69) (70)*. The development of low volume spraying techniques offers the greatest possibility of finding an economic method for the control of Black Pod.

According to present experience, the following procedure can be recommended:

1. Harvest at short intervals and remove all infected pods from the trees and the plantation.*

2. Do not open the pods on the plantation and do not leave piles of old husks in the fields.

3. Carry out a spraying program comprising either low or high volume spraying according to preference and circumstances. In either case, it is recommended that the times of application be chosen according to the climatic conditions that prevail during the different seasons of the year.

The elaboration of a suitable spraying program for any particular area can only be accomplished by experience. The following suggestions may be helpful:

a) Under conditions of abundant rainfall with relatively low temperatures, apply fungicides more frequently, for example, Bordeaux mixture at high volume applied at intervals of not more than a month, or concentrated fungicides at low volume applied at intervals of two weeks and not more than three weeks.

b) When the mean air temperature rises to 25º C (77º F) or above, but with continuing rain, extend the interval between applications to two months in the case of Bordeaux mixture, or to one month or six weeks in the case of low volume sprays.

c) During the hot dry times of the year, suspend the spraying altogether.

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* Evidence has been adduced in Ghana* to prove that harvesting carried out weekly gives a greater weight-yield of fermentable beans than harvesting carried out every six weeks, even when the trees are sprayed weekly with copper fungicides against Black Pod disease. In an experiment, weekly harvesting gave five times as many infected pods as were produced by trees that had been sprayed. Nevertheless, the weight of the usable crop of beans was nearly 15 percent greater than that produced when harvesting was carried out every six weeks, and nearly 7 percent greater than that produced by trees that had been sprayed. Frequent harvesting, apart from the extra labor required, has the disadvantage that, unless co-operative fermentaries are established, insufficient beans are produced by a small farm to permit successful curing by the customary methods practised in Ghana.—Editor.

* *H. Owen, Annals Appld. Biol.*, 1951, 38, 3, 715-718.

(III) MONILIA DISEASE

Monilia, (Monilia Pod Rot) Watery Rot, or Quevedo disease is caused by the fungus *Monilia roreri,* Cif. and Par. It is believed that this disease originated in Ecuador whence it has spread to Colombia, Peru and parts of Venezuela. *Monilia* has been found recently in Panama south of the Canal. The disease was first reported in 1915 by Rorer *(60).* Thus in a period of a little more than 40 years, its area of incidence has spread considerably and is likely to spread further to new areas in the future.

Economic importance: *Monilia* disease affects only the pods of cacao. Neverteless, the attack on the pods is often so severe that the disease is considered to be one of the most serious limiting factors to cacao production. Losses have been reported in Ecuador and Colombia varying from 16 up to 57 percent or more. The effect in production is therefore comparable to that of Black Pod disease. The reduction of crop by *Monilia* attack in a typical cacao plantation in Ecuador is shown in Table 2.

TABLE 2.

EFFFECT OF THE APPEARANCE OF MONILIA ON CACAO PRODUCTION ON A PLANTATION IN ECUADOR

(After J. B. Rorer, 1926 *(61)*)

YEAR	100 POUNDS OF DRY CACAO	
1916	650	Monilia absent
1917	710	Monilia absent
1918	225	Monilia appeared
1919	36	Monilia present
1920	—	Plantation abandoned, trees cut down and bananas planted

The severity of attack by *Monilia* varies from place to place and from year to year, according to climatic conditions *(14).* The fact that *Monilia* is one of the most severe diseases of cacao occuring in Ecuador, while Black Pod is of relatively little importance *(14) (60)* suggests that the climatic conditions which are favorable to the development of the two diseases are different. The spread of *Monilia* is apparently favored by higher temperatures than that of Black Pod.

Symptoms and signs: Field evidence indicates that infection by *Monilia* takes place principally during the first stages of growth of the pod and that the pod becomes progressively more resistant as it ripens *(6) (14)*. It also indicates that injuries made by insects provide a ready means of entrance for the fungus *(45)* and that wounded pods are more prone to infection than unwounded pods *(24)*.

Having gained entrance during the early stages of growth of the pod, the fungus seems to be capable of invading the interior of the pod whilst it continues to grow without any symptoms of disease appearing on the pod surface. Pods having such hidden infections often attain almost full maturity with every appearence of being healthy and then suddenly develop the characteristic spots of the disease on the surface. The first evidence of hidden infection usually is the appearance of small spots of color that suggest premature ripening on the surface of unripe pods. For example, yellow spots on green pods and orange spots on purple pods. Frequently pods having hidden infections show swellings similar to those that at times accompany hidden infections of Witches' Broom disease. When such pods are opened, they are found to be more-or-less rotten inside and appear to be heavier than healthy pods of the same size *(61)*. Eventually a brown spot, surrounded by a yellow transition zone, appears on the surface of the pod. This spot may grow until it covers a large part or the whole of the pod surface. Under humid conditions a kind of dense white felt, made up of the mycelium of the fungus, grows over and eventually occupies the spot. The fungus produces large numbers of spores that give a cream or pale coffee-brown color to the mycelial mass. The spores break away and are easily spread by wind or by shaking the pods. They are also carried by insects. The seeds within infected pods disintegrate and liquefy and develop a moist rot characterised by the accumulation of an appreciable amount of liquid inside the pod.

Control: Studies made in Ecuador have shown that the incidence of *Monilia* disease is related to the amount of rain that falls during the first stages of pod growth *(14)*. This fact is important since it indicates that, in order to control the disease, the pods should be protected against infection at this time. Spraying should be initiated at the beginning of the flowering period and continued throughout the period of greatest fruit formation. The application of fungicides for the purpose of protecting ripe or almost ripe pods against *Monilia* has little effect because the infection will have already become established and the pods would in any case by then have developed their own resistance against new infections *(14)*. Taking advantage of the distribution of rainfall and the flowering cycle of cacao within any given area, a suitable economic program of control could be devised involving a minimum number of sprayings applied during the period when they will exert greatest effect.

Effective control of *Monilia* disease has been obtained in Ecuador together with an increase in production of 100 percent or more by spraying with various fungicides at high volume *(18) (19)* and also at low volume *(73)*. Striking results have been obtained from twelve applications at intervals of two weeks of 12 gallons of fungicidal liquid per hectare *(75)*. It was found that Zineb, ½ lb. per gallon of water, or in an emulsion of 60 percent spray oil, applied at the rate of 12 gallons per hectare, gave control of *Monilia* equal to that given by Zineb at 2 lb. per 100 gallons applied at the rate of 500 gallons per hectare. Zineb in water, applied both at low volume as well as at high volume, gave an increase in production of 100 percent, whereas the mixture containing oil did not increase the crop. This suggests that the oil had a toxic effect on the tree. Similar results have also been obtained in Ecuador with ½ lb. per gallon of copper hydroxide in water applied at low volume *(73)*.

Criollo cacao has been stated to be more resistant to *Monilia* pod rot than either Forastero or Trinitario cacao *(45)*. A relationship between pod color and susceptibility to *Monilia* attack, however, was not established within a Trinitario population, according to the results of an investigation that was carried out in Ecuador *(24)*. Even though Criollo is superior to Forastero and to Trinitario cacao, the fact has only small practical significance to the commercial cacao grower because Criollo cacao is highly susceptible to *Phytophthora* and *Cerastotomella* diseases.

In accordance with the best information available at present the following recommendations for the control of *Monilia* may be offered:

1. Harvest at short intervals and remove all infected pods from the trees and the plantation.

2. Do not open the pods on the plantation and do not leave piles of old husks in the cacao fields.

3. Carry out a program of spraying which is precisely related to the period of greatest production of flowers and formation of fruits and to fluctuations in the rainfall. Spraying should be carried out every two or three weeks, beginning with the period of greatest flowering and continuing during the period of greatest fruit formation, employing either high volume or low volume spraying. Good results may be expected from the application of wettable sulfur, Zineb or various copper products.

(IV) CERATOSTOMELLA DISEASE

This disease, caused by the fungus *Ceratostomella fimbriata* (E. & H., Elliot), has been know in Ecuador for many years but it has only recently become important in other countries. It was first described in Ecuador and attributed to a species of *Sphaeronema (60)*. The same species of fungus causes diseases in coffee, sweet potato, rubber *(Hevea brasiliensis)* and in pigeon pea sometimes used as temporary shade in new cacao plantations, on plants that are dying of old age.

Because of its long association with wounds, this disease has been known as "Mal de Machete" in Ecuador and also as "La Esferonema" in consequence of the original diagnosis *(60)*. In other countries it is known as "Canker", "Necrosis del Tronco", "*Ceratostomella*" and "*Ceratostomella - Xyleborus* complex" because of the common association of the disease with boring insects of the genus *Xyleborus*. For the same reason, the disease has been known also by the name of "La Polilla".

Economic importance: *Ceratostomella* disease has attracted attention only in recent years. Before 1950, the disease was known to occur in Ecuador, causing cankers associated with wounds on the trunks of the cacao trees, as well as a chupon wilt and a pod rot of lesser importance. Since 1950, *Ceratostomella* disease has increased rapidly in importance in several other countries besides Ecuador. It was described as having reached epiphytotic proportions in Venezuela *(43)* Mexico *(47)* and Colombia *(37)* and was also reported as the cause of serious injury to the cacao trees at one plantation in Ecuador *(74)*. The disease also occurs in Trinidad and in America as a scattered infection.

Symptoms and signs: *Ceratostomella* in its most dangerous form is associated characteristically with the attack of boring insects mainly belonging to the genus *Xyleborus* that perforate the infected parts and probably serve as a means of carrying the infection *(16)*. The infection was described in Venezuela as always associated with wounds, especially wounds in the jorquette, and not necessarily with boring insects *(43)*. Association of the disease with insects has been reported, however, in Colombia and Mexico *(37) (47)*. *Ceratostomella* attacks the aerial parts of the tree and may cause the quick death of a branch or of the entire tree according to the locus of the infection. If the infection appears on the trunk or on the principal branches, the infected part is indicated by its darker color and slightly sunken surface. When the affected part is cut, the wood shows a color varying from red to purple. The part of the tree above the affected part eventually dies. The dead leaves remain attached to the branch for a long time after the branch has died. The occurrence of *Xyleborus* insects, along with the discoloration of the wood and the death of a branch with the leaves still attached, are usually indications of an attack by *Ceratostomella*.

The fungus causing this disease is known also as an invader of wounds, as already indicated, without essentially involving the presence of insects. This manifestation of the disease often results in severe necrosis and death of the branches but normally the disease is not as destructive under these conditions as when it is associated with *Xyleborus*. A chupon wilt similar to that caused by *Phytophthora palmivora* is also caused by this fungus.

Pod symptoms: *Ceratostomella* disease also appears as a pod rot but, as such, it has little importance. The affected spots are dark colored, somewhat sunken and develop slowly. On close examination, they are usually seen to coincide with wounds through which the fungus gained access to the pod wall tissues. The seeds underneath the lesions are often affected by a brown dry rot. Occasionally, a sparse white growth of fungus mycelium and conidiophores can be seen to occur near the centers of the spots, and sometimes the long dark necks of the perithecia of the fungus can be observed in the wounds, each perithecium being topped with a gleaming brown colored droplet of exuded ascospores resembling small pins. The perithecia are often found, when a diseased pod is opened, on the inner surface of the pod wall. Fresh pieces of wood taken from a trunk or branch infected with *Ceratostomella* frequently develop a growth of mycelium and conidiophores bearing macro and micro conidia when placed for a few hours in a moist chamber. Occasionally also, perithecia may develop on them.

Susceptibility of cacao varieties: A manifestation of *Ceratostomella* disease in its most destructive form has been observed since 1951 in the Tropical Experiment Station at Pichilingue in Ecuador in a collection of introductions of cacao varieties received from various countries *(16)*. The incidence of the disease in the different varieties was observed to be greatest on cacao of the Criollo variety, 54 percent of the trees having predominantly Criollo characteristics being already dead or heavily infected, whilst Forastero and Trinitario types of cacao showed only 2.5 percent infection and no deaths (see Table 3).

TABLE 3.

COMPARATIVE EFFECT OF CERATOSTOMELLA INCIDENCE ON CACAO POPULATION WITH AND WITHOUT CRIOLLO CHARACTERISTICS

(After Desrosiers, 1956 *(16)*)

	HEALTHY TREES	TREES AFECTED OR DEAD	Total
Criollo	44	52	96
Non-Criollo	116	3	119
TOTAL	160	55	215

X^2=74.4460 ** Significant at odds greater than 99 to 1.

From these observations it can be deduced that resistance to *Ceratostomella* disease resides in the variety or the section of species known as Forastero, while the variety Criollo shows a high degree of susceptibility. The variable Trinitario cacao population, which is considered to be of mixed Criollo and Forastero ancestry, should display variable susceptibility because of the predominance of genes of one or the other of its ancestors *(16)*. Lately, the epiphytotics of *Ceratostomella* observed in Mexico, Colombia and Venezuela, have been reported to be associated predominantly with cacao of the Criollo variety.

Clone ICS 1, a Trinitario type, showed a high degree of susceptibility to *Ceratostomella* disease at Hacienda Clementina in Ecuador where it had been extensively planted in pure stands *(22) (74)*. This susceptibility was manifest in spite of the fact that the ICS 1 clone does not give the impression of containing a high proportion of genes of the Criollo ancestry. Clone ICS 45, a Criollo type, also showed high susceptibility. The evidence obtained at Hacienda Clementina is a good example of the danger that can arise by planting large areas of only one clone when a new disease appears to which that clone is highly susceptible. Other clones in Ecuador have given indications of resistance; These include the clones S 62, a Trinitario type, and S 48, which appears to have Cacao National ancestory.

The evidence of resistance to *Ceratostomella* shown by Forastero cacao and by segregants of the Trinitario complex suggests the possibility of selecting for resistance to the disease. Furthermore, since resistance to Witches' Broom also resides in the Forastero lineage and in segregants of the Trinitario population, selections might possibly be made having desirable degrees of resistance to both these diseases.

The role of Xyleborus: The part played by *Xyleborus* insects in the incidence and spread of *Ceratostomella* disease is not fully understood, and much more detailed investigation is needed to determine whether the insects open the way for the entry of the fungus, whether they themselves serve as agents of transportation of the fungus, or whether their activities provide more favorable conditions for the development of the fungus within the host.

The suggestion has been offered, based on observations made in Colombia, that the presence of cankers caused by *Phytophthora palmivora* is a necessary condition predisposing the caaco tree to infection by *Ceratostomella*. Possibly insects first penetrate the tissues infected by *Phytophthora* and thus inoculate the tree at the same time with *Ceratostomella fimbriata* which then destroys the tree. Although double infestation of this type doubtless sometimes occurs, it is probably not a necessary condition, however, especially in Ecuador where *Phytopthora* is a disease of little importance. Exploratory trials carried out at Hacienda Clementina in Ecuador indicate that the control of the *Xyleborus* insects might achieve good control of *Ceratostomella* disease *(74)*. Treatment with insecticides and fungicides in combination have there been found to reduce the degree of infection by the fungus. It is clear that a great deal of investigation is still needed on this disease and its associated insects.

Control: According to what is known about *Ceratostomella* disease, the following recommendations for its control are offered:

1. Do not plant large areas to a single cacao variety or clone. Especially avoid planting the Criollo variety extensively in areas where symptoms of the disease have been observed.

2. Avoid unnecessary damage to cacao trees during operations of cleaning and removing suckers (chupons).

3. Sterilize the implements used in pruning and removing chupons after completing the work on each tree. This can best be done with formalin, using a scabbard lined with felt soaked in the liquid into which the worker puts the implement before beginning work on the next tree.

4. Remove and burn all infected branches and dead trees so as to destroy both the fungus and the *Xyleborus* insects.

5. Put into operation a carefully-planned program of spraying for the control of pod rots *(Phytophthora* and *Monilia)* combined with a program of insecticide application for the control of harmful insects. Such a combined program of fungicide and insecticide applications should effect a substantial reduction in the incidence of *Ceratostomella*.

(V) DIE-BACK

This condition, often attributed to the weather, although a number of other factors contribute to it, probably ought not to be considered as a fungus disease but mainly as the result of insect attack. It is mentioned here because, when it occurs in a cacao plantation, it is likely to assume the proportions of a disaster and to obtrude itself upon the attention of the plant pathologist, no matter how much he may try to discount its significance. The situation is almost always complicated by the operation of several inter-dependent factors, notably, infestation by species of *Monalonion*,* attack by thrips, defoliation induced or aided by the activities of certain fungi, including species of *Colletotrichum*, *Diplodia* and *Nectria*, and the interrelationships between soil fertility, shade and drainage.

Numerous insect pests and fungus diseases other than those mentioned may be present further to complicate the matter. Hence the die-back syndrome might best be considered as a complex of effects rather than a simple single phenomenon. One of the agents involved, however, is sufficiently serious to be considered as having prime importance.

Economic significance of cacao Die-Back: It is not possible to estimate the effect of die-back on cacao yields; in fact, no attempt has yet been made to do so in most countries. Planters grow accustomed to regard die-back of cacao as a natural condition which they must learn to accept. A conservative estimate is that, where severe, this condition reduces cacao yields by abount 50 percent.

Symptoms: An established cacao plantation seriously affected by die-back presents an appearance of severe defoliation. The leaves turn yellow and fall off, leaving a straggly structure of bare branches and twigs. The defoliated twigs die back and, under repeated attack over a period of time, develop a broomed or staghorn appearance as the result of repeated branching and shortening of the internodes. Trees in full sunlight are affected most, whilst neighboring trees under shade usually present a quite healthy and normal appearance. Severely stricken trees may die.

Causal agents: Prominent among the primary agents of cacao die-back in Costa Rica are capsids of the genus *Monalonion*.* Several species of these sucking bugs have been identified in South and Central America. The damage caused by a heavy infestation of *Monalonion* closely resembles that caused by the African species of capsids *(8) (30)*. The insects feed and lay eggs both on the pods and young shoots and, during the feeding process, the bugs are believed to inject a toxin which speeds the death of shoots so affected. The scab-like scars caused by *Monalonion* on cacao pods are characteristic and resemble those caused by the capsid *Helopeltis* in Africa. The insect attack seems to have little effect on large pods, although it probably causes considerable

* *Monolonion* is a synonym of *Monolonium*.

loss of small fruits, which may pass unnoticed, either through direct killing or by opening the way for attack by pod-rotting fungi. Apparently, however, the most destructive stage of the attack is that which affects the twigs and shoots.

A heavy infestation by *Monalonion* results in severe defoliation and dieback of the young shoots. The affected shoots are invaded by several normally weakly pathogenic fungi, including species of *Nectria, Diplodia* and *Colletotrichum*. Isolations made from such material usually produce species of *Fusarium* which may represent the imperfect stages of a species of *Nectria*.

Thrips are likely to be conspicuous on cacao trees showing die-back and are often wrongly regarded as the cause of damage primarily due to *Monalonion*. Admittedly thrips do considerable damage to cacao trees but it seems unlikely that they are important primary causes of die-back and defoliation*. An investigation (unpublished) by entomologists at the Estación Experimental Tropical, Pichilingue, Ecuador, in 1952-53, failed to incriminate thrips as a primary cause of cacao defoliation. It seems probable that the presence of a heavy population of thrips may be a symptom, rather than the cause, of an unhealthy condition of the trees.*

Lack of overhead shade is often a characteristic of cacao trees showing serious evidence of die-back and defoliation. Inquiry will usually elicit the information that fertilizers have never been applied to the plantation, so that malnutrition, intensified in its effect by the lack of shade, must be considered as a contributing factor to the condition.** Both *Monalonion* and *Thrips* are usually, though not necessarily always, to be found attacking trees exposed to the sun rather than those that are heavily shaded. Another factor of great importance having direct relationship to the question of soil productivity is drainage ins o far as it affects aeration of the soil and the amount of root room allowed to the tree.

Control: (1) *Insecticide application:* Where *Monalonion* is discovered to be the primary cause of cacao die-back, control of this insect should obviously be given high priority in any control program. The appearance of this insect on cacao is cyclical, particularly in relation to rainfall. In Africa, capsids have been brought under satisfactory control by two applications a year of BHC Gamma Isomer, and increases in yield of 100 percent have been obtained over a period of two years *(8)*. The first application was timed to coincide with the arrival of the capsids and, since it has no effect on eggs of the insect, a second application was made one month later to kill the insects which had emerged after the first application. It is evident that a similar program which can be linked with a fungicide spraying program and a general insect control program might be developed for the control of *Monalonion* in the Americas, although considerable study still needs to be made of the habits of the insect before a suitable procedure can be formulated *(25)*.

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* *See* Fennah, R. G. The epidemiology of cacao-thrips on cacao in Trinidad. A Report on Cacao Research, 1954:7-12. Imp. Col. Trop. Agr., Trinidad, 1955.

** *See* Murray, D. B. The role of shade and fertilisers in the cultivation of cacao. Journ. Agr. Soc. Trin. & Tobago, 57:193-208. 1957.

(2) Fungicide application: It has been observed that spraying with fungicides alone, if carried out in a thorough and systematic manner, reduces the amount of die-back although it by no means eliminates it, and also that trees that have been sprayed develop a much denser foliage canopy than unsprayed trees *(19) (75)*. This is one of the secondary effects commonly observed to result from a program of spraying carried out primarily to control one of the pod diseases. It doubtless results from the control of some of the fungi of minor importance which are associated with die-back, such as *Nectria, Diplodia* and *Colletotrichum*. *Colletotrichum* causes severe defoliation when it attacks young cacao leaves. Another possible effect of fungicidal sprays is a repelling action against *Monalonion* and *Thrips* as well as against other insects.

(3) Correction of nutritional and drainage deficiencies. A cacao planter who finds his trees badly weakened by die-back and defoliation and also fully exposed to the sun should obviously hasten to apply fertilizers. A full analysis of the soil for major and minor nutrient elements should be made as a basis for fertilizer application. Deficiencies which might exist in the drainage system of the land should be rectified.

(4) Pruning: Dead and diseased wood and staghorn formations should be eliminated from the trees as a normal part of the pruning operation.

Although the treatment of some single aspect of this complex problem as, for instance, spraying with an insecticide to control *Monalonion*, might produce significant results by itself, it is more likely that a program embracing the several features mentioned above, combined with a thorough fungicide application program for controlling pod rots, will produce far greater, more certain, and much faster results, and is therefore strongly to be recommended.

(VI) OTHER DISEASES

(i) DIPLODIA: "Charcoal Rot"

The fungus, *Diplodia theobromae*, Nowell, has a world-wide distribution and is known as a parasite of a large number of hosts. On cacao, it is considered as a weak parasite, affecting trees which are weakened by other causes. It is associated with die-back (see last section) and also with failures of budding and grafting and poor rooting of cacao cuttings *(15)*. This fungus also produces a rapidly destructive rot of the pods which is, however, confined to pods that have been left on the tree beyond the time of normal maturity. Pod rot caused by *Diplodia* is characterized by a black lesion which rapidly covers the surface of the pod and, under humid conditions, is covered by the black mycelium of the fungus and the exudation of large quantities of black spores from the pycnidia of the fungus which are embedded in the diseased tissues. These spores are readily dislodged and distributed by wind, rain and insects.

Control: Those aspects of *Diplodia* disease associated with die-back have already been considered in the last section. Timely harvesting, that is, not permitting the pods to remain too long on the tree, will avoid losses due to Diplodia pod rot. A thick suspension of Ferbam, applied to both stock and scion before making the graft, will greatly reduce infection and improve the "take" of grafts. Ferbam or Ziram, used as a suspension at the concentration of $\frac{1}{4}$ to $\frac{1}{2}$ lb. in 12 gallons of water in which cuttings are prepared will reduce infections occuring in the propagating bins and improve rooting *(15)*.

(ii) ANTHRACNOSE

This is another disease of cacao having world-wide distribution and its causal fungus, namely, *Collectotrichum gloeosporioides,* Penz., also has an extensive range of hosts. This disease affects both leaves and pods of cacao and can also be isolated from twigs suffering from die-back and from diseased cuttings in propagating bins. As a pod rot, the disease is of little importance. Lesions produced on pods are brown in color, slightly sunken and somewhat wrinkled. Under humid conditions, small pink masses of spores of the fungus develop on these spots. Although the lesions are rather slow growing, they may penetrate through the pod wall and affect the seeds inside. Such infections are, however, normally quite scarce.

A more important aspect of Anthracnose is its effect on cacao leaves. The young leaves and stipules of a new flush are extremely susceptible to attack by *Colletotrichum* and heavy infection frequently ends in the complete defoliation of the shoot, resulting in the bare-tip symptom. Repeated defoliation.. may cause the eventual death of the shoot and, as a result of the development of side shoots, it may produce a type of false Witches' Broom. This phenomenon of rapid defoliation and bare tip often occurs among seedlings and rooted cuttings that are being raised in nurseries, since these plants are readily infected by spores of the fungus splashed from the soil during rain of during watering. Occasional irregularly shaped brown Anthracnose spots occur on older leaves. These are not normally sufficiently numerous adversely to affect the growth of the tree. Nevertheless they constitute a source of infection of other cacao trees, together with infected pods left on the tree and also dead twigs in which the fungus may be present either as a pathogen or a saprophyte. The sticky masses of spores are not carried by wind but are splashed about by rain and transported by insects.

Control: Removal of dead and infected wood and diseased pods as a normal part of pruning and harvesting should do much to reduce the incidence of Anthracnose in mature trees. If these operations are carried out in connection with a well-planned fungicidal spraying program for the control of pod rots, in which the whole tree is sprayed and not merely the fruiting area, excellent results should be obtained in the control of Anthracnose.

It is recommended that, in order to prevent rain splashing, a thick layer of mulch be spread over, and for a considerable distance around, the nursery beds. This should reduce contamination with soil which probably contains *Colletotrichum* spores. The same sort of protection may be given to plants newly set out in the field. Seeds planted in soil sterilized by chlorpicrin or formalin and contained in wooden frames raised above ground level usually produce a complete stand of healthy plants which do not lose their leaves nor develop leaf spots.

(iii) THIELAVIOPSIS POD ROT

This disease, caused by the fungus *Thielaviopsis paradoxa*, was first reported from Ecuador *(13)* and has since been observed in Costa Rica. Since the causal organism has an extensive geographic distribution and host range, it probably occurs in other countries as well. The fungus is a wound parasite and penetrates the pods after they have been damaged by birds. Only mature pods appear to be susceptible and a comparatively deep wound, such as made by the pecking of a bird, is evidently necessary for infection to occur. After entering a wound, the infection is rapidly destructive. Unwounded pods are difficult to infect *(13)*. The infection takes the form of a medium to pale brown discoloration which rapidly covers the whole pod. The interior of the pod is involved in a moist rot exhibiting an abundant growth of grey mycelium and conidiophores of the fungus. Clusters of whitish mycelium and conidiophores may appear on the surface of the pod under humid conditions. Sometimes clusters of conidiophores bearing only whitish microconidia occur on the surface, and conidiophores producing only grey marcroconidia occur in the interior of a pod.

Thielaviopsis disease can be identified in the field by the sweet odor of apple or pineapple which is detectable on a freshly-cut surface of an infected pod, and also by the comparatively fragile condition of the infected pod wall. Whereas pods infected by other diseases remain relatively firm and hard, the wall of a pod infected with *Thielaviopsis* rapidly weakens and crunches like an eggshell under pressure of the thumb.

Control: This disease is normally thought to be quite rare and therefore not to require special control measures. Much bird activity in cacao plantations, coupled with infrequent harvesting, favor its spread to the level when it might take a heavy toll of the crop. On the Atlantic Coast of Costa Rica, for example, a considerable amount of *Thielaviopsis* infection has been observed to occur on several occasions on freshly harvested cacao pods. The control of *Thielaviopsis* should not, however, be a serious problem. Prompt harvesting, which ensures that ripe pods are not left too long on the tree, and a fungicidal spraying program for the control of other, more serious, pod rots should effectively reduce the incidence of *Thielaviopsis*.

(iv) THREAD BLIGHT or KOLEROGA

This disease, caused by the fungus *Pellicularia Koleroga (Corticium Koleroga)* occurs sporadically in cacao plantations, but it is not likely to be a serious disease in well managed plantations. It can be recognized in the field by its strong threads of brown-colored fungus mycelium growing along the branches of the cacao trees. Wefts of mycelium grow out from these threads onto the leaves which are killed and subsequently absciss but do not fall because they remain suspended by the fungus mycelia. This can result in rather serious defoliation and the death of branches.

Control: Affected twigs should be removed as a normal part of the pruning operation. The mycelium can generally be easily removed from larger branches.

A well-planned spraying operation for the control of pod rots should control this disease as well. Good control has been reported by the use of Bordeaux mixture, 4-4-50, Perenox and Crag 531 *(50)*.

(v) PINK DISEASE

This disease, caused by the fungus *Corticium salmonicolor,* closely resembles Koleroga. The mycelium, which grows over the branches in a similar manner is, however, pale colored and the sporulating areas are colored pink. Affected leaves die and fall off.

Control: Infected parts should be removed during pruning operations. Normal pod rot spraying operations should control this disease effectively. Successful control has been reported with effectiveness of up to one year by the use of Bordeaux mixture *(66)*.

(vi) ROOT ROTS

Root rots are not the really serious problem in cacao plantations in the Americas that they appear to be in other parts of the world. The most common root rot appears to be the Black Root Rot caused by *Rosellinia bunodes* and by other species of *Rosellinia*. These are normal inhabitants of forest soils and are likely to be transferred from forest tree roots to the roots of cacao plants after the forest is felled and a plantation established. Frequently several cacao trees may be infected in a closely circumscribed area at about the same time. Examination will probably disclose an old stump somewhere in the area from which the fungus has spread along contacting roots to the trees. Infected plants display wilting and death of the leaves and eventual death of the plant. Examination of the roots will disclose the rhizomorphs of the fungus and, beneath the bark, fan-shaped plates of fungus mycelium.

Control: Cacao plants which die in this manner should be examined for signs of *Rosellinia* on the roots. Infected roots should be carefully removed and as completely as possible and an attempt made to identify the source, such as an old stump, roots of forest trees or similar material, from which the infection emanated. This should then also be removed. When the infected stump has been removed and destroyed, replanting may be attempted, the new plants being kept under observation for symptoms of the infection. These same procedures should be followed in dealing with any root rot of cacao. Several comparatively inexpensive soil fungicides are now available which might be used for treatment of the soil prior to replanting.

(VII) SUGGESTION FOR THE DEVELOPMENT OF A COMPREHENSIVE DISEASE CONTROL PROGRAM

The day is fast approaching when the causal and leisurely operation of the cacao farm by purely exploitative methods, that is, taking off the harvest but never putting anything back into the soil, will be a thing of the past. Mechanization, modern technology and modern business methods are beginning to be used by the progressive cacao planter. Eventually, perhaps, a high level of efficiency in every aspect of cacao production will be achieved, and unsprayed cacao plantations may be hard to find, relics of a more leisurely, easier and perhaps more pleasant epoch. That day has not yet, however, arrived, and a great deal of teaching and propaganda is still required to effect changes in the methods of cacao growing.

How often one hears a cacao planter comment that, while he realizes the importance of spraying, he is unable to undertake it because the yield of his plantation is so low that he cannot afford it. Undoubtedly some planters who adopt this attitude are absolutely right. Unquestionably cacao plantations exist that are in such poor shape that no bank would ever lend their owners money for any purpose. The best recommendation that can be made for such plantations is that their owners should sell them, always assuming that a buyer can be found. In all probability, however, the planters who claim that they cannot afford to spray their cacao trees fall within another group who really cannot afford *not* to spray and adopt other methods needed to control diseases and pests and otherwise improve their holdings. These men's plantations may also be in bad condition though not yet hopeless. They will not, however, improve as a result of further neglect. The fact should be kept in mind that if one does not advance, one slides backward. To stagnate is not possible. The same is certainly true of a cacao plantation and, if the planter does not put into practice the measures needed to improve his property, it will not remain perpetually in a static condition but will steadily deteriorate until it reaches a condition of being truly uneconomical to operate.

Regarding the cost of a disease control program, the author's own estimate of a low volume spraying operation, making ten applications per year at approximately 12 gallons per hectare, is US $ 45.00. This estimate is supported by other findings *(75)* which proved that 12 applications of Zineb at the concentration of ½ lb. per gallon, applied at 12 gallons per hectare, cost approximately US $ 59.00. Experience gained so far with fungicidal spray programs which have been carried out in a thorough manner, has shown that the normal expectation is that yields will increase approximately 100 percent in the first year *(18) (19)*. This proved to be true in the case cited *(75)* and also in another case *(73)* in which copper hydroxide in water was applied at low volume with similar results to those obtained in the first case. Several private individuals have obtained results of a similar nature through spraying either at high or low volume. A planter starting with a cacao production of 400 to 500 pounds per hectare (160 to 200 lb. ac.) should be able to raise the yield to 800 to 1000 pounds per hectare (320 to 400 lb. ac.) by spraying. With soils of high natural productivity or with the use of fertilizers, correspondingly higher proportionate yields can of course be realised. The spraying, if carried out by low volume methods, would cost the equivalent of no more than 200 pounds of cacao. Whatever increase is obtained beyond 200 pounds, would thus be profit and the venture would be economically sound. The results of spraying can be expected to be more impressive and more certain during the second year.

SUMMARY AND SUGGESTIONS

Th following notes summarise the discussion of cacao diseases and their control; they might be considered as suggestions for the development of a sound disease control program. Details of such a program will vary from country to country and, in many cases, from one area to another within the same country. Certain of the suggestions are applicable to governmental or research agencies and others to the planter himself.

(1) *Planting material:* High yield, disease resistance and quality are the three factors which are most important to consider in the selection of planting material. Selection programs are in progress in most of the cacao-producing countries and these are devoted primarily to the development of high-yielding clones and, in some cases, clones exhibiting certain desirable market qualities. Even in those countries where they do not occur, resistance to certain diseases, such as Witches' Broom and *Ceratostomella,* should be introduced into the planting material. Serious consideration should also be given to the evidence which already exists of wide differences in susceptibility to Cushion Gall among clones of cacao. *Ceratostomella* is evidently a widely distributed disease. Apparently its seriousness is not evident in those areas planted with a highly-variable seedling cacao population. If, however, large clonal populations should be established, or if large areas were to be planted to hybrid cacao having restricted variability, *Ceratostomella* might become a serious problem unless the material planted is highly resistant. The same is true with Witches' Broom disease. Although at present large areas of cacao occur that are free from Witches' Broom disease, assurance that this situation will continue cannot be entertained. Responsible agencies in the countries concerned should therefore take the necessary steps to obtain breeding material, notably from Trinidad and Ecuador, known to be resistant to these diseases, so that the resistance factors may be incorpored in the new lines of planting material that are being developed.

(2) *Propagation:* Considerable advances have been made in recent years in the techniques of propagating cacao, both by sexual and by asexual means, and these are discussed at length elsewhere in this Manual. Suffice it to say here that a few simple precautions, such as the use of a thick mulch on and around nursery beds in which cacao plants are being raised, will be of considerable help in avoiding injury or loss of leaves by disease. Alternatively or preferably, the plants should be grown in sterilized soil and protected against splashing rain. Several chemical substances are available for sterilizing the soil. The use of a thick suspension of Ferbam on both stocks and scions in grafting operations should be made a routine operation. The same is true of the use of Ferbam or Ziram, applied at the concentration of between ¼ and ½ lb. per 12 gallons in the water in which cuttings are made. Alternatively, a fungicide may be mixed with the powder which carries the rooting hormone.

(3) *Field:* A rational spraying program aimed primarily at the control of pod rots should be developed. In the timing of applications, consideration should be given to factors affecting the development of the fungus which is being controlled. Timing of application and total number of applications made

during the year vary considerably from place to place. Emphasis should be given to making the greatest number of applications during the critical period when the disease is at its worst and fewer applications, more widely spaced, at other times. Evidence has already been adduced to show that temperature is a critical factor in the epiphytotic development of *Phytophthora* Pod Rot *(28) (38) (54)*. Low temperature, unless occurring in dry weather, would be expected to provide conditions favoring the greatest development of this disease. Such a period would seem therefore to be the logical time to put on more frequent applications of spray.

In the case of *Monilia* pod rot, since the fungus evidently gains entry to the cacao pod only in the earliest stages of pod development and since the incidence of the disease varies directly with intensity of rainfall the best time to spray with fungicide should be whilst the pods are beginning to form (the cherelle stage) and when the weather is dry. A spray program developed for the control of a pod rot will evidently pay extra dividends derived from the control of miscellaneous other diseases. The pod rot program should preferably be correlated with a similar program for the control of cacao insects *(8) (25)*.

An extremely important factor influencing the amount of loss attributable to pod infections is the timeliness of harvest. Harvesting should be carried out at as short intervals as possible, not exceeding two weeks. Leaving pods on the tree for a month invites heavy losses from pod rots of all kinds in addition to depredations by squirrels and birds. As part of the normal pruning operation, dead and diseased wood, including witches' brooms, should be regularly removed from the trees. As a means of greatly reducing inoculum potential, cacao pods should be removed from the plantation rather than opened and left to lie in heaps on the ground as is the customary practice. Dead witches' brooms and wood infected by *Ceratostomella* should be removed from the plantation and destroyed for the same reason.

In regard to pruning, the importance of avoiding unnecessary damage to the trees cannot be over-emphasized. Pruning and the removal of chupons should not be carried out with a machete. The machete cannot possibly be considered to be a pruning tool. Adequate care should always be exercised to avoid injury to one branch while pruning another. Cuts should be made clean and no stumps should be left. Wounds should be dressed with a fungicide such as a thick Bordeaux paste. After pruning one tree and before starting on the next, the pruning implements should be sterilized in order to avoid the transmittal of such diseases as *Ceratostomella*. A simple method for the sterilizing of pruning tools is the use of a scabbard lined with thick absorbent material soaked in formalin through which the implement may be passed.

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CHAPTER 20

CUSHION GALL*

History: In the Western Hemisphere, the disease now known as cushion gall of cacao, sometimes called buba, was first noted in Santo Domingo in 1929, and was then described as a woody gall (agallas leñosas) *(3)*. It was independently described in 1940 as cushion gall (verruga del cojín floral) from observations made in Colombia in 1938-40 *(5)*. The galls described were confined to the flower cushions. In 1951, cushion gall was reported from Nicaragua, Costa Rica and Panama, and its rapid spread in cacao plantations was viewed with alarm *(12)*. The formation and features of cushion gall in Nicaragua were described in 1954 *(18)* and reference was made to previous records of abnormal growths occurring on cacao trees that had attracted attention in 1911 and 1923. Cushion gall has also been seen in Surinam where it was called yaws *(17)*.

In Venezuela, galls have been reported to occur on the stems of cacao plants that are too young to flower and not therefore associated with cushions *(14)*. Resemblance to other kinds of galls affecting the buds of various fruit and timber trees, such as mango, orange, plum and birch, and attributed to bud stimulation by mites, had been noted in 1955 *(6)*.

Various causes have been suggested for the incidence and development of cacao cushion gall which include, beside fungus infection, environmental growth conditions, genetic factors and certain biological agencies such as bacteria, virus and insects. The information that had been accumulated up to 1957 was summarised in a mimeographed publication issued by the Inter-American Cacao Center of the I. A. I. A. S., Turrialba, Costa Rica, which stressed the urgent need for further investigation of the disease and of possible means for its control *(1)*.

Through the initiative and support of the American Cocoa Research Institute (A. C. R. I.) of New York, and of the Inter-American Institute of Agricultural Sciences (I. A. I. A. S.) of Turrialba, the Cacao Center has been able to intensify research into the nature and bionomics of cushion gall and to procure the services of a whole-time scientific specialist to study its features and mode of transmission, and to assess its effects on the cacoa crop.

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* This section is based mainly on the writings of L. M. Hutchins and has been revised by him.

Symptoms: As far as is known at present, the symptoms of cushion gall in bearing cacao trees are solely confined to the flower cushions *(8)*. Affected cushions frequently swell up and produce brown, hemispherical, spongy, cauliflower like excrescences that rapidly increase in size. They may attain three or more inches in diameter and two or more inches in height. Affected cushions produce large numbers of bud initials.

In one type of cushion gall, these bud initials fail to develop flowers, but remain as green points on the corrugated, brown surface of the growing gall; this type is called *green point gall*. A tree that has been affected by green point gall for several years usually shows a large number of cushion galls extending from the trunk and main branches well out onto the small limbs. In extreme cases, nearly every flower cushion is affected and pod production is greatly reduced or completely inhibited. In another type, normal flowers develop in large numbers over the surface of the growing gall; this type is called *flowery gall (7) (8)*. Trees heavily affected by this gall bear large masses of flowers on the galled areas of the trunk, the framework limbs and the smaller branches.

Flowery gall first received detailed study in 1958, in which year it reached epidemic proportions at Turrialba and La Lola in Costa Rica. Surveys showed it to be severe also in some other countries. Observations of flowery gall are not of sufficiently long standing to permit evaluation of eventual consequences to the affected plantings but the situation is not encouraging. In 1958, for example, the flowers borne by this gall were seldom pollinated by natural means, and very few pods were matured from the flowery galls *(11)*.

The flowery type of gall was at first confused with multifloral cushions born by the so-called "male" tree which is an incompatible type of cacao *(8)*. Flowery gall may therefore in the early days have been wrongly attributed simply to incompatibility. Apart from the fact that flowery galled cushions produce normal flowers, the flowery gall and the green point gall are similar in many respects *(8)*. Both kinds often occur on the same tree and occasionally even on the same cushion *(10)*. Both are often borne on short stalks, $\frac{1}{4}$ to $\frac{1}{2}$ inch in diameter. Typically, the lower surface of such galls is flattened against the bark without attachment except by the stalk. Sometimes the stalk is slender, sometimes the basal attachment is broad, but the characteristic features of these two kinds of gall differentiate them clearly from all other kinds of cacao flower-cushion galls. After growing for a year or more, these galls, particularly the large green point galls, usually die. Their tissues then become black and carbonaceous and are easily crumbled. The two types described above are the only ones at present showing epidemic features in Nicaragua, Costa Rica and Colombia *(8)*.

Classification of cacao galls: During the course of plantation surveys, the two distinct types of cushion gall above mentioned were specifically identified, namely, green point gall and flowery gall. Other types of gall also are known to develop in the flower cushions of caaco. Two of these have been named *knob gall* and *hard flat gall (8)*. The first is smooth and woody in texture and has a diameter of about one inch. It does not bear any flowers. The second is corrugated and dark colored. Its diameter varies from 2 to 3 inches. It sometimes carries flowers and sets fruit. Both types are attached to the tree over the entire basal area of the gall. They mostly occur on old trees. Occasional

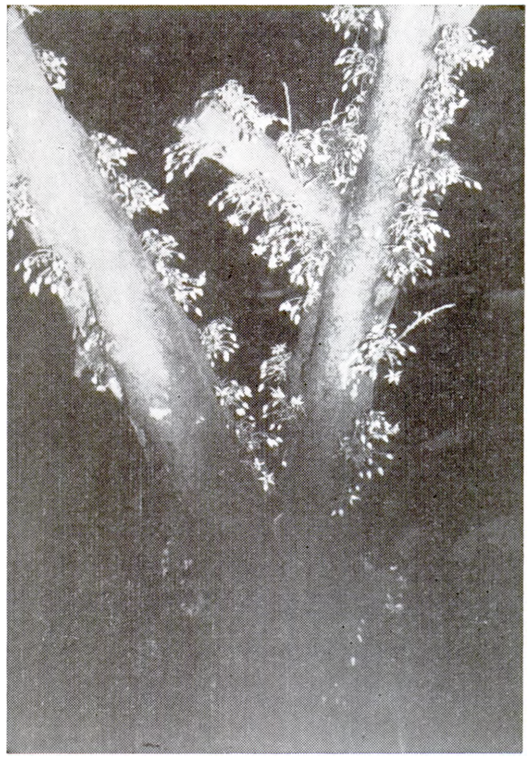

Fig. 1. Flowery Gall type of Cushion Gall in cacao.

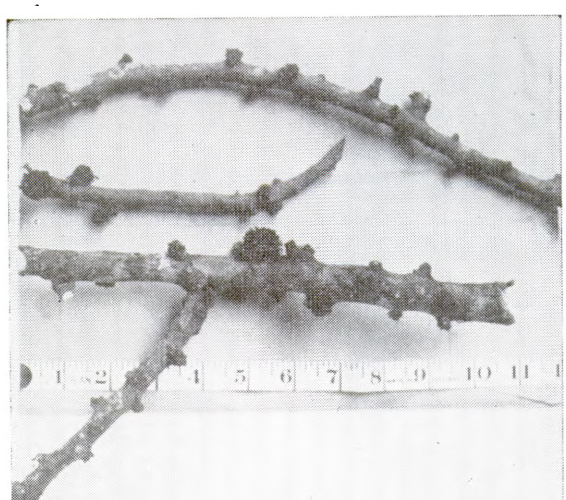

Fig. 2. Green Point Gall type of Cushion Gall.

cases of broom-like hypertrophies from the flower cushions have also been observed *(10)*.

Distribution in the Western Hemisphere: In order to ascertain the distribution and intensity of cushion gall in Latin America and the West Indies, a survey was undertaken in May, 1958, by the appointed specialist *(6) (9)*. This survey confirmed the early reports and revealed the recent introduction of the disease into Trinidad. The survey was continued intermittently during 1958 and 1959, and was supplemented by authentic reports from several sources. Cushion gall is now known to be present, though for the most part sparsely distributed, in most if not all of the cacao-growing regions of the Americas *(10)*.

Transmission: A detailed study of the incidence and distribution of cushion gall in a badly-infested plantation in Nicaragua, carried out in 1958, created the suspicion that cushion gall may be an infectious disease and that the infective principle may become systemic in the tree, that is, it may occur within the tissues of the plant body from which it may pass into the newly developing shoot *(7)*. Evidence was obtained which showed that the disease spreads naturally from diseased to healthy trees. The conclusion was reached that it might therefore be inadvertently introduced into new plantations or replanted fields through infected propagation material such as cuttings, buddings and possibly even seeds from infected trees *(7)*. The recommendation was accordingly made that propagating material should be taken only from healthy trees devoid of galls, and preferably growing in a gall-free area.

Transmission of cushion gall by inoculation was experimentally investigated at the I. A. I. A. S., Turrialba, in July-August, 1959 *(10)*. Five-year-old healthy trees comprising seedlings and cuttings growing near the Institute and at La Hulera nearby were used for the experiments. Small pieces of green point gall tissue were applied to the freshly-cut surfaces at or near the point of insertion of cacao pods growing on healthy trees, that is, trees on which galls were entirely absent. The implants were bound in position with plastic tape. In some cases, gall tissue was inserted deep in the bark or between the bark and the wood at the base of the pod stalk. Observations made on 143 inoculations on 17 trees proved that 14 of them (or 9.7 percent) had "taken" *(10)*. Green point galls developed within 34 to 111 days after treatment. The length of the incubation period was thought to vary according to (a) the size of the piece of diseased tissue that was applied, (b) from what part of the gall it was taken, (c) the abundance of the gall-inducing agent in the inoculum and (d) the method of application.

In August, 1959, more than 126 flowery gall pod-stalk implantations were made on 16 cacao trees. Initiation of gall development appears to have taken place in a few cases but the experiment is still in its early stages. As a check on these inoculations, pieces of tissue taken from normal cushions of 6 different trees each entirely free from gall were implanted in 102 pod-stalks belonging to 13 gall-free trees. This experiment was begun in early August, 1959, and observations made 98 days after failed to show any instance of infection *(10)*.

Transmission of cushion gall by budding and the possibility of controlling cushion gall by means of insecticides are being investigated in a preliminary manner at La Lola, Costa Rica *(16)*. The experimental cacao plants comprise

149 cuttings trees mainly of U. F. clones, 4 to 6 years old. The treatments are, (a) budding with buds taken from trees severely affected by cushon gall, (b) spraying with insecticide every 3 weeks, (c) budding and spraying with insecticide and (d) control (no treatment). Data on gall development are collected at fortnightly intervals. The results obtained up to December, 1959, showed that 148 out of 149 experimental trees were affected by cushion gall. A total of 6183 galls was recorded. Of these, 29 percent occurred on the budded trees, 24 percent on the sprayed trees and 12 percent on the budded-and-sprayed trees. The control trees carried 35 per cent of the total number of galls counted. These results show that, even when budding with presumably "infected" buds was carried out, a lesser number of galls was produced than arose naturally on the untreated or control trees, and that insecticidal treatment failed to suppress gall formation. The least number of galls was recorded on the trees that were both budded and sprayed. Conclusive evidence either of bud transmission or of transmission by insects is not afforded by these data. It is possible that the cacao trees were already infected with cushion gall disease before they were brought into the experiment. Nevertheless, out of 35 trees that were budded, 19 trees carried between them a total of 64 galls on the bud outgrowths whereas, out of 31 trees that were budded and sprayed, only 6 carried a total of 8 galls. This suggests that insecticide treatment in some way suppressed gall formation though it does not prove that it did so by destroying possible insect vectors. Another experiment has been started at La Lola in which seedlings, cuttings and buddings, prepared both from apparently healthy trees unaffected by cushion gall disease and from trees carrying galls, are being grown for future observation *(16)*. Yet another experiment has also been started in which cacao trees affected in varying degrees by the disease have been heavily pruned. The development of galls on the new shoots that may subsequently arise will be recorded *(16)*.

The possible role of insects and mites as agents causing the formation of cushion gall was investigated in 1955 in some cacao plantations situated on the Atlantic Coastal Plain of Costa Rica *(13)*. Ten species of insects belonging to six different families and several species of mites were caged on normal flower cushions occuring on trunks and branches of cacao trees of varying age above 3½ years. The caged insects had previously been fed on galls of the green point type. Only one of the insect species, namely, *Clastoptera globosa,* and two of the mite species gave any indication that they might be gall formers *(13)*.

Varietal susceptibility: Investigations carried out in a cacao variety collection at Zent in Costa Rica in 1959 *(11)* demonstrated pronounced differences between certain clones in regard to susceptibility to the flowery type of cushion gall. Trees belonging to three particular clones, namely, UF 29, 242 and 273, were found not to carry any galls at all, even though they were surrounded by trees belonging to other, apparently highly susceptible, clones which bore large numbers of flowery galls. Trees belonging to still other clones showed intermediate susceptibility. Few green point galls were observed on any of the trees. A second inspection, made three months later, confirmed the earlier observations. It was noted that the canopies of resistant trees were closely interlacing with those of adjacent susceptible trees, thus affording full opportunity for unrestricted natural spread.

Effect of cushion gall on yield of cacao: The relation of incidence of cushion gall to yield of cacao has been established by many years of observation in widely separated areas for the green point gall. It is less well known for the flowery gall. Green point gall reduces the flowering area of the tree in proportion to the number of cushions showing fully developed galls. It is rare to find a pod growing from a gall of this type. At Turrialba, Costa Rica, epidemic outbreak of flowery gall first occurred in 1958. In that year, pods on trees heavily attacked by flowery gall were borne mostly on the few remaining normal cushions scattered haphazard along the trunk and branches. So far, identifiable characters of these gall types occurring on bearing trees have been seen only in the flower cushions. Experience indicates that galled trees of the green point type become less and less productive as the affection progresses and increases. In the most severe cases of attack, the crop fails completely. The flowery gall and its behavior are now also under close observation. Crop records for trees showing different intensities of gall infestation of both types are being maintained.

Recommendations for control: Under favorable conditions, both the green point gall and the flowery gall are capable of rapid spread in a cacao plantation. When these galls become well established in the trees, both types present a hazard to commercial yield of cacao beans. No curative treatment for the affected trees is known. In view of the undoubted threat that these galls present to the successful growing of cacao, efforts should be made to reduce their spread and to eliminate them from the cacao fields where this is practicable. Until the current research program has produced specific recommendations based on more complete knowledge of the cause, the behavior and the manner of dissemination of this disease the rigorous application of the principles of plant sanitation is recommended as a measure of control. The following procedure should be followed:

(1) Inspect cacao plantings systematically two or three times a year for the presence of cushion gall. If only a few galled trees are found, remove and destroy them at once. If the galls are numerous and if federal or local regulatory measures are not in force, the property owner must decide whether to remove all of the affected trees, or whether to let them stand and thereafter continue to tolerate the disease under conditions of diminishing returns.

(2) Select cacao propagating material (buds, scions, cuttings, seeds) only from healthy, gall-free trees growing in an area free of the disease.

(3) Observe regulations regarding inspection and movement of planting stock.

(4) Report observations to responsible governmental and institutional authorities and try to implement at once the specific recommendations offered by these authorities.

An approach to control of flowery cushion gall has been made through the discovery of certain high-producing cacao clones that thus far have not contracted the disease, even under the most favorable conditions for its spread and development. *(11)*.

Cushion gall in West Africa: Early records *(4)* show that galls apparently identical in appearance with those described as green point have been known in Ghana since 1923 *(2)*. Similar galls were reported in 1929 occurring in Nigeria *(2)*. A survey made in Ghana in 1958-59 revealed the occurrence of 44 trees affected with galls resembling those described in Latin America. The survey covered one-eighth of the total cacao area of 4 million acres. Twenty of the affected trees occurred in one small farm. The occurrence of a few "male" trees was also noted.

Using the single cotyledon method of inoculation employed for mealybug transmission of swollen shoot virus, transmission of the gall symptoms to young cacao seedlings was successfully effected from cushion galls occurring on mature cacao trees, not only by the agency of mealybugs as vectors, but also by merely brushing the cotyledons with small moist brushes which had first been used to brush the surfaces of the galls. Transmission was also obtained by infecting the cotyledons with liquid extracts of bacteria isolated from cushion galls by various mechanical means of transmission, including brushing. The galls produced on an infected cotyledon borne by a young seedling first appear as enlargements of the axillary bud which later proliferate and develop markedly swollen bases. The largest gall produced in this manner was about $^3/_4$ in. (2 cm.) in diameter.

Bark and graft inoculations by means of gall tissue and patches of bark and wood taken from trees bearing galls have so far failed to transmit the disease to apparently healthy trees, thus indicating that the infection is not systemic. Attempts made to isolate a bacterial pathogen have so far not been entirely sucessful but they are being continued.

It is not yet known whether the gall disease of cacao occurring in Ghana and that occurring in Latin America are induced by the same pathogen. The cotyledon brushing method of transmission has not been successfully performed at Turrialba with the material there available, but further investigations of this method are being carried out. In the meantime, steps are being taken in Ghana to remove the galls from the few trees that bear them and to restrict in future the importation of vegetative cacao propagating material from Latin American countries except that from trees that have been growing for a period of at least seven years' duration in an international quarantine station and have proved not to be contaminated with gall disease.

Cushion gall in Asia: The occurrence of cushion gall within a limited area in Ceylon was reported in 1959 *(15)*. This occurrence was regarded as being identical with the kind of gall occurring in Nicaragua and Costa Rica *(18)*. The description and a photographic illustration corroborate this conclusion and show plainly that Ceylon cushion gall belongs to the type now designated green point gall *(8)*.

SUMMARY

1. A brief account is given of the history, symptoms, classification, distribution, transmission, varietal susceptibility and the effect on yield of cushion gall disease of cacao occurring in Central and South America.

2. Two main types of cushion gall have been identified, namely, green point gall and flowery gall. Their essential features are described. Two other types of gall of lesser importance, namely, knob gall and hard flat gall, are mentioned.

3. Experiments are described whose results indicate that cushion gall is the manifestation of an infectious disease. Attempts to transmit the disease by inoculation and transplanting pieces of gall tissue into healthy trees have proved successful in about 10 percent of the attempts made. The results of further trials are pending. Evidence has been obtained that the disease is spread naturally from diseased to healthy trees and that it is systemic in the affected trees.

4. Pronounced differences between cacao clones in susceptibility to cushion gall disease have been observed in a variety collection in Costa Rica.

5. Cacao yields are reduced by the incidence of green point gall to an extent proportionate to the number of flower cushions affected.

6. In order to control cushion gall, only healthy propagating material taken from gall-free trees should be used, and all affected trees should be destroyed if this is practicable. Resistant clones should preferably be used for replanting.

7. The reported occurrence of cacao cushion gall in Ghana and in Ceylon is mentioned.

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CHAPTER 21

VIRUS DISEASES*

INTRODUCTION

The damage done by plant viruses equals or exceeds that done by all other disease agents. Great advances in the study of viruses have been made during the last decade. By means of the electron microscope and of refined physical techniques viruses have been shown to consist of ultramicrosocpic, ultrafilterable discrete particles which the biochemist has proved in some cases to consist of nucleo protein. The smallest viruses are not much larger in size than molecules. The method of reproduction of viruses is not at present understood. Viruses can grow and multiply only inside the living cells of plants or animals. They have never been grown on artificial media of any sort in the laboratory *(31) (32)*.

The symptoms produced by viruses in plants are varied and almost every kind of reaction that the plant con make to disease stimulus is shown, for example, the development of leaf symptoms such as mottling, striping or streaking, distortion, curling, dwarfing and vein-clearing, as well as change in the color of flowers and formation of swellings, tumors and other outgrowths of stems *(31)*. These various symptoms have been used for classifying virus diseases though they do not, of course, classify the viruses that are responsible for them. Among the plant virus diseases, the following principal classes are recognized: mozaic, distortion, dwarfing, necrosis, tumors, and yellows *(31)*.

Plants infected with virus either react visibly or they do not obviously react at all. In the first case, the reaction is mild and transient, or it is severe. With some virus diseases the symptoms disappear in due course although the plant still carries the disease. With others, the symptoms persist and become increasingly severe, often resulting in the death of the plant. In the second case, where reaction is altogether absent, the plant appears to be normal. Symptomless carriers of this sort are common among plants and their existence greatly complicates the study of virology *(31)*.

The effects of a virus on a plant is either localised, for example, in an inoculated leaf, or it becomes systemic and spreads throughout the host. When the effect is local, it generally appears as a necrosis, leaf mottling or vein

* This section has been revised by L. M. Hutchins.

clearing. When the effect is systemic, the virus moves through a particular tissue such as the phloem and the rate of movement accordingly is either rapid or slow, depending on the kind of tissue which transmits the virus *(31)*.

Plant viruses are able to mutate and so to form various strains or biotypes. Some mutant strains are less virulent than either the original virus or other mutants. Differing degrees of resistance or even immunity to a particular virus or strain are shown by certain plants. Such resistance to virus attack is apparently not imparted by antibodies as in animals. Induced or acquired immunity is known to occur in some plants *(32)*.

Viruses are transmitted naturally from one plant to another in five different ways, namely, (i) by insects, mites or nematodes, (ii) by contact, (iii) by seed, (iv) through the soil and (v) by vegetative propagation. The commonest means is by insects. Transmission by seed and through the soil is uncommon. Artificial transmission can readily be brought about by various means, such as inoculation through abrasions or wounds in the plant tissue, and by budding and grafting *(31)*.

The relationship between plant viruses and their insect vectors is not fully understood, for example, the reasons are not known why some viruses are insect-borne and others are not, and what are the changes that go on during the incubation period of a virus within the vector insect's body. Insect vectors show specificity in regard to the particular viruses that they are capable of transmitting. Some viruses persist in the insect's body for a long time, others disappear within twenty four hours *(31)*.

Plant diseases caused by viruses are controlled by the following general methods: (i) quarantine to prevent entry, (ii) elimination of the sources of virus infection, (iii) elimination or avoidance of the insect vectors, (iv) growing only resistant varieties of the crop plant, (v) curing of the virus infected plants and (vi) vaccination of the crop plant with a non-virulent strain of the same virus. The last named method is at present rather academic and is not yet practicable *(31)*.

CACAO VIRUS

(I) WEST AFRICA: (GHANA, NIGERIA AND THE IVORY COAST)

A complex of viruses is the cause of Swollen Shoot disease of cacao in West Africa which first appeared in Ghana around 1920 and later in Nigeria and afterwards in the Ivory Coast. The severity of the attack can be gauged by the facts that, between the years 1939 and 1945, the death rate in the cacao population in Ghana was over five million trees a year and that, during the period 1945 to 1951, nearly twelve million cacao trees were cut out in an attempt to control the disease *(30)*. The true virus nature of the disease was not established in Ghana until 1938 *(14)*.

At least three different West African viruses, each having several distinct strains, have been identified *(15) (33) (37)*. They comprise three groups, namely, (i) swollen shoot virus, (ii) mottle-leaf virus and (iii) necrosis virus.

(i) *Swollen Shoot virus:* This is now widespread in Ghana, Nigeria and the Ivory Coast. It is unrelated to the other two viruses as proved by protection tests *(28).* Besides producing the characteristic swellings on the shoots and the roots of the cacao tree, this virus also causes a red vein banding on the young leaves and a reticulate mozaic on some of the older leaves caused by vein clearing and banding alongside and between the main veins. This virus is transmitted by several species of mealybug, notably *Pseudococcus njalensis, P. citri* and *Ferrisiana virgata (14) (22) (24) (26) (34).*

The disease first spread onto the cacao from certain forest trees belonging to the Malvales and the Tiliales which were left standing when the cacao was originally planted.

(ii) *Mottle-leaf virus:* This occurs in Ghana outside the main area affected by the Swollen Shoot virus disease. It occurs also over scattered areas in Togoland and in the Trans Volta district, and in Nigeria. It is unrelated to the other two viruses. The symptoms comprise red vein banding and mottling, both on young and old leaves, caused by vein clearing alongside but not between the main veins. The virus does not cause shoots to swell. The virus is transmitted by several species of mealybugs but not by *Ferrisiana.* The host range, like the last, is restricted to the Malvales and the Tiliales, notably the baobab *(Adansonia digitata).*

(iii) *Necrosis virus:* This virus is restricted to south-west Nigeria. It is unrelated to the other two viruses. It does not cause swollen shoot. The symptoms comprise necrosis of young leaves, without vein banding or clearing or leaf mottling, and also leaf distortion. The virus is not transmitted by mealybugs and outbreaks spread slowly.

Effects on the cacao trees: The caaco trees involved in an outbreak of virus disease have been found often to be infected with different viruses or strains of virus at the same time, and individual trees often show differing degrees of severity of attack, judging by the varying expression of the visible symptoms *(27) (28).* Besides the stem and leaf symptoms caused by virus infection, cacao trees affected by virulent strains produce small and rounded pods which are sometimes mottled dark green or, when exposed to sunlight, pink on the outer surface *(17) (19) (2).* Infected seedlings have abnormally small leaves *(6).* Infected trees are generally less vigorous than healthy trees *(5) (27) (28).* Yields gradually diminish in diseased trees. Virus infected trees often live for many years, particularly when the strain is a mild one. When infected by a virulent strain, and especially when the trees are also attacked by capsids, the trees deteriorate rapidly, shed their leaves and eventually die.

Transmission: The only kind of natural transmission responsible for the spread of cacao viruses are mealybugs *(14) (22) (24) (26) (34) (36).* None of the virus isolates that has so far been tested has been transmitted by sap inoculation, although possibly a suitable technique might eventually be elaborated *(37).* The virus is not seed borne nor soil borne *(19) (30) (37)* nor is it spread by mere contact between infected parts of the cacao plant.

The mealybugs feed mainly on the young shoots occurring on the periphery of the tree and as many as 2000 mealybugs sometimes occur on a single tree.

They walk from one tree to another in contact with it and thus spread infection. They are also blown by winds and in that way they set up new centers of attack. The most common method of dispersal, however, is by ants *(Crematogaster)* which tend the mealybugs and carry them bodily from one place to another. The ants build protective tents over the mealybugs. Before they become infective, the mealybugs must feed on a virus-containing plant for several hours. The virus persists in the insect for only a short time, probably in most cases less than one hour, after which time it becomes ineffective *(37)*.

Hosts of cacao viruses. Cacao viruses have been found to occur in a large number of indigenous forest trees in West Africa. They evidently spread in the first place from the forest trees *(21)*. Afterwards, they are passed on from one cacao tree to another and so the rate of spread increased rapidly. The origin of the three main groups of cacao virus cannot have been one common source since they are distinct and not related. Probably several different foci of infection were involved *(21)*. Virus-infected forest trees have been identified many miles away from centers of cacao virus infection. The species of trees that are susceptible to virus infection belong to the families Sterculiaceae, Bombacaceae and Tiliaceae of the Tiliales, and Malvaceae of the Malvales *(25) (37)*. The commonest susceptible trees are species of *Ceiba, Adansonia* and *Cola,* apart from species of *Theobroma*.

The experimental testing of forest trees is most conveniently carried out by the cacao bean method in which a single cotyledon is inoculated and the seedling plant produced by it afterwards inspected for symptoms of the disease *(20) (25) (26)*.

Control: This can be accomplished by (i) removing the sources of virus infection by cutting out diseased cacao trees, chopping them up and piling the pieces in heaps, (ii) replacing the cacao trees by clonal trees known to be resistant to virus disease *(36)*.

(i) *Removing sources of infection (16):* This method is being carried out on a grand scale in West Africa though its progress in the early stages was hindered by the non-cooperation of the cacao farmers. When over 30 percent of the trees are affected, this method applied alone is not effective. In addition to roguing out the infected trees, the first ring of symptomless trees around each outbreak center should also be cut out, dismembered and piled in heaps (burning is not necessary). The cacao trees immediately outside this ring should also be cut back or coppiced.

(ii) *Destruction of vector (36):* Direct destruction of the insect vector has been achieved by means of systemic insecticides, but this method has not yet been applied on a large scale *(11)*. The application of insecticides in the form of spray or dust is ineffective against mealybugs because of the protection provided by their waxy covering. Indirect destruction has been attained by killing the ants that tend the mealybugs. The best insecticide for this purpose has proved so far to be Dieldrin applied to the cacao tree trunks *(35)*.

(iii) Resistant clones: Different varieties of cacao have been found to vary in susceptibility to virus disease *(27)*. Certain Upper Amazon clones from Ecuador appear to be difficult to infect but reliable information is not yet available on the natural spread of virus within blocks of presumed resistant trees. The existing West African Amelonado cacao is highly susceptible to virus attack.

Selection among trees surviving in farms that have been devastated by cacao virus led to the discovery of mild strains which are able to protect cacao trees against more virulent strains. Infected pods and vegetatively-propagated planting material can readily spread virus disease *(36)*. Hence great care must be taken when planting up new areas of land or rehabilitating land which formerly grew cacao to use planting material which is not infected with virus.

NIGERIA: Virus is widespread in the cacao area of Nigeria which is less than one-quarter as extensive as that of Ghana. Some areas of infection have had to be abandoned *(9)*. Most of the virus isolates studied cause shoot swellings and some of the virus symptoms are severe *(37)*.

IVORY COAST: Cacao virus disease was first reported in the Ivory Coast in 1945 *(29)*. Several different strains of virus have been identified *(10)*. Some of these resemble strains occurring in Ghana and not all of them cause shoot-swellings *(29)*.

SIERRA LEONE: Cacao virus was reported in 1958 in Sierra Leone as a mild form occurring in peasants' farms *(37)*. The symptom is a mozaic of the leaves. Swollen shoot is absent. The outbreak probably started as a natural infection from *Ceiba pentandra*.

(II) CEYLON

The occurrence of a mild strain of cacao virus was first reported in Ceylon in 1950 *(13)*. The symptoms comprise vein flecking and vein clearing in the leaves, as well as swollen shoots. Later, swollen roots were also observed *(12)*. The round-pod symptom was noted in a few instances *(2)*. The leaf symptoms mainly take the form of oak-leaf mozaic similar to one of the symptoms of swollen shoot disease occurring in West Africa *(12)* The presence of virus has not visibly affected cacao yields and has not so far assumed virulence. One isolate of the virus has been found to be transmissible by mealybugs *(2)*.

(III) JAVA (INDONESIA)

Cacao virus has been reported to occur in Java *(37)*.

(IV) TROPICAL AMERICA

1. TRINIDAD: Cacao virus was first indentified in Trinidad in 1943 *(18)*. Two types of virus have been recognised, namely, strain A which causes a red mottling or banding of the leaves and pods, and strain B, which causes vein clearing and yellow banding of the leaves *(1)*. Swollen shoots and root necrosis have not been reported in Trinidad. The virus causes considerable reduction in yield of affected cacao trees *(4)*. The disease at present is confined to the western part of the Northern Range. The virus vector is mealybugs of which five species have been recorded, *Pseudococcus* citri being the most active. This insect is controlled in Trinidad by natural parasites and predators; consequently, it has not attained pest proportions. Control of the virus by cutting out infected cacao trees is less effective in Trinidad than in West Africa because of the large variation in the Trinitario tree population and the great length of the latent period of the virus in the cacao tree.

2. VENEZUELA: Cacao trees were noticed in 1944 having yellow leaf mozaic resembling the symptoms of virus disease, though quite distinct from the red mottling and vein clearing kinds observed on cacao in Trinidad *(23)*. The symptoms occur sporadically on scattered trees in cacao plantations situated in the Paria Peninsula in eastern Venezuela and so far appear to be confined to that area.

3. DOMINICAN REPUBLIC: A disease having the symptoms of a virus was described in 1930 as occurring in the Cibao Valley in the Dominican Republic long before swollen shoot was identified in West Africa as a disease caused by a virus *(3)*. The disease described causes distortion and narrowing of the leaves and the irregular indentation of their margins. The newest leaves are reduced in size. Later a mozaic pattern develops. Affected trees are scattered sporadically within the cacao area. The disease has been artificially transmitted by budding.

3. COLOMBIA: A disease similar to that described as occurring in the Dominican Republic has been reported as occurring in the Cauca Valley of Colombia in the vicinity of Palmira *(3)*.

4. COSTA RICA: Symptoms of a virus disease of cacao, provisionally named cacao mozaic *(8)* were observed in Costa Rica at Turrialba and at La Lola in 1958 *(7)*. They consist of chlorotic spots and streaks and vein clearing in restricted areas of the leaves, together with distortion of the lamina. The disease is not thought to be connected in any way with the Cushion Gall disease, though the symptoms of both diseases often occur on the same tree. Transmission tests are in progress *(8)*.

The symptoms appear to resemble those described for virus-infected cacao in Venezuela. The young leaves show large lesions having green centers and red margins. Lesions also occur on old hardened leaves and consist of vein constrictions which form a reticulate pattern. Abundant aphids usually occur on the affected trees and they possibly are the transmitters. The disease is spreading in Costa Rica.

THE NEED FOR QUARANTINE MEASURES*

Urgent need for the setting up of central quarantine stations for the purposes of testing and distributing cacao planting material is evident because of the increasing demand for new types, particularly disease resistant types, of cacao in countries where cacao growing is rapidly expanding or where, as in West Africa, new kinds of planting material are being developed for planting out in cacao areas that are being rehabilitated. The quarantine station set up by the U. S. D. A., at Coconut Grove in South Florida proved not be satisfactory, mainly because of the risk of damage by frost to the cacao trees. This station is now being moved to a non-cacao growing area at Mayaguez in Puerto Rico.

The efficiency of a quarantine station depends on its having a fully qualified staff of specialists who are able readily to recognise the symptoms of virus infection appearing on test plants, cuttings or buddings, as soon as they appear. Most of the obvious features of already well-known viruses will be recognised by the resident pathologists working at the places of origin of the planting material which is being sent from the different cacao-growing countries that are using the Station. The real problem at the Station itself will be to recognise mild symptoms that might be restricted to a few leaves. This requires the attention of specialists who have had long and varied experience of the different viruses that affect cacao, and who will be fully familiar with all the available techniques required for testing, for example, controlled insect transmissions, budding and grafting. For investigating transmission by insects, special insect proof cages will be required.

The only viruses of cacao that are at present well known are those occurring in West Africa and Trinidad. Other viruses that are lesser known and have been described only in a preliminary manner should first be fully investigated, especially those that have recently been discovered in Central and South America. The true virus nature of these occurrencies should be verified, the properties of the viruses should be described, the vectors responsible for their natural transmission should be identified, their symptom expression when they are transferred to the chief commercial types of cacao should be noted, and the most sensitive indicator plant should be sought for.

Ideally, such work should be carried out at an international central quarantine station as it is unlikely that it could be undertaken by the governments of all the countries where cacao virus diseases occur or are likely to occur. The main flow of new cacao planting material is from Central and South America to West Africa and countries east, and an ever-increasing demand for improved selections is likely to arise in the near future. Merely to transfer cacao selections that might be infested by what appears to be only a mild strain of virus, say from South America to West Africa where it might prove to be extremely virulent when transmitted to the widespread Amelonade cacao of that country, would be risky if not highly dangerous.

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* This section is based on a memorandum prepared by T. W. Tinsley, W. A. C. R. I., Ibadan, Nigeria, Dec. 1959.

SUMMARY

1. A general account is given of the main characters of plant viruses and of their effects on plants, their mode of transmission and methods used for their control.

2. The viruses that attack cacao trees in West Africa are described. They comprise a complex consisting of at least three unrelated main types each having several strains.

3. The effects of the cacao viruses on the stems, leaves and pods of the cacao tree are mentioned. Only one of the three chief viruses causes swollen shoot.

4. The natural transmission of caaco viruses is outlined. The main vector is mealybugs which are tended by ants. Transmission by contact, by seed, and through the soil does not normally occur.

5. The cacao viruses apparently originated in infected indigenous forest trees and several foci of infection were involved. Subsequent spread to the planted cacao areas by mealybugs and wind was extremely rapid.

6. Control consists in (i) removing sources of infection, (ii) destroying the insect vector by systemic insecticides or killing the attendant ants by contact insecticides and (iii) planting selected resistant cacao clones.

7. The occurrence of cacao viruses in Nigeria, Ivory Coast and Sierra Leone, West Africa, is mentioned.

8. The occurrence of cacao viruses in Ceylon and Java, and in Tropical America (Trinidad, Venezuela, Dominican Republic, Colombia and Costa Rica) is briefly described.

9. The types and strains of cacao virus occurring in Latin America do not include virulent kinds that produce swollen shoots. Their symptoms are mostly restricted to vein clearing and vein banding, chlorosis and distortion of the leaves of the affected cacao trees.

10. The urgent need for a central quarantine station for testing and distributing cacao planting material is mentioned in particular relation to virus disease.

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CHAPTER 22

INSECTS IN RELATION TO CACAO*

INTRODUCTORY

Cacao is a good example of a crop plant that suffers from severe attack by insects and yet at the same time depends on insects for the production of a crop. For this reason, the complete extermination of insects in a cacao plantation would result in economic disaster. Besides pollinators, other beneficial insects occur in cacao fields, namely, predators and parasites, which destroy insects that attack the plant. Harmful insects comprise many thousands of species but only a few of them are important pests because most of the harmful insects are reduced to small numbers by natural control owing to the activity of beneficial insects and to certain environmental conditions which ensure the vigorous growth and possibly the resistance of the host plant to insect attack. In addition to harmful insects that invade the cacao tree, other insects infest cacao beans in storage, both on the plantation and overseas, and occasionally they infest even the finished chocolate in the retailer's shop. Finally, many species of insects are known to be carriers, or vectors, of fungus and virus diseases, for example, mealybugs, certain species of which transmit Swollen Shoot virus in West Africa.

It is evident from these considerations that insecticides should be used in the cacao plantation with extreme caution and great discrimination, otherwise beneficial insects will be destroyed along with the pests, thus upsetting the balance of nature to the detriment of the crop.

HARMFUL INSECTS (INSECT PESTS OF CACAO)

Classification: The total number of important plant-feeding insects species that occur in the cacao plantation is probably less than ten. They belong to the following groups:

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* This chapter is based mainly on notes prepared and used in lectures given in the Cacao Course by E. Dresner, I. C. A., U. S. O. M. San José, Costa Rica, and also partly on notes prepared and used by G. Berg, F. A. O., Nicaragua, who has also taught in the Cacao Course.

ORDER		GROUP	COMMON NAME
(1)	Hemiptera	Capsidae (Miridae)	Capsid bugs
(2)	Homoptera	Aphididae	Aphids, plant lice
		Coccidae	Scale insects
			Mealybugs
(3)	Thysanoptera	Thripidae	Thrips
(4)	Hymenoptera	Formicidae	Ants
(5)	Lepidoptera	(Many groups)	Caterpillars of butterflies and moths
(6)	Coleoptera	Scarabaeidae	Scarabid beetles
		Chrysomelidae	Chrysomelid beetles
		Curculionidae	Snout beetles

Insects whose larvae bore into the cacao pod are also important in some parts of the world, for example, West Africa. These too mostly belong to the Lepidoptera, as do also insects of the cacao store.

Habits: In considering the damage done to the cacao tree by insects, it is perhaps most convenient to group them according to their habits, that is, the parts of the plant on which they feed, as follows:

(1) INSECTS THAT ATTACK BOTH PODS AND YOUNG SHOOTS

Capsids: The chief cacao capsid species that occur in Central and South America belong to the genus *Monalonion*.* Both adults and nymphs suck the sap of the pods and the young green shoots. When feeding on the pod, the tissue around the puncture becomes depressed and black in color. When numerous, the pod punctures cause the shell to break and the beans are then spoiled. Moreover the punctures form avenues for invasion by disease fungi. The life cycle of *Monalonion* is about 35 days.

The chief cacao capsids of West Africa, which are very serious pests, are *Sahlbergella singularis* and *Distantiella theobroma.* These insects lay eggs in the pods, pod-stalks and leafy twigs. The nymphs hatch out in 15 days. The adults appear in 25 days more and begin to lay eggs after 7 days and continue to do so for six weeks, after which they die. The pods become extensively spotted during attack but they are seldom seriously damaged, though the twigs are greatly injured, not solely by the insects, but also by a fungus called *Calonectria* which enters the punctures and destroys the shoots. Damage done to cacao trees by capsids in West Africa is associated with breaks in the canopy whose formation normally preceeds the attacks and are mostly caused by adverse water relations or by fallen shade trees *(23).* Where cacao is grown without shade,

* The name of this genus is sometimes spelled *Monolonium.*

the capsids themselves cause the breaks and the damage to the shoots imparts a stag-headed appearance to the cacao *(23)*. These two West African capsids do not occur in the western hemisphere.

Another widespread capsid in cacao common in Indonesia and Ceylon is *Helopeltis sp.* This is most abundant in the wet season but disappears in the dry season. The cacao capsids of the western Hemisphere closely resemble *Monolonion* in their life cycles.

Thrips: Cacao thrips *(Selenothrips rubrocinctus)* is a small black sucking insect whose nymphs are yellow and have a conspicuous red band across the abdomen. Attacked pods become russet brown in color, making it difficult to determine when they are ripe. In the West Indies, thrips mostly attack the shoots and lay their eggs on the underside of the leaves. The drops of voided excreta when they dry leave brown spots, causing marked speckling. In Trinidad, the thrips population increases greatly as the wet season advances. This has been attributed to the fact that the leaf cell-sap becomes more acceptable to the insect through retarded protein synthesis as growth conditions deteriorate *(6)* and in certain cases, appears to be associated with potash deficiency in the leaves *(7)*.

(2) INSECTS THAT ATTACK LEAVES AND YOUNG SHOOTS

Ants: These damage cacao trees either (i) directly by cutting the leaves, or (ii) indirectly by tending and protecting certain insects against attack by predators. The first are called parasol ants (for example, *Atta cephalotes*). They build large earth mounds from which they make runs that lead to the trees being attacked.

The second include the enxerto ant of Brazil *(Azteca paraenis)* which makes large nests in epiphytes and protects mealybugs and other scale insects which weaken the trees by sucking the sap. It feeds on the honeydew which these insects excrete. It builds covers over them made of paper-like material. The enxerto ant also damages young shoots by making incisions that exude a gummy substance which they use in making the covers. The injury causes broom-like out-growths to develop and eventually the affected tree dies.

(3) INSECTS THAT ATTACK LEAVES

Beetles: Adults of the scarabid and chrysomelid beetles cause considerable damage to young cacao plants, feeding during the night and making holes in the leaves, for example, *Adoretus* sp. which is a serious pest of cacao in the eastern hemisphere *(21)*.

Butterflies and moths: The larvae (caterpillars) of a very large number of species of butterflies and moths attack cacao leaves, but only one species has ever been found to be sufficiently abundant to cause serious damage *(11)*. Almost all of the leaf-feeding caterpillars feed only on young flush leaves. The amount and frequency of flushing, as has already been demonstrated, are largely controlled by temperature which is an environmental circumstance. This fact may explain why the numbers of caterpillars are often small in cacao growing under satisfactory ecological conditions.

Aphids: Certain aphids also attack cacao leaves, for examp'e, species of *Toxoptera (12).* When abundant, they cause distortion and wilting of the flush leaves. *Weevils* and *grasshoppers* also eat the edges of cacao leaves.

(4) INSECTS THAT ATTACK PODS

Moths: The larvae of two species of moths, namely, *Acrocercops cramerella* and *Characoma strictograpta,* are pests of cacao in Indonesia and West Africa where they severely damage cacao pods, though they do not attack the beans inside. They retard pod growth and development and provide an entry for fungi. The eggs are laid in the pod furrows in the first case and in the stalk end of the pod in the second case. Several other insects also attack cacao pods but none does much damage.

(5) INSECTS THAT ATTACK THE TREE TRUNK

Beetles: Species of longicorn beetles occur in most cacao growing countries and do considerable damage to the trees. The chief is *Steirastoma breve* (cacao beetle) which is a fairly large black insect having long antennae. The adult female makes holes in the bark in which she lays eggs and then seals them up. The larvae feed on the bark and make tunnels in the wood, sometimes ringing the branches or trunks, especially those of young trees. Cacao beetles lay eggs preferably in cut and creviced bark rather than in smooth bark. They visit unshaded trees rather than shaded trees. This has been explained by the fact that soluble carbohydrate is more abundant in trees fully exposed to light *(5).* Several other species of longicorn beetles also damage the bark and wood of cacao trees, for example, *Glena novemguttata* and *G. aluensis,* and various species of *Monochamus (21).*

Moths: In some countries, lepidopterous borers cause damage to young cacao but they are not usually so serious as the coleopterous borers mentioned above.

(6) INSECTS THAT ATTACK DAMAGED BRANCHES AND TRUNKS

Beetles: The most important of the beetles that attack damaged cacao wood are species of the borer beetles, *Xyleborus* and *Platypus,* which are closely and perhaps causally associated with the disease fungus, *Ceratostomella (9) (22).* It is not yet decided, however, whether this borer can attack healthy wood and so make way for the fungus, or whether the wood has to be softened first by fungus attack before the beetle is able to bore into it. No less than seven species of *Xyleborus* and three of *Platypus* have been encountered in cacao plantations *(9)*.

Termites (Isoptera): These normally attack only the dead wood of the cacao tree which they enter through wounds caused by other insects. They prevent wounds from healing by hindering callus formation and thus in some cases bring about the death of the tree *(21)*.

(7) INSECTS THAT ATTACK ROOTS

The larvae (grubs) of certain beetles, for example, species of *Phyllophaga, Lachnosterna, Adoretus* and *Anomala,* eat the young roots of cacao and the adults also attack the leaves. Weevils such as the fiddler beetles (*Pachnaeus* and *Prepodes* species) are cacao pests in Jamaica and have this habit.

(8) INSECTS THAT ATTACK CACAO BEANS IN STORAGE

These mainly comprise species of *Ephestia, Lasioderma, Araeocerus,* and *Trilobium (14)*. The first is a moth and the rest are beetles. The larva of *Ephestia* spends its whole life within the cacao bean which it fouls by its excreta. The adults emerge in the cacao storage overseas and enter the chocolate factory and there lay eggs on the chocolate, if not prevented from doing so. The larvae of the beetles pass their lives within the bean. The beetles are also pests of other agricultural products such as cowpeas, copra, palm kernels and various cereal grains *(14)*.

INSECT VECTORS OF CACAO VIRUS

Vectors of cacao virus, as far as is known at present, all belong to the Coccidae and mainly comprise species of *Pseudococcus* (mealybug). Early reports of aphid vectors have not been confirmed. All but one of the 15 virus strains so far tested in West Africa are transmitted by *P. njalensis, P. citri* and *P. bukobensis.* All but two can also be transmitted by *Ferrisia virgata,* and *P. longispinus* can transmit these two *(21)*. In Trinidad, four different coccid genera transmit the Trinidad virus *(10)*. Cacao viruses are the only ones known to be spread by Pseudococcidae which have several characteristics that are unusual among virus vectors, for example, sedentary habits, inability to fly (the males fly but are not vectors of virus because they do not feed on the leaves of cacao) and obligatory ant attendance. *Pseudococcus njalensis* is the commonest vector in Ghana; all the other species, with the exception of *P. citri,* are seldom found in large numbers. At least 108 different plant species are suitable as hosts for the mealybugs and therefore virus incident in any one of them can readily be transmitted to cacao as alternative host.

The ants that tend the mealybugs build cartons or mud tents over them and thus protect them from attack by predators and from contact with insecticidal sprays. Some 75 percent of the mealybug colonies are ant tended. The most common attendant ant in Ghana is *Crematogaster striulata*. The ants feed on the honey dew secreted by the mealybugs and by so doing prevent it from becoming infected by certain mould fungi which might involve and destroy the mealybugs themselves if allowed to develop. The ants carry the young mealybug nymphs to fresh feeding grounds and so indirectly cause the spread of cacao virus *(20)*. The movements of *P. njalensis* are sluggish at temperatures below 23.5º C (74ºF) *(14)*. Activity increases greatly at temperatures higher than this, and consequently it is greatest during the afternoon. Thus the density of the nymphs increases upward from the base of the cacao tree trunk, reaching a maximum a few feet below the top of the canopy *(4)*. Activity is greatest in general during the dry season in Ghana when the temperature frequently rises to 32ºC. Nymphs travel about 28 feet in search of suitable feeding sites and can only pass from one tree to another when the tree canopies are touching. Occasionally the nymphs are carried by ants *(4)*. Pruning, wide spacing and the inter-planting of a crop other than cacao, for example, Robusta coffee, consequently provide means for reducing or preventing nymphal migration and therefore stop the spread of cacao virus *(4)*.

CACAO POLLINATORS

The pollination mechanism of cacao is imperfectly understood. A peculiar feature of it is the enormous number of flowers that are not pollinated. The proportion of pollinated flowers is seldom greater than 5 percent of the total number of flowers produced *(21)*. The structure of the cacao flower seems to be such that none of the regular means of pollination is really appropriate. The flower does not have any scent nor nectar to attract insects, and its pollen is too sticky and the anthers too rigid to allow wind pollination *(21)*. Furthermore, the position of the anthers, hidden as they are within the pouched petals, and the ring of staminodes around them hindering access to the stigmas, are features that would appear not to facilitate pollination by most known insects *(21)*. Nevertheless, investigations carried out by several observers since 1925, have shown fairly conclusively that several different insects are actually involved in the inter-pollination of cacao flowers *(8) (18) (1) (13) (3)*.

Self pollination of cacao is affected by various kinds of crawling insects, for example, thrips and aphids, but these do not solely comprise the kinds of insects that visit the flowers, as is proved by the fact that, when a section of a trunk carrying flowering cushions is isolated by sticky bands placed around it, several of the flowers nevertheless are pollinated, presumably therefore by some flying insect *(21)*. It is known that many varieties of cacao are self-incompatible, that is, they do not set fruit when pollinated with their own pollen, yet they produce cacao pods abudantly. Clearly, therefore, some winged insect or insects must be involved in cacao pollination *(3)*.

It was found in Trinidad in 1941 (1) that two ceratopogonid midges *(Forcipomyia quasi-ingrami* and *Lasiohelia nana)* frequently visit cacao flowers. Other species of the same genera have since been found doing so in West Africa *(13)*. Doubtless other species and other genera will be found visiting cacao flowers when further careful observations are made. In Costa Rica, three different insects have been found to pollinate cacao other than species of *Forcipomyia,* one of which is a thrip *(17)* another an ant and the third a honey bee.

The breeding places where the larvae of *Forcipomyia* are mostly found in cacao plantations are moist situations where bacteria, yeast and moulds flourish *(15)* for example, in the leaf axils of bromeliads and other epiphytes, in wet moss growing on tree trunks, or in soil, and particularly in the wet dead leaf mats that cover the soil surface *(15).*

In order to test the possibility that the use of insecticides might reduce pollination by destroying pollinating insects, an experiment was started at La Lola, Costa Rica, in which plots of mature cacao trees are severally treated by spraying once a month with two different insecticides with and without the addition of Bordeaux mixture.* Some plots were left untreated as control. One tree in each plot was artificially pollinated by hand twice a week. Each treatment involves about 210 trees. So far, little difference has been observed between the average number of pods collected from each plot within a period of 18 months' duration. Hand pollination was successful in 46 percent of the flowers that were pollinated and 30 percent of these produced mature fruits. Only 14 percent of the hand-pollinated flowers produced pods and these did not appreciably affect the yield. Evidently therefore lack of adequate pollination is not the limiting factor in cacao production at La Lola.

ANIMALS OTHER THAN INSECTS WHICH ATTACK CACAO

Monkeys, squirrels and rats are attracted to ripe cacao pods into which they bite and extract the seeds. They suck the sweet mucilage and spit out the seeds which they do not eat, probably because of their bitter taste. In this way cacao is spread naturally, for the pods do not fall to the ground otherwise, nor do they dehisce on the tree. These animals sometimes become serious pests when they occur in large numbers and need to be controlled by shooting, snaring or by the use of poison bait such as "Warfarin", one part of a 5 percent concentration mixed with 20 parts of maize meal.

Parrots and wood peckers and certain other birds occasionally damage cacao pods by making holes in them which allow disease fungi to enter.

Snails do damage to young cacao in Ceylon where they infest some cacao plantations in large numbers.

CONTROL OF INSECT PESTS OF CACAO

(A) NATURAL CONTROL

The natural enemies of insects include other insects which are either predatory or parasitic in habit. Predators devour the bodies or the eggs of their prey or suck their blood. Parasites lay eggs on the bodies of other insects

* Guide to La Lola Experiment Station, March, 1960, pp. 12-14.

or inside them. The larva lives on the blood and body tissues of the host. When fully grown, it emerges and makes its pupal cocoon on the surface of the dead or dying host, and the adult in due course emerges from the pupa, thus completing the life cycle of the parasitic insect.

The various ecological factors operating in the environment of the cacao tree, not only control the physiological processes that are manifest in bud-bursting, leaf-flushing, flowering, fruit-setting, pod-growth and pod-maturation, but also in the inter-relationships that occur between the host plant and the various pathogenic organisms (fungi, bacteria, viruses) and harmful insects that attack it and cause severe damage to its various parts, resulting in greatly diminished crops. These same ecological factors also partly control the inter-relationships between the insects that act as predators and parasites on other insects and their hosts.

Predators: The most important predators belong to the following insect orders and groups. The particular group or groups that are represented within a cacao plantation depends on the prevailing ecological conditions. Some of the predators suppress, not only certain insect pests, but also mites (Acarina) which are not insects but Arachnida which includes the spiders.

	ORDER	GROUP	COMMON NAME
(1)	Neuroptera	Chrysopidae	Lace wing flies
(2)	Coleoptera	Coccinellidae	Lady bugs, lady birds
		Carabidae	Ground beetles
		Cicadellidae	Leaf hoppers
		Staphylinidae	Rove beetles
(3)	Diptera	Syrphidae	Syrphid flies
		Asilidae	Robber flies
(4)	Hymenoptera	Formicidae	Ants
		Sphecidae	Sphecoid wasps
		Vespidae	Typical wasps
(5)	Dermoptera	——	Earwigs
(6)	Orthoptera	Mantidae	Praying mantis
(7)	Hemiptera	Reduvidae	Assassin bugs
		Anthrocoridae	Flower bugs
(8)	Thysanoptera	Tubulifera	Thrips

Parasites: The most important parasites of cacao insect pests comprise a much greater number of species of insects than the predators but they belong to fewer orders. Commonly, two or three different species of parasites attack each of the immature stages of the insect host. Few parasites (except those that attack certain species of Aphididae (aphids) and Coccidae (Mealybugs)) are found attacking adult insects. The chief orders and groups to which the parasites of cacao-feeding insects belong are:

ORDER	GROUP	COMMON NAME
(1) Diptera	Tachinidae	Tachinid flies
(2) Hymenoptera	Ichneumonidae	Ichneumon wasps
	Brachonidae	Brachonid wasps
	Chalcididae	Chalcid wasps
	Cynipidae	Cynipid wasps

The parasitic Diptera affix their eggs to the body surface of the host or distribute them over the foliage of plants. The larvae which emerge then attach themselves to passing caterpillers. The parasitic Hymenoptera mostly lay their eggs in or on the body of the host. There may be between one and one- hundred individual parasites within the body of a single host insect, depending on the species of the parasite.

Biological control: Attempts have frequently been made to increase the number of predatory and parasitic insects that prey on cacao pests by breeding them out in special cages and releasing them in large numbers into the cacao fields. Unless the environmental conditions are entirely suitable to their existence, however, they usually die off without effecting appreciable control. Some parasites have hyperparasites that attack them and these frequently account for the rapid reduction in numbers of cage-reared parasites released into cacao fields.

In practice, this method of increasing the number of predators and parasites is normally not recommended. Biological control is more frequently successful where it consists in deliberately introducing new insects imported from regions or countries far distant from the plantation where the indigenous pest insects do not exist. This procedure involves the risk of also importing hyper-parasites and it should therefore be carried out by or under the guidance of trained entomologists.

Entomophagous fungi: Certain fungi, for example, *Aspergillus spp.,* are capable of reducing the numbers of insects of various sorts, including some that are pests of cacao. Attempts have been made to control cacao pests in Ghana by releasing insects artifically contaminated with *Aspergillus* spores into the cacao field but so far without success.

The employment of disease fungi and other disease organisms for controlling insect pests is still a new field for research. Under natural conditions, epidemic outbreaks of insect pests are frequently automatically controlled by fungus, virus, bacterial and protozoan diseases. The best procedures for distributing such disease organisms in the field are now being investigated.

Effect of weeds: The presence of weeds in or near cacao fields is particularly harmful in that weeds harbor cacao-feeding insects. Many of these insects leave the trees during the hottest part of the day and hide in the weeds or, in some cases, in the soil. The removal of weeds is therefore an important operation in the proper cultivation of cacao.

Cultural treatment and orchard sanitation: The control of insect pests of cacao can partly be effected by careful attention to special cultural treatments including manuring, and to certain aspects of plantation management sometimes referred to as *orchard sanitation.* This mainly consists in controlling weeds, destroying or burying cacao residues, such as fallen dead branches, prunings and cacao husks that have been broken and left in the field after extracting the beans. Husks should be dusted with slaked lime if not buried. Fallen branches and prunings should be buried in trenches dug between the cacao rows. They have considerable manurial value when they decompose.

(B) ARTIFICIAL CONTROL

The use of powerful insecticides, such as are available at the present day, for destroying harmful insects in the cacao plantation is fraught with extreme danger because it may also destroy beneficial insects comprising predators, parasites and pollinators. The spraying and dusting of insecticides onto the leaves of cacao trees generally cause greater destruction of predators and parasites than of harmful insects. This is because the beneficial insects are much more mobile, continually running over the plant in search or prey to attack, whereas the harmful insects usually stay in one place for long periods, sucking or eating the soft succulent tissues but changing their position only occasionally when moving to fresh feeding grounds. Parasites that lay their eggs in or on host insects, move quickly from one host to another, but predators normally take a little longer time to kill and consume their prey. Because of this great danger of destroying useful insects, spraying and dusting operations in cacao plantations should be most carefully planned and executed.

If at all possible, the application of insecticides to the foliage should be strictly avoided. The cost of insecticides is high and much skill is needed to apply them effectively yet economically by avoiding waste. Ideally, an insecticide should be applied only at that particular stage in the life cycle of an insect when it is not causing any damage to the plant, or when it is not in any way associated with it. Many insect pests of cacao spend part of their life in the soil or on the soil surface, for example, the larvae or grubs of beetles that either feed partly on roots or lay their eggs in the soil. Certain sucking bugs, for instance *Monolonion,* leave the plant in the hottest part of the day and hide among the weeds or surface litter and débris that cover the soil. Leaf-cutting ants make their nests within the soil which they excavate and bring up to the surface to form mounds.

The only important feeding insects which attack cacao trees that are not associated with the soil are the Homoptera and Thrips. Homopterous insects, however, are generally tended by soil-nesting ants which partially protect them from predators and parasites. Hence, by destroying the ants while they are inhabiting the soil, the sucking insects become exposed to agencies of natural control. Thus considerable success has been achieved in Ghana in the control of Swollen Shoot virus by destroying the *Crematogaster* ants which attend the mealybugs that act as vector for the virus, using formicides applied to the trunks of the cacao and forest trees *(19).*

Soil application of insecticides: Insect control which is effected by applying insecticides solely to the soil offers the following advantages:

(1) The activity of predators and parasites is less disrupted and reduced.
(2) The movements of pollinating insects that fly into the field from outside are not prevented (although the larvae of pollinators that live in or near the soil of the field may be destroyed).
(3) The cost of application of the insecticide is relatively low.
(4) The duration of the residual effect of the application is high.

In order to control leaf-feeding beetles and other cacao insect pests that lay their eggs in the soil, it is usually sufficient to treat only 10 percent of the surface area with an appropriate insecticide. This is effected by applying the insecticide in strips between the rows. Within one week of application a large proportion of the harmful soil-ovipositing insects will have been destroyed by this procedure because, by this time, many egg-laying adults will have come into contract wich the insecticide.

Trunk application: The application of insecticides to the lower parts of the cacao tree trunks up to height of about 25 cm. (10 ins.) apart from the fact that it is relatively cheap, is also effective in controlling several of the insect pests that pass upwards or downwards between the plant and the soil, for example, ants and some Homopterous insects. It may also partly control tree borers such as *Xyleborus* which emerge from the trunks periodically and thus come into contact with the insecticide *(22)*. The trunk surface should be sprayed, painted or dusted with insecticide and a substantial amount of the substance should be applied at the same time to the soil near the trunk in a ring to a distance outwards of about half a meter (20 ins.).

Systemic insecticides: Certain insecticides, implanted into the tree trunk, circulate within the plant and are absorbed in small quantities by sucking insects which they thereupon destroy. In some cases they are partly taken up by the tree if merely applied in solution to the soil surface. Such insecticides are described as systemic. They are mainly organo-phosphorus compounds. They are expensive and highly toxic to animals, including man. They should therefore be used with the greatest caution. In some cases, they enter the fruit and cause a taint or off-flavor, or leave a poisonous residue in the seeds unless the time of application is carefully chosen.

Systemic insecticides have the great advantage that they do not in any way affect predators and parasites of the insect pests of cacao nor the pollinators of the flowers and do not have any residual effects on them. They are being tried in Ghana for destroying mealybugs on cacao, but so far they have not been recommended for general use, even though they have proved to be highly effective in mealybug control. Investigations have also been carried out in Costa Rica to test the rate of translocation and the persistence of systemic insecticides within the caaco tree *(2)*. Off flavors were not detected in chocolate made from beans produced by cacao trees that had been treated with the particular systemic insecticides that were tested.

Use of chemical insecticides: In general, when the insect population of a cacao plantation has reached pest proportion, it can be assumed that the natural enemies are not present in sufficient numbers to effect control. Under these circumstances and when orchard sanitation and good husbandry have failed to produce any improvement, then recourse must be made to chemical insecticides in order to suppress the pests or, what is more important, to prevent their multiplication and spread. When these substances are skilfully applied at the correct time, with full knowledge of the life histories and habits of the insects that they are intended to destroy, the use of insecticides should be wholely advantageous. It is preferable nevertheless to carry out comparative field experiments with different substances before finally selecting any one of them, and to investigate different methods and times of application before undertaking large-scale operations for pest control. The manufacturers of insecticides issue descriptive literature giving full instructions as to how and under what conditions it is best to apply specific insecticides in the cacao plantation *(16)*.

Classification of insecticides: It is customary to group insecticides into four classes, namely contact, stomach, fumigant and systemic substances. This classification applies more to the older insecticides than to the new synthetic substances produced since the last world war. Many of these new products, for example DDT, are both contact and stomach poisons and some belong to all three classes, for example, BHC. Systemic insecticides are translocated within the plant.

Contact insecticides are used principally against sucking insects such as aphids, thrips and scales. Stomach insecticides are more effective against the larvae of moths, butterflies, beetles and other insects that devour leaf tissues. Fumigants are mostly used for killing insects infesting beans stored in closed places or in transit in the holds of ships. Systemics particularly destroy sucking insects.

Insecticides are applied either as dusts or sprays but usually they must be suitably diluted with some inert powder, such as talc in the case of dusts, or water or oil in the case of sprays. Wetting agents, emulsifiers, stickers and spreaders are often added to ensure proper solution, suspension or emulsification, and to increase adhesion and coverage.

Insecticides for cacao: Some examples of insecticides used at the present time to combat cacao pests are the following:

1. DDT (Dichloro-diphenyl-trichloro-ethane)
2. BHC (Gammexane; benzyl hexachloride)
3. Chlordane (a chlorinated hydrocarbon)
4. Toxaphene (a chlorinated camphene)
5. Dieldrin (a chlorinated naphthalene derivative)
6. Aldrin (similar to Dieldrin)
7. Endrin (similar to Dieldrin)
8. TEPP (a phosphorus compound; tetra-ethly-pyrophosphate)
9. Parathion (an organic thiophosphate).

DDT is chiefly used to control mosquitoes, horse flies and lice and is not commonly employed to suppress cacao pests. *BHC* has proved to be a powerful insecticide against capsids of cacao and has given good control in Ghana. *Chlordane* is used to destroy leaf-cutting ants and other soil inhabiting insects in cacao fields. *Toxaphene* is a slow-acting poison on caterpillars but is not often used on the cacao plantation. *Dieldrin, Aldrin* and *Endrin* are powerful general-purposes insecticides which are effective against beetle grubs that live on or below the soil surface and consume cacao roots. They can be used to control ants by dusting or spraying over the soil and onto the lower parts of cacao tree trunks. Stem borers can also be controlled by painting them onto the trunks. *TEPP* and other similar phosphorus insecticides are used as poisons against sucking insects such as mealybugs. They can also be used as sprays.

Apparatus: Application of insecticides in solutions or emulsions is nowadays carried out mostly by spraying, using low volume mist sprayers having specially-designed delivery nozzles *(16)*. Motor-driven knapsack pressure sprayers are favored for use in cacao plantations. Dusting is recommended for dealing with insect pests that hide in crevices in the trees and with highly mobile insects. Their small residual effect is an advantage in regard to their action on beneficial insects *(16)*.

SUMMARY

1. The different ways in which insects are related to cacao and affect its growth and production are shown in the following table.

   (A) *Beneficial insects*

   (i) Pollinate cacao flowers

   (ii) Destroy harmful insects

   (iii) Feed on weeds and diminish their competition with the cacao trees for water and nutrients.

   (B) *Harmful insects*

   (i) Reduce the vigor of the tree:
   (a) By sucking the sap
   (b) By eating the leaves
   (c) By eating the roots

   (ii) Transmit diseases:
   (a) By sucking infected plants and afterwards sucking cacao tissues.
   (b) By injuring the cacao tree, thus making an entry for disease fungi.

   (iii) Injure the tree:
   (a) By girdling the bark near the soil level

   (iv) Destroy beneficial insects, namely:
   (a) Predators and parasites of harmful insects
   (b) Hyper-parasites of predators and parasites of beneficial insects.

   (v) Directly reduce yield:
   (a) Suck the sap of flowers and prevent setting
   (b) Suck the sap of young fruits and cause fruit shedding or wilting
   (c) Damage pods and beans.

2. The most injurious pests of cacao in the world are capsids, chiefly *Sahlbergella* and *Distantiella* in the eastern hemisphere and *Monolonion* in the western hemisphere. The first two also act as vectors of disease fungi, for example, *Calonectria.*

3. Thrips are especially injurious in unshaded cacao and have spread to most parts of the world, though indigenous to the American Tropics.

4. Wood and bark-boring beetles, for example, *Steirostoma,* are destructive to cacao trees weakened by drought or other causes.

5. Ants are troublesome because they tend mealybugs which are the vectors of West African viruses. Leaf-cutting ants *(Atta)* and shoot-destroying ants *(Azteca)* cause severe damage, especially in Brazil.

6. Mealybugs are widespread in cacao-growing regions and cause much damage by sucking, but they are more important as virus vectors, for example, of Swollen Shoot disease ii West Africa.

7. Certain insect pests attack cacao beans in storage and during transit from plantations to factories overseas.

8. Rodents, birds and snails damage cacao in some countries.

9. Natural control of harmful insects operates in cacao plantations through the activity of insect predators and parasites which often occur in great numbers in cacao plantations and are represented by a wide range of different species. Their efficiency depends largely on the prevailing ecological conditions. They suffer loss through the indiscriminate use of insecticides.

10. Weed destruction and the elimination of vegetable residues aid in natural control.

11. Artificial control can be effected by the use of insecticides which, however, are costly to buy and to apply.

12. Insecticides should not be applied directly to the cacao foliage except when absolutely necessary, but rather to the soil in strips (10 percent coverage) and to the bottom parts of the tree trunks.

13. Some recently-discovered synthetic organic insecticides are mentioned and their classification, chief features and methods of application are briefly described.

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PART VIII:

CACAO BOTANY

CHAPTER 23

MORPHOLOGICAL BOTANY OF THE CACAO PLANT*

HISTORICAL

The cacao tree was cultivated in Mexico by the Toltecs and the Aztecs long before America was discovered. When Hernandez Cortez conquered Mexico he found that the Indians were using the cacao bean, not only as a material for making a beverage, but also as money. For one hundred cacao beans a slave could be bought and a rabbit for ten beans. The Aztecs believed that the cacao tree had divine origin and that Quatzulcault, their mythical prophet, sowed cacao seeds brought from Paradise in the gardens of the kings. The general belief existed that the partaking of cacao as a drink conferred discretion and wisdom. This idea caused Linneaus to give the name *Theobroma* to the genus which implies that it is the "food of the gods" *(12)*.

Chocolate (called chocolatl by the Aztecs**) was a privileged beverage of the royal household and of the nobles of imperial rank. It was made by grinding cacao and maize together in a stone mill, boiling in water and adding a little red pepper. The common people did not consume much of it because of the difficulty of obtaining the bean, but they used small amounts of cacao as a condiment in a drink called atolle which they made with maize meal. The kind of drinking chocolate used at the present time, which is mixed with sugar and certain aromatic substances, was invented by Spanish nuns in 1850. For some time, the preparation of chocolate was kept secret by the Spaniards but, around 1606, its use became common in Italy and later in other countries of Europe *(12)*.

The origin of cultivated cacao was Mexico and Central America according to reliable historical evidence. The Spaniards did not find it under cultivation in South America, but they came across it in many places in this region growing naturally in the forest alongside the tributaries of the Amazon and the Orinoco rivers *(19)*.

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* This chapter is based mainly on an account written by J. Soria who has lectured on botany in the Cacao Course.

** See Preface: Etymology and history of cacao.

MORPHOLOGY OF THE CACAO TREE

The cacao tree grows to a height of 6 to 8 meters (20 to 25 feet) except the Nacional cacao of Ecuador *(11)* and the Amelonado cacao of West Africa which sometimes grow as tall as 12 meters (40 feet). The size of the tree partly depends, however, on the conditions of growth. When it is grown in full sunlight, the tree is reduced in size. The natural habitat of cacao is the lowermost story of the Wet Tropical Forest. The seeds germinate within 10 to 15 days in the seed bed. The cotyledons are exalbuminous and epigeal and, together with the hypocotyl, are colored green on the outside through the development of chlorophyll. The first true leaves appear in 15 to 20 days after germination.

THE ROOT

The tap root, principal or primary root of the seedling tree tends to grow straight downwards into the soil. Its final length and shape vary greatly depending mainly on the structure, texture and consistency of the soil *(14)*. In well-aerated deep soil it grows to a length of about 2 meters (6½ ft.) *(15) (17) (18)*. When grown in stony soil the tap root becomes twisted or tortuous but when grown in soil having uniform granular structure and clayey texture it is straight. The tap root does not penetrate deeply into compact soil nor into soil in which a high water table exists during a large part of the year.* A definite collar occurs where the tap root meets the trunk. Most of the secondary roots arise just below this collar over a distance of 15 to 20 cm. (6 to 8 ins.) within the humic surface soil *(2)*. These secondary roots often extend for distances up to 5 or 6 meters (16 or 20 ft.) from the tree trunk *(17) (18)*. They grow out horizontally from the collar, give off side branches and divide repeatedly. Often they change direction abruptly at an acute angle, or frequently deviate from a straight line, depending on the presence of obstructions and irregularities in the soil material. Their terminals tend to grow upwards into the moist humic layer *(17)*. Secondary roots which arise low down on the tap root below the collar, on the other hand, tend to grow downwards in the direction of the parent rock or towards a water table *(14)*. Usually the middle part of the tap root is devoid of outgrowing secondary roots.*

In old cacao plantations, a dense layer or mat of intermingling and much-branching rootlets, originating from the ends of secondary roots arising from adjacent trees, can frequently be observed just below the decaying surface leaf litter with which the rootlets are in close physical contact, the association between the two possibly involving mycorrhizal fungi *(16)*. The occurence and the density and thickness of this root mat depend mainly on rainfall and soil permeability, the mat being densest and thickest where the rainfall is heavy and continuous and the permeability of the soil is low, because, under these conditions, the highest degree of soil aeration occurs in the superficial shallow layer of soil consisting of decomposing organic matter and soil crumb.** Possibly the feeding roots produce auxin (growth hormone) when well aerated *(14)*.

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* See *Chapter 8*: Cacao soils: pedological aspects.

** See *Chapter 8*: Cacao soils: pedological aspects, and *Chapter 4*: Water and air relations of cacao.

Root anatomy: A microscopical study of the anatomy of the primary and the secondary roots of cacao shows that a unique difference occurs in them, namely, that the metaxylem comprises six strands in the primary root but only four in the secondary root *(2) (3)*. The metaxylem strands alternate with groups of metaphloem vessels, being separated from them by parenchyma which disappears when secondary thickening begins. Some of the parenchymatous cells have large vacuoles filled with mucilage. The metaphloem is separated from the endodermis by a single layer of pericycle cells which form a distinctly hexagonal cylinder in the young primary root. The endodermis cells are mucilaginous. They consist of large parenchymatous cells and the single layered epidermal cells also contain mucilage. Root hairs are formed only on young lateral roots near their ends *(2) (3)*.

Secondary xylem consists of thick-walled, lignified, pitted tracheids together with non-lignified parenchyma and medullary ray cells. The xylem rays are numerous in the cacao root and are rectangular in section. They contain starch grains and mucilage. The rays end in the phloem tissue in which they widen out into a triangle, a characteristic feature of the Sterculiaceae. The secondary phloem consists of sieve tubes, companion cells, fibres, parenchyma and phloem rays, all of which are small in size. Cork cambium is initiated at different depths within the cortex and the phloem. The mature root is encased in cork layers which are progressively sloughed off *(2) (3)*.

THE STEM AND BRANCHES

The branches of the cacao tree, like those of other species of *Theobroma*, are dimorphic. One kind of branch grows vertically upwards (trunk and chupons) and the other obliquely outwards *(6) (7)*. The seedling grows as a single stem until it is one to 1½ meters (3 to 5 ft.) tall at the age of about 14 months. The terminal bud then stops growing and 3 to 5 lateral branches emerge apparently at the same level though each comes from a separate node *(2) (3)*. This whorl of lateral branches is called the jorquette (horqueta; molinillo). Criollo cacao frequently produces 3 to 5 laterals in a jorquette which, however, show a distinct space between their points of origin on the main stem whereas, in Forastero cacao, the laterals all come off at the same level *(12)*. When the tree matures, the bases of the laterals in any case form a single ring. Lateral branches grow out at an angle of approximately 45 degrees. Normally a chupon or new stem grows out just beneath the jorquette and, in due course, itself forms another jorquette or second whorl of lateral branches. The process is usually repeated, forming a third, or even a fourth jorquette or whorl *(2) (3)*.

Trunks or stems below a jorquette produce only chupons which morphologically are the same as stems. They bear leaves which in all cases have $^3/_8$ phyllotaxy. Branches of the jorquette, by contrast, bear leaves arranged in one rank only, with ½ phyllotaxy. They are accordingly called fan branches. They give rise to further fan branches or, under certain conditions, to chupons, for example, when they are pruned or accidentally wounded. At the base of a chupon is a root primordium which grows out vigorously into a primary or tap root when the point of insertion of the chupon is near ground level, or if moist soil or moss is packed around the chupon base *(2) (3)*.

Rooted chupon cuttings have the same habit as the stem and produce true tap roots but rooted fan cuttings develop adventitious root systems devoid of tap roots

They develop tap roots only from the bases of chupons which in due course generally grow out from fan branches of established fan cutting trees *(2) (3)*.

Stem anatomy: The anatomy of young cacao stems and branches resembles that of roots and shows similar developmental stages, both for chupon and for fan stem growths. A characteristic feature is the occurrence of large elongated cavities in the pith which are filled with mucilage. The cortex also contains numerous mucilaginous cells but they are shorter. The phloem, endodermis and pericycle tissues are hard to distinguish even in the young stems and branches. Secondary thickening in the stems is similar to that in the root *(2) (3)*.

THE LEAF

The cacao leaf carries two stipules which are shed early, a conspicuous petiole, bearing a swollen pulvinus at the base and another at the top, and a lamina. Stem leaf petioles are longer than branch leaf petioles. The leaf lamina is simple, lanceolate to nearly oval, with entire margin, pinnate venation and glabrous (hairless) surfaces, both upper and lower. The main vein is prominent and the leaf apex is acute. The size of the leaf varies with its position on the tree. Leaves in the middle of the tree which receive least light are much larger than those on the periphery. Leaf flushes occur periodically at approximately 8-week intervals between flushes on the same shoot. Bud bursting and leaf flushing are thermoperiodic and occur when the average air temperature exceeds a certain high value associated with a wide daily range* *(1)*. The color of the flush leaves varies according to the quantity of anthocyanin pigment present which differs in the different varieties and strains of cacao. The presence of pulvini permits movements to occur in the leaf lamina, for example, when either light or temperature or both are excessive. *(2) (3)*.

Leaf anatomy: The lamina contains three layers of palisade cells on the upper side and an equally thick layer of spongy tissue on the lower side. The palisade cells are small and contain abundant chlorophyll plastids. The intercellar spaces in the palisade tissue are small but include large cavities filled with mucilage. The leaf cortex also contains mucilaginous cavities as well as starch cells *(2) (3)*. The upper epidermis differs from the lower in that it consists of large thin-walled cells covered with cutin whereas the lower epidermis consists of extremely small cells which are fairly thick-walled. Numerous tiny stomata are irregularly distributed over the lower epidermis only. Their guard cells also are small. Between 1,200 and 1,300 stomata occur in the lower epidermis per square millimeter of leaf surface *(4)*. The movements of the pulivini are attributed to parenchymatous cortical cells containing abundant small granules of starch. Small starch grains also occur throughout the tissues of the cacao leaf *(2) (3)*.

THE INFLORESCENCE

The flowers of the cacao tree are borne directly on the old wood of the main stem and lateral branches, a feature termed cauliflory *(6) (7)*. The inflores-

* See *Chapter 3*: Temperature relations of cacao.

cence is a dichasial cyme but the branches of the cyme are greatly reduced or compressed into a short stem structure whose true morphology is sometimes revealed when the inflorescence is stimulated by infection with Witches' Broom fungus, causing them to grow out into an elongated shoot. The inflorescence originates as a bud in a leaf axil *(6)*. Its greatly shortened and twisted branches form a dense mass which, as it grows old, broadens out into a cushion. A single flowering cushion bears up to 40 or 60 flowers at the same time. The large differences in the number of flowers borne on one cushion that have been noted to occur between one tree and another have been attributed partly to heredity.

Inflorescence anatomy: The basal part of a flowering cushion is so twisted that much tissue that would otherwise be sloughed off is trapped and retained, forming a suitable nidus for large numbers of tiny insects *(3)*. The internodes that carry the flowers bear green stipules. These are particularly conspicuous in the so-called Green-Point Cushion Gall disease of cacao*.

THE FLOWER

The cacao flower is borne on a pedicel of length between 1.3 and 3.0 cm. which is 2 or 3 times as long as the tiny branch that carries it. Flowering goes on almost all the year round provided the conditions of temperature and humidity are favorable. Periods of maximum and minimum flowering are distingishable, however, although precise quantitative information regarding the factors that control flowering periodicity is not yet forthcoming *(9)*.

Structure: The flower has a superior ovary with 5 loculi. The *calyx* has 5 small fleshy sepals, 7 to 11 mm. long, wedge-shaped and united at the base, and colored pink or white. The *corolla* consists of 5 petals alternating with the sepals and forming an envelope having a characteristic shape. The basal part of each petal is concave and pink in color and encloses an anther. The upper part consists of a thin connection with the basal part and ends in a rectangular yellowish expansion which bends outwards and backwards *(2) (3)*.

The *stamens* are 10 in number; 5 of them are functional and carry anthers, the others alternate with them but are sterile and are called *staminodes*. These are erect filaments ending in 3-pointed awns and are colored brown. The staminodes form a cylinder surrounding and protecting the style. The *anthers* at the ends of the stamens are double-chambered and hold 4 pollen sacs which dehisce longitudinally. Actually, each stamen consists of two fused parts each having two anthers which, in the course of floral evolution, have become united *(2) (3)*.

The *pollen grains* are small; diameter 20 microns. They are binuclear and each has 3 pores. The anthers begin to dehisce almost as soon as the flower opens and immediately the pollen is functional. Viability extends over 48 hours which is the maximum period under natural conditions *(3)*.

* See *Chapter 20*: Cushion Gall.

The superior ovary terminates in a style, 2 to 3 mm. long. It has a central placenta attached to which are 30 to 50 ovules. The style is tubular and is made up of 5 parts fused together, except at their tips which form the stigmas.

Pollination takes place solely through the agency of insects. The frequency of natural pollination varies from 4 to 50 percent as estimated from investigations on crossing. Fertilisation takes place within 10 to 24 hours after pollination *(5) (13)*. Fusion of the two nuclei of the pollen tube, one with the nucleus of the egg cell and the other with that of the endosperm, takes place (double fertilisation) *(5)*.

THE FRUIT

The fruit of the cacao tree botanically is a drupe but it is commonly called a pod. Its size and shape vary greatly. Some pods are as long as 32 cm. (13 ins.) and others are as short as 10 cm. (4 ins.). The shape ranges from oval to cylindrical. Some pods have prominent points at the ends, others are blunt. Some have wide bases, others have constricted bases *(2) (3)*. When young, the pods are either green or red in color. Green pods first turn yellow and then orange-red but red pods merely darken in color when they ripen. The surface of the pod is either smooth and devoid of furrows or ridged with 5 or 10 furrows. The pericarp or husk varies in thickness and consistency according to the variety or strain of cacao. The pod ripens in 5 or 6 months after fertilization. The seeds are dispersed by squirrels, rats and other rodents which bite through the husk and extract the seeds. They suck off the sugary acid pulp and spit out the astringent seeds after they have carried them for some distance from the parent tree.

THE SEED

The seed or bean of the cacao tree is covered with a sugary acid pulp. The beans number 20 to 50 in a pod. Their size and shape depend on the variety or strain of cacao. In Criollo cacao, they are large, 3 to 4 cm. long (1 to 1½ ins.) nearly oval in shape and white or violet in color. In Calabacillo cacao they are small, 2 to 3 cm. long (¾ to 1¼ in.) flat and purple in color. The main bulk of the seed is made up of two convoluted cotyledons which contain fat, alkaloid like substances, tannins and other substances whose alteration products give flavor and aroma to the manufactured chocolate*. The embryo (radicle and plumule) is enclosed and protected by the cotyledons which provide it with food for some days after the seed has germinated. The endosperm is greatly reduced and takes the form of a thin membrane called by chocolate manufacturers the beeswing. The testa is thin and leathery. It is sometimes called the skin or, when the bean is roasted, the shell. Its surface bears long thin-walled mucilage-cells which comprise the pulp.

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* See *Chapter 26*: Curing of cacao (Biochemistry) and *Chapter 27*: Manufacture of cacao products.

An important characteristic of the cacao seed is that it does not require any rest period in order to germinate and quickly dies through dehydration or when fermented or subjected to extremes of temperature. Living cacao beans therefore cannot be stored for any appreciable length of time and generally they can be stored only for 10 to 13 weeks without losing their viability *(10)*.

SUMMARY

1. The history of the development of commercial cacao-growing is briefly related.

2. The morphology and anatomy of different parts of the cacao tree, namely, root, stem and branches, leaf, inflorescence, flower, fruit and seed are described.

3. The formation of chupons and jorquettes, which are characteristic features of the cacao tree, are explained.

4. The occurrence of pulvini on the leaf petioles, and of flower cushions on the stems and branches, which are other characteristic features of the cacao tree, is also mentioned.

5. The characteristic formation of mucilage by certain cells present in various tissues of the root, stem, and branches and the leaf is noted.

6. The differences in phyllotaxy and in rooting habit of the chupon stems and fan branches are mentioned and their implications stressed.

7. The peculiar morphology of the cacao flower, which fits it for insect pollination, is described.

8. The features of the fruit and the seeds (pod and beans) are described. The seeds are dispersed by certain animals, which bite through the pod wall and extract the sugary pulpy seeds.

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CHAPTER 24

TOXONOMY OF CACAO AND RELATED SPECIES*

(SYSTEMATICS OF THE GENUS THEOBROMA)

The genus *Theobroma* L. comprises some 30 species. They are trees of variable height, with a main trunk which branches into a regular whorl (jorquette) of 3 or 4 main laterals. In some species, a lateral bud develops below the branches and grows upwards and divides again into another whorl of 3-5 branches. In other species, the terminal bud continues to grow and eventually produces a new jorquette. This jorquetting habit continues until the trees reach complete development. The main trunk eventually acquires an aspect of uninterrupted and straight growth. Frequently the trees exhibit an irregular shape due to the growth of new verticals (chupons) or to the uneven development of the lateral branches.

The leaves are simple, with a short or long petiole, provided at the insertions to the branch and to the lamina with thick pulvini. Venation often palmate with 3-5 main basal veins or with a midrib with lateral veins.

Flowers small; solitary or in cymes. Inflorescences on the trunk and main limbs (cauliflory) or axillary on young branches or new growths. The flowers have 5 (sometimes 3) divisions. Sepals 5 or 3. Petals 5, consisting of a conchoidal structure to which is attached a spathulate or filiform ligule. Stamens 5, with 2 or 3 anthers forming with the 5 staminodes a short tube. Staminodes filiform or petaloid. Ovary sessile with 5 loculi and many ovules in each locule; style filiform.

Fruit a large drupe with 5 cells. Seeds surrounded by pulp; exalbuminous; radicle short; epigeal.

The characters mentioned above are useful in the recognition of the different species of *Theobroma* but they are not completely constant. Some species, for instance, may bear when young the flowers on new branches but when old only on the trunk or main limbs.

Systematic position: Linnaeus (1753) first placed the genus *Theobroma* into the family Tiliaceae. Later, he considered that it might better be included in the Sterculiaceae, and this view is now generally accepted. As at present defined, this family is somewhat artificial, and recently Endlin, 1935, has suggested that the genus be placed in a separate family, the Byttneriaceae. Another problem

* This chapter was preparated by J. León, Head of the Plant Industry Dept.

arises as to whether the genera *Herrania* and *Theobroma* should be separated or put into one genus. The genus *Herrania,* named by Goudot, comprises a natural group whose claim to genetic status is accepted by the majority of botanists.

The generic relation between *Theobroma* and *Herrania* seems definitely to have been clarified. Schultes (14) describes the main differences as follows: "*Herrania* can be separated from *Theobroma* immediately by its habit (having compound-digitate leaves and, in general, comprising small, delicate, slender trees). It further differs from *Theobroma* in the placement of the stamens, in the number of division of the calyx, in the length and shape of the ligules, in its wood anatomy and in the structure of the pollen grains". Nevertheless, the two genera are closely allied, as proved by their chromosome numbers *(10)* and by successful experimental pollination *(1)* in which the two genera were crossed but the embryos failed to grow.

Theobroma is also closely related to *Guazuma,* a tropical American genus of trees or shrubs. Other genera in the Sterculiaceae having close affinity to *Theobroma* occur in Africa, for example, *Scaphopetalum.*

Speciation: The number of species of *Theobroma* known at present is around twenty. In recent years several new species have been described and it is highly probable that several more will be discovered in explotations that may be carried out in the future. On the other hand, there are several species, for example, *T. kalagua* de Willd., *T. quinquenervia* Bern. and *T. asclepiadiflora* Schery, which seem of doubtful identity.

The genus originated evidently in South America, possibly in the Amazon basin. The Brazilian species are quite different from the others and some have their counterparts in the western side of the Andes; for example, *T. microcarpa, T. gileri; T. subincana* and *T. nemorale.* Another center of speciation is the Pacific slope of the Colombian Andes, where several new species have been found recently; this center probably spread to the Atlantic side of Central America.

Theobroma plants occur frequently in groups in the forest. They never are numerous or dominant, and the natural isolation, together with the apparent barriers in crossing, have preserved their specific identity.

Man has helped to disturb the natural pattern of distribution. Some of the Brazilian species, such as *T. grandiflora,* are used in the preparation of cold beverages while *T. bicolor* and *T. angustifolia* have been used in the preparation of chocolate in Central America since pre-Conquest times.

Geographical distribution: The genus *Theobroma* is confined to Tropical America, from Mexico (Veracruz) to Brazil (Matto Grosso) and Bolivia. The wild Theobromas grow under the shade of tall trees, as in the Brazilian hilaea, or in sites subjected to seasonal floods (várzea) from sea level to abount 1000 m. (3250 ft.). The trees occupy areas of high and permanent humidity, or with alternate dry and wet seasons. Native species are not known to occur in the Antilles. Most of the species have a restricted geographical range. Besides the cultivated *T. cacao,* only one, *T. bicolor,* has a wide geographical distribution; dispersal by man may account in part for this extensive range.

Specialised studies: The genus *Theobroma* presents many taxonomic difficulties, especially in regard to certain species of doubtful identity. The first specialised study was that made by Bernoulli *(2).* Later, K. Schumann *(15)* published a study of the species as they occur in Brazil. Other more recent monographs are those of Pittier *(11)* and of Chevalier *(6)*. The Brazilian species have been studied by Ducke *(7)*. A survey of the Colombian species has been made in connection with the spread of Witches' Broom disease *(3)*. Presently Dr. José Cuatrecasas, Smithsonian Institution, Washington, D. C., U. S. A., is working on a new monograph, and would be grateful for any herbarium specimens or new information that might be sent to him.

Sub-generic divisions

(1) Schumann *(15)* divides the genus *Theobroma* into three sections, the third of which corresponds to *Herrania* regarded by Goudot as an independent genus.

Section	I —	*Eutheobroma*	(Simple leaves; stamens with 2 anthers each)
Section	II —	*Bubroma*	(Simple leaves; stamens with 3 anthers each)
Section	III —	*Herrania*	(Divided (digitate) leaves)

(2) Bernoulli *(2)* classifies the genus into five sections, namely:

Section	I —	*Cacao*	(Stamens with 2 anthers; closed ligules, linear staminodes, erect, pointed)
Section	II —	*Oreanthes*	(Stamens with 3 anthers; staminodes linear and erect)
Section	III —	*Rhytidocarpus*	(Stamens with 2 anthers disc-shaped ligules, club-shaped staminodes)
Section	IV —	*Telmatocarpus*	(Stamens with 3 anthers, staminodes broad at base)
Section	V —	*Glossopetalum*	(Stamens with 3 anthers, petaloid staminodes)

(3) Pittier *(11)* has combined into one class the sections suggested by Bernoulli and by Schumann, and has relegated Bernoulli's sections to sub-sectional status, thus:

Section I — *Herrania* (K. Schum.)
Section II — *Eutheobroma* (K. Schum.)
- *Sub-section* — *Cacao* (Bern.)
- *Sub-section* — *Rhytidocarpus* (Bern.)

Section III — *Bubroma* (K. Schum.)
- *Sub-section* — *Telmatocarpus* (Bern.)
- *Sub-section* — *Oreanthes* (Bern.)
- *Sub-section* — *Glossopetalum* (Bern.)

(4) Chevalier *(6)* in his monograph adopts Bernoulli's grouping rather than that of Schumann.

KEY TO THE GENUS THEOBROMA

(Macroscopic characters of the principal species)

(A) Fruits borne generally on the trunk or main branches

Fruits not pubescent	
Flowers small, yellowish	*T. cacao*
Flowers, large, dark purple	*T. guianensis* (*T. speciosa*)
Fruits pubescent (soft hairy)	
Staminodes linear	
Fruits longer than 20 cm. (8 in.)	*T. bernoullii*
Fruits shorter than 20 cm. (8 in.)	*T. capillifera*
Staminodes petaloid, fruits longer than 20 cm. (8 in.)	
Staminodes red	
Fruit with white pubescence	*T. calodesmis*
Fruit with rusty-red pubescence	*T. simiarum*
Staminodes yellow	*T. cirmolinae*

NOTE:—The two little-known Colombian species, *T. kalagua* and *T. stipulata,* may be included here.

(AA) Fruits borne on terminal branches

Branches and petioles pubescent (soft hairy)	
Fruit less than 10 cm. (4 in.) long	
Staminodes sharply pointed	
Fruit smooth, slightly pentagonal, greenish-blue in color	*T. spruceana*
Fruit with 10 well-marked ribs	*T. microcarpa*
Staminodes petaloid	
Fruit with thin warty husk	*T. obovata*
Fruit with thick smooth husk	
Fruit 10 or more cm. long	*T. sylvestris* (*T. subincana*)
Fruit less than 10 cm. long	*T. nemorale*
Fruits longer than 10 cm. (4 in.)	
Staminodes sharply pointed	*T. gileri*
Staminodes petaloid	
Fruit with prolonged apex	*T. mammosa*
Fruit with blunt apex	
Flowers reddish	*T. grandiflora*
Flowers yellowish	*T. angustifolia*
Branches smooth	
Flowers small, greenish	*T. bicolor*
Flowers scarlet-red	*T. asclepiadiflora*

SECTION II - EUTHEOBROMA

Sub-Section - CACAO

1. *Theobroma cacao* L. Sp. Pl. 782, 1753

Low tree, usually 4-8 m. (13-26 ft.) in height, at times up to 14 m. (45 ft.) Main trunk short, branching normally in whorls of 5 branches. Branching dimorphic; (a) verticals or chupons growing from trunk or main limbs with leaves arranged in $^5/_8$ phyllotaxy; (b) lateral branches with $^1/_2$ phyllotaxy. Petioles with two joint pulvini, one at the base and the the other at the point of insertion of the leaf. Stipules 2, deciduous. Lamina elliptical-oblong or obovate-oblong, 12 to 30 cm. (5 to 12 in.) long; generally smooth, sometimes hairy, rounded and obtuse at the base, pointed at the apex. Dichasial inflorescence; primary peduncle very short, frequently lignified and thick. Flower peduncle, 1 to 2 cm. (0.4 to 0.8 in.) long. Sepals 5, triangular, whitish or reddish in color. Petals 5, the bottom part cup-shaped, whitish-yellow with two dark purple bands inside. Ligule spathulate, yellowish. Stamens 5, fertile, alternating with 5 staminodes, the two whorls united to form a tube. Anthers 4 to each stamen (really two fused stamens). Ovary superior with a single style terminating in 5 stigmas. Fruit of variable shape, usually ovoid-oblong, sometimes pointed and constricted at the base or almost spherical; furrows 10, 5 of which are prominent. Seeds enveloped in pulp; flat or round, with white or purple cotyledons.

Area of origin: Theobroma cacao is indigenous to Tropical America and occurs between latitudes 20°N and 20°S within the lowlands. It is a component of the understory, both of the continuously wet forest and of forest with alternate wet-dry seasons.

Sub-species: Several different evaluations have been given to the wide and varied population of *T. cacao*. The most recent of them is that of Pittier *(12)* who considers the species described by Linnaeus as the type commonly known as Criollo and reserves the species name *T. leiocarpa,* proposed by Bernoulli, for Forastero cacao. He recognises numerous inter-specific crosses between these types, ranging from Criollo to Calabacillo. Pittier regards the type described by Bernoulli, known as Lagarto, as a separate species, namely *T. pentagona,* though closely related to *T. cacao.* This opinion has been debated by A. Ducke *(7)* who relegates *T. leiocarpa* to a form of *T. cacao.* Other authorities have since regarded *T. pentagona* also as a form of *T. cacao.*

Chevalier *(6)* considers that *T. leiocarpa, T. pentagona, T. sativa, T. sphaerocarpa* and *T. sagittata* are all jordianian forms of *T. cacao.* The present day tendency is to place the whole population of caaco types under the Linnaeus species name, *T. cacao.*

Regional distribution of forms and varieties: The form Criollo occurs between Mexico and Panama and was that originally used in cultivations. *T. pentagona* occurs between Mexico and Costa Rica and was also used in early cultivations because of its quality. *T. leiocarpa* occurs between Colombia and Brazil and is represented by many regional varieties.

The cultivation of cacao during pre-Colombian times extended solely from Mexico to the present boundary between Costa Rica and Panama. The notion that cacao was cultivated at this period along the coastal region near to the Equator is doubtful. Its spread to new areas was extremely rapid after the arrival of the Spaniards who carried the seeds of Criollo cacao from Central America to Venezuela, especially since the beginning of the sixteenth century and, as the Conquest progressed, they profited by the natural trees that existed within the forests and later established formal plantations, employing both improved as well as native seed. The crosses gave rise to the many commercial types of cacao.

During his extensive explorations in South America, F. J. Pound *(13)*, came across Angoleta and Cundeamor types of cacao which he considered to be crosses between Criollo and Forastero forming a large part of the indigenous cacao population, as well as Calabacillo cacao. According to Pound, the following natural populations occur in South America. (i) In the upper reaches of the Amazon River he found a series of types called Lagarto having greyish-green pods and dark purple cotyledons. (ii) In the Guianas, he encountered an indigenous population of Amelonado cacao which is mixed with the latter in the Lower Amazon basin giving various hybrid types. (iii) At the base of the Cordillera to the west of the Amazon, and also within the riverine belt of Ecuador, he found a type of cacao known as Nacional, having high quality, whose origin is not known with certainty, and is perhaps a separate type of cacao to Criollo and to Amelonado. (iv) In Colombia and Venezuela, Criollo cacao was found although it is thought not to be indigenous or native which, hybridizing with Guianian Amelonado, has given rise to what is known as the Trinitario complex.

The cultivated sub-species of Theobroma cacao

(a) Ssp. *sativa* (Lam.) Lign. & Le Bey, Bull. Soc. Linn. Normandie, VII, p. 263, 1902.

According to Chevalier, this form corresponds more-or-less to Criollo. It originated in Central America and Mexico and is possibly not a native of South America.

The fruit is oblong, obtuse at the base and distinctly pointed at the apex, which occasionally is curved. The surface is warty and shows 5 furrows corresponding to the divisions of the carpels. These furrows are deep and narrow and there are 5 shallow furrows between them. The color varies between green and dark purple. The cotyledons are round and white inside.

Distribution: Mexico and Panama.

(b) Ssp. *leiocarpa* Bern., Neue Denkschr. allg. Schweiz. Gesell. 24, 6, 1871.

The fruit is ovoid, nearly smooth or with 5 shallow furrows. Both ends are rounded. Color, green or purple. Seeds, flat and triangular in cross section. Cotyledons dark purple.

Distribution: South America (Colombia and Brazil)

(c) Ssp. *pentagona* Bern., Neue Denkschr. allg. Schweiz. Gesell. 24, 6, 1871.

The fruit is oblong-oval and of dimensions 20 x 9 cm. (8 x 3½ in.). Color, reddish-yellow. Ribs (carpellary sutures) prominent and continuous. Surface warty. Seeds, large, round.

Distribution: Guatemala to Panama.

Numerous species of *Theobroma cacao* have been described within these three forms, most of which are either accidental or local varieties, for example, *T. saltzmanniana* Bern., *T. sphaerocarpa* Chevalier and *T. sagittata* Ruiz y Pavón. The three sub-species described above, namely, *sativa, leiocarpa* and *pentagona,* cross readily. Some authorities consider that *T. pentagona* is the form originally cultivated.

Classification of commercial cacao types

Different authorities classify the commercial types of cacao in different ways, without taking into consideration the range of botanical sub-species. The most generally used of these common systems of classification are those of J. H. Hart *(9),* van Hall *(8),* van Buren *(16)* and Cheesman *(5).*

Van Hall's classification is as follows:

Class I — Criollo
Class II — Forastero

(i) Fruits with deep furrows, surface warty, long, without basal constriction. *Angoleta*
(ii) Fruits oval, deep furrows, surface warty, constricted at the base. *Cundeamor*
(iii) Fruits with slight furrows, surface somewhat warty or smooth. Length greater than half the width, with or without constriction at the base. *Amelonado*
(iv) Fruits with shallow superficial furrows, surface smooth, width half to three-quarters of the length. *Calabacillo*

Sub-Section II - RHYTIDOCARPUS

2. *Theobroma bicolor* H. & B. Pl. Aequinoct. I, 104. 1808.
(T. ovatifolia DC ex Mox. & Sessé. Prodr. I, 468. 1824).

Dimorphic branching, vertical stems with long-petiolated, cordate leaves, dividing in whorls of 3 lateral branches and producing the new vertical shoot below the whorl. Lateral branches with elliptical-oblong leaves, cordate at the base, with 5-7 main veins at the insertion of the petiole. Leaf blades 15-30 cm. long 10-15 cm., wide (6-12 x 4-6 ins.) lustrous green above, white and hairy in the underside (bicolor). Inflorescences borne in the axils of the outside branches. Flowers small, finely hairy, greenish or purple. Sepals 5, stiff, triangular. Petals 5, the cup-shaped part ribbed; ligule, small, oval, curved. Fertile stamens fused, with 4 anthers. Staminodes club-shaped, short. Ovary pentagonal. Fruit-husky woody, deciduous, ellipsoidal, 15-10 cm. (6-4 in.) long, with 5 marked, elevated sutures; areas between ridges, deeply reticulate; greenish-yellow at maturity. Seeds flat, with white cotyledons, surrounded by yellowish pulp; germination hypogeal.

Distribution: Mexico (Veracruz) to Brazil (Pará) often cultivated outside its natural range. "Pataste" or "pataxte" (México to Costa Rica); "bacao" (Colombia); "cacau do Pará", "macambo", "cupuassu", "cacau do Nova Granada" (Brazil).

3. *Theobroma bernoullii* Pittier, Fedde Rep. 13:319. 1914.

Tree up to 15 m. (50 ft.) in height. Leaves elliptical, with a long apex and three main basal veins, 15-32 cm. long 5-9 cm. wide (6-13 x 2-4½ in.); shiny green above, whitish beneath. Inflorescences borne on the trunk in cushions of many flowers. Pedicels tomentose, 5-8 mm. long. Calyx with 5 red elliptical sepals, 8-9 mm. long. Petals with a shell-shaped base; ligule suborbicular, red. Staminodes lanceolate, 6 mm. long, red. Stamen with 2 anthers. Ovary ovoid, pubescent. Fruit oval-oblong, 17 cm. long 9 cm. wide (7 x 4½ in.) covered with thin, radiating hairs of rusty appearance.

Distribution: Panama.

4. *Theobroma capillifera* Cuatr., Rev. Acad. Colomb. Cienc. Fis. Nat. 4:547. 1946.

Tree 15-20 m. (50-65 ft.) in height, Leaves elliptical-oblong with long apices, 17-30 cm. (7-12 in.) long, 7.5 - 10 cm. (3-4 in.) wide, with 5 main basal veins, green on the upper side, whitish beneath. Inflorescences on the trunk, congested, with numerous flowers. Pedicels thin, like hairs, 18 mm. long, permanent (This character originated the name *capillifera).* Sepals 5, narrow, dark red. Petals red with a conchoidal (shell-like) base, ligule wide, suborbicular. Staminodes lanceolate, 6-8 mm. long. Fruit oblong, with a constriction at the base, and 5 well-marked ridges, 14-25 cm. (5½-10 ins.) cm. long 6-8 cm. (2½-3 in.) wide, covered with short, rusty hairs.

Distribution: Colombia ("cacao de monte")

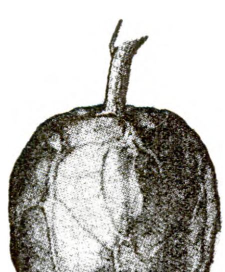
5. *Theobroma calodesmis* Diels, Notizbl. Bot. Gard. Berlin 14:336. 1939.

Tree up to 15 m. (50 ft.) in height. Leaves elliptical, 15-35 cm. long 12-20 cm. wide. Inflorescence on the trunk, with numerous flowers. Sepals

T. angustifolia

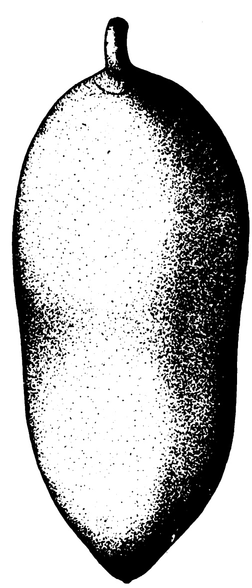
T. bicolor

From: Preuss, Exp. Nach. Cent. & Süd Amerika, 1901.



T. gileri

From: Rev. Inst. Bot. Appl. Agric Trop. 33:563, 1953.



T. stipulatum

From: Fieldiana Bot. 27:85, 1950

5. Petals red, with a conchoidal base and long, suborbicular ligules. Staminodes long, lanceolate, red. Fruits elliptical, slightly constricted at the base, up to 13 cm. long and 9 cm. wide (5 x 4 in.) bluish-green at maturity.

Distribution: Peru, Colombia (Amazonian region)

6. *Theobroma asclepiadiflora* Schery, Ann. Mo. Bot. Gard. 29:360. 1942.

Trees up to 30 m. (100 ft.) in height. Leaves glabrous on both sides, elliptic, 30-40 cm. long, 10-13 cm. wide (12-16 x 4 - 5 in.) acuminate at the apex. Inflorescence, a many-flowered cyme. Flowers red. Sepals reflexed, oval, 12 mm. long, covered by short hairs. Petals with a conchoidal base and a round ligule. Stamens with 2 anthers. Staminodes lanceolate, 10 mm. long. Ovary ellipsoidal, covered with short hairs. Fruit unknown.

Distribution: Panama

Section III - BUBROMA

Sub-Section I - TELMATOCARPUS

7. *Theobroma microcarpa* Mart.

Tree up to 10 m. (32 ft.) in height, with terminal growth above the jorquette. Leaves small, 10-18 cm. long 4-5 cm. (4-7 x $1\frac{1}{2}$-2 in.), oblong-lanceolate, with few basal veins, shiny green above, dull green underneath. Inflorescences in the axils of young branches, in groups of 2-3. Sepals 5, oblong, 4-6 mm. long. Petals with conchoidal base, 2 mm. long and rudimentary ligules. Stamen with 3 anthers. Staminodes thin, 5 mm. long. Fruit ellipsoidal to nearly spherical, 5-9 cm. long, 5-6 cm. wide, with 5 primary and 5 secondary longitudinal ridges, and with prominent reticulation in between.

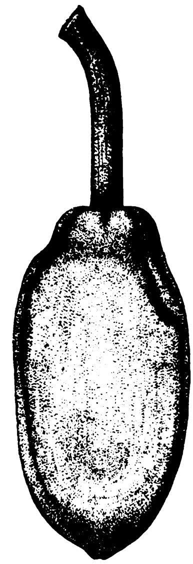
Distribution: Colombia, Brazil (Amazonian region). "Cacao rana", "cacau jacaré" (Pará). Distributed in the forest, or occurring as the dominant species on the "vegas" or levees of the Amazonian river (Huber).

8. *Theobroma gileri* Cuatr., Rev. Int. Bot. Appl. Agric. Trop. 33:562. 1953.

Tree 12-14 m. high (45 ft.). Leaves elliptical-lanceolate, large, 5-16 cm. long, 2-4 cm. wide (2-6 x 1-2 in.) with a long apex. Flowers small, borne in the axils of the branchlets or on cushions on the trunk. Sepals ovate-lanceolate 6 mm. long. Petals red with the conchoidal base 3-4 mm. long and a rudimentary ligule. Stamens 1-2 mm. long, triantheriferous. Staminodes red, narrow, 7 mm. long. Ovary ovoid, pubescent. Fruit oblong-ovoid, 7-10 cm. long, 7-9 cm. wide (3-4 in.) with 5 main and 5 secondary ridges, the area between them with transverse reticulations.

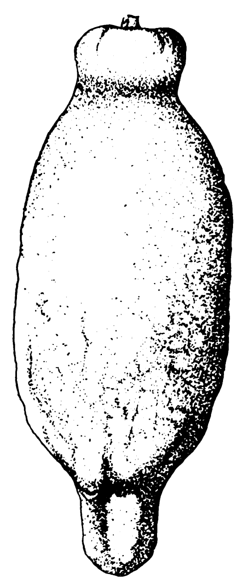
Distribution: Ecuador, Colombia (Pacific region)

T. capilliferum



T. calodesmis

T. cirmolinae



T. mammosum

All illustrations on this page by Ing. Guillermo Orbegoso, 1957.

Sub-Section II - OREANTHES

9. *Theobroma guianensis* (Aublet) G. F. Gmelin, Syst. Vegt. 1151. 1796.
(T. speciosa Willd, ex Spreng. Syst. 3:332. 1826).
(Cacao guianensis Aublet, Hist. 2:685. 1775).

Tree up to 15 m. in height. Leaves oblong, 15-25 cm. long 6-10 cm. wide (10 x 4 in.) acuminate, glabrous, deep green above, whitish or rusty and finely hairy underneath. Inflorescences in compact cymes on the trunk. Sepals reflexed, dark red. Petals 8-10 mm. long, red, with a conchoidol base and a large, broad and emarginate ligule. Stamens with 3 anthers. Staminodes narrow, red, 10-14 mm. long. Ovary ovoid, hairy 5 mm. long. Fruit ellipsoid, with 5 indistinct ridges, 8-10 cm. long 6-8 cm. wide (3-4 x $2\frac{1}{2}$-3 in.) yellow at maturity.

Distribution: French and Dutch Guiana; Brazil ("cacauú", "cacau rana"). Bolivia.

10. *Theobroma spruceana* Bern., Neue Denkschr. Schweiz. Gesell. 24:9. 1871.

Small tree. Leaves oval-oblong, long acuminate, with three basal veins shiny green above, whitish beneath. Inflorescences borne on young branches. Sepals lanceolate, strongly reflexed, 8-12 mm. long. Petals 4-6 mm. long with a conchoidal base, yellow: ligule large and emarginate. Stamens triantheriferous. Staminodes lanceolate, 6-9 mm. long. Ovary ellipsoid, pubescent. Fruit 6-8 cm. long, 4-6 cm. wide with 5 smooth ridges, greenbluish at maturity.

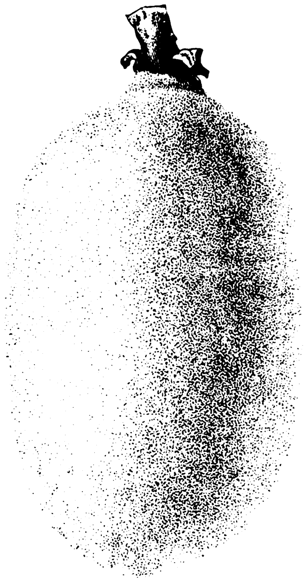
Distribution: Brazil ("cacau azul").

SubSection III - GLOSSOPETALUM

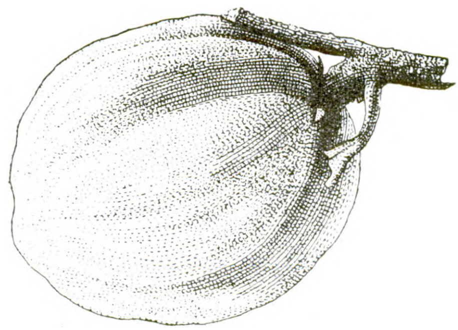
11. *Theobroma angustifolia* Moc. & Sessé ex DC., Prod. 1:484. 1824.

Trees 3-15 m. in height. Leaves 15-20 cm. long 4-5 cm. wide (6-8 x $1\frac{1}{2}$-2 in.) oblong, with long apex, 3 basal veins glabrous or sparsely hairy above, rusty pubescent underneath. Inflorescences on the young branches. Sepals 3, broadly triangular, 9-12 mm. long, ferrugineous (rusty-red) pubescent outside. Petals red, with a conchoidal base, terminating in a spathulate ligule. Stamens triantheriferous. Staminodes petaloid, yellow. Ovary ovoid, ferrugineous, pubescent. Fruit ovoid, irregular, 12-16 cm. long 6-8 cm. wide (5-6 x 2-3 in.) roughly pentagonal, covered with short ferrugineous hairs.

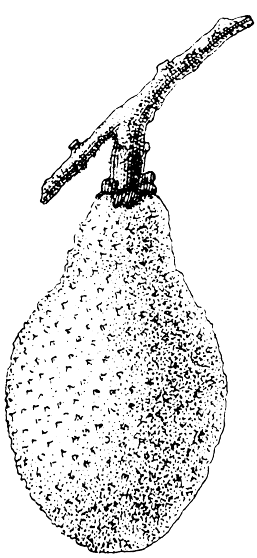
Distribution: Mexico to Panama (Costa Rica "cacao de mico", "cacao silvestre").



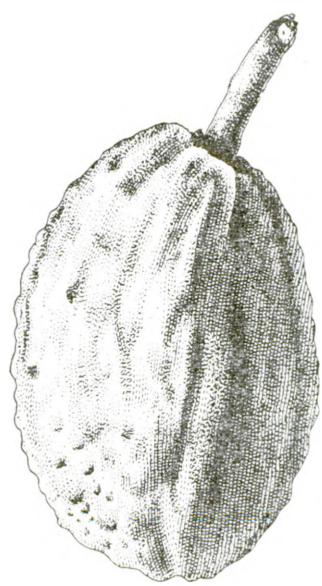
T. grandiflora



T. spruceana



T. obovata



T. guianensis

All illustrations on this page from: Addison & Miranda Tavares, Bot. Tec. Ins. Agron. do Norte, Nº 25, 1951.

Standley and other authors state that this species is cultivated in Soconusco (Mexico) where its seeds are mixed with cacao. In Costa Rica a similar use still persists in the Nicoya peninsula.

12. *Theobroma cirmolinae* Cuatr., Notas a la Flora de Colombia VI:5, 1944.

Trees 12-20 m. (40-65 ft.) in height. Leaves large 30-50 cm. long 25-30. cm. wide (12-20 x 10-12 in.) ablong-elliptical and markedly unequal at the base; apex short; green above, glabrous below with prominent veins, rusty hairy Sepals 5 yellow, broadly triangular, 10-15 mm. long. Petals yellow, 8 mm. long, with a conchoidal base and a thin spathulate ligule. Stamens triantheriferous. Staminodes petaloid, wellow, 11 mm. long. Ovary ovoid, pubescent. Fruit fusiform, 25-30 cm. long 8-11 cm. wide (10-12 x 3-4 in.) with 5 blunt ridges, covered with short, rusty hairs.

Distribution: Colombia (Pacific region), 1000-1400 m. altitude (3250 - 4550 ft.)

13. *Theobroma grandiflora* (Spreng.) K. Schum., in Mart. Fl. Bras. 12(3):76. 1896.

Tree up to 15 m. (50 ft.) in height. Leaves narrow oblong, 15-58 cm. long, 7-15 cm. wide (6-23 x 3-6 in.) devoid of hairs on both sides. Inflorescences on the axils of young branches, with 4 flowers. These are the largest in the genus. Sepals 3, broadly triangular, up to 25 mm. long. Petals with a conchoidal base, cream colored, about 5 mm. long, with a broady spathulate ligule; crimson, 8 mm. long. Stamens with 3 aithers. Staminodes large, 12 mm. long, petaloid, acute, deep crimson. Fruit ellipsoidal to subglobose, 20-24 cm. long 8-12 cm. wide (8-10 x 3-5 in.) covered with a short white pubescence. Pulp white, acid, with agreeable odor.

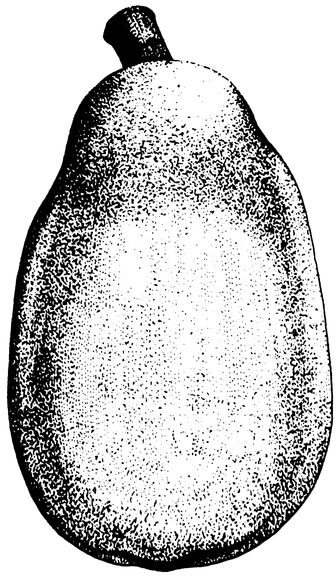
Distribution: Brazil ("cupuassú") Colombia.

Frequently planted in the region of Pará and Maranhao in Brazil and Amazonian Colombia. Native on the southern side of the Amazon in the Xingu and the Tapajoz basins. Used in Pará to prepare an aromatic, sweet beverage, and in the manufacture of candies. The seeds are a source of fat similar to cocoa butter. The trees are highly susceptible to Witches' Broom disease.

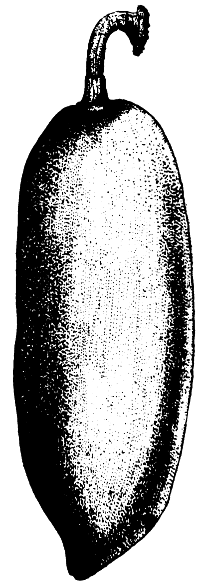
14. *Theobroma mammosa* Cuatr. and J. León, Int. Am. Inst. Agric. Sc. Bol. Tec. 2:1, 1949.

Tree 6-8 m. (20-26 ft.) high. Leaves oval-oblong, 12-29 cm. long, 4-8 cm. wide (5-12 x $1\frac{1}{2}$-3 in.) with a well-marked apex, glabrous on the upper surface, soft hairy below. Inflorescences on the young branches. Sepals 3, triangular, rusty pubescent. Petals with a conchoidal base, 6-8 mm. long, red, with a narrow ligule, 6-7 cm. long. Stamens triantheriferous. Staminodes large, red, spathulate, 11 mm. long. Ovary pentagonal. Fruit ellipsoid, with a well-developed apex.

T. bernouilli

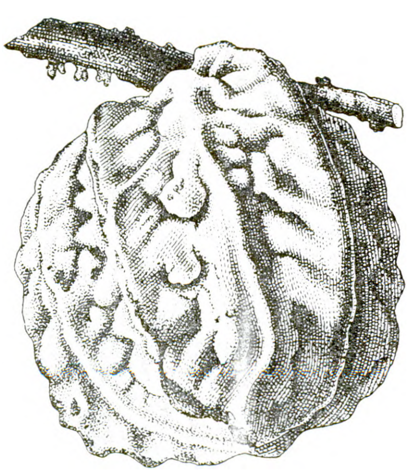


T. nemorale

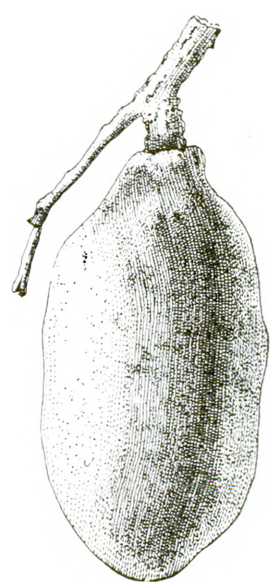


T. simiarum

These illustrations were made by Ing. Guillermo Orbogoso, 1957.



T. microcarpa



T. sylvestris

These illustrations from: Addison & Miranda Tavares, Bot. Tech. Ins. Agron. do Norte, Nº 25, 1951.

Distribution: Costa Rica.

15. *Theobroma obovata* Klotzsch, in Bern. Neue Denkschr. Schweiz. Gesell. 24:14. 1871.

Tree 6-15 m. (20-48 ft.) in height. Leaves elliptic, 15-20 cm. long 5-8 cm. wide (6-8 x 2-3 in.) glabrous on both sides. Inflorescences on young branches with 1-2 flowers. Sepals 5, broadly triangular, 10 cm. long. Petals with a conchoidal base, 3 mm. long and a wide recurved ligule, 5 cm. long. Stamens with 3 anthers. Staminodes petaloid, broad, 4 mm. long. Ovary ovoid, pubescent. Fruit ellipsoidal, narrowly constricted at the base, 6-8 cm. long 3-4 cm. wide (2½-3 x 1½-2 in.) husk thin and covered with small and rough papillae; orange when ripe.

Distribution: Brazil, Colombia

16. *Theobroma simiarum* Donn.-Sm., Bot. Gaz. 25:145. 1898.

Tree 12-30 m. in height. Leaves obovate-oblong to elliptical, 30-40 cm. long 14-19 cm. wide (12-16 x 5-8 in.) with a marked apex, glabrous on the upper side, rusty-hairy underneath. Flowers borne on the trunk and main branches. Sepals 5, curved, ferrugineous, up to 10 cm. long. Sepals with a conchoidal base, red; ligule narrow, 5 mm. long. Stamens with 3 anthers. Staminodes petaloid, erect, red at the tip, yellow at the base, 10-15 cm. long. Ovary ellipsoidal, soft pubescent. Fruit ellipsoidal, 24-26 cm. long 8 to 9 cm. wide (9½-10 x 3-3½ in.) covered with soft ferrugineous pubescence.

Distribution: Costa Rica ("Cacao de mico") Panama, Colombia.

17. *Theobroma stipulata* Cuatr., Fieldiana Bot. 27:84. 1950.

Tree 32 m. (104 ft.) in height. Leaves obovate-elliptical, 23-45 cm. long 11-17 cm. wide (9-18 x 4-7 in.) above sparsely pubescent, below sparsely hairy, with prominent veins. Stipules thick, permanent, 8-12 mm. long. Inflorescences borne on the trunk. Sepals 5, ovate-triangular 10-15 cm. long with ferrugineous pubescence. Petals 5, the conchoidal base 6 mm. long; ligule narrow at the base but broad at the apex, 3-4 cm. long. Stamens with 3 anthers. Staminodes spathulate, 11 mm. long. Ovary oblong, covered with fine hairs. Fruit ellipsoidal, 18-22 cm. long 9-10 cm. wide (7-9 x 3½-4 in.). Surface not ridged and covered with a short, fine ferrugineous pubescence.

Distribution: Colombia (Pacific region).

18. *Theobroma sylvestris* (Aubl.) G. Don, Gen. Syst. 1:522. 1831.
(*T. subincana* Mart. in Buchn. Rep. Pharm 35:23. 1830).

Tree 12-16 m. height; the terminal growth starts above the jorquette. Leaves oblong, pointed, 20-48 cm. long 10-15 cm. wide (8-20 x 4-6 in.).

Flowers borne on the young branches. Sepals large, reflexed, 8-10 mm. long. Petals with a conchoidal base 3 cm. long; ligule with narrow base and spreading into a round tip, red, 3-4 cm. long. Stamens with 3 anthers. Staminodes large, petaloid, red, 5-6 mm. long. Ovary ovoid, covered with a fine pubescence. Fruit elliptical, 8-12 cm. long 5-6 cm. wide (3-5 x 2-2½ in.) covered with fine brown pubescence; yellow at maturity.

Distribution: French Guiana, Brazil ("cupuí") Colombia. A widely distributed and apparently variable species.

19. *Theobroma nemorale* Cuatr., Rev. Acad. Colomb. Cienc. Ex. Fis. Nat. 8:487. 1952.

Tree 8-10 m. in height. Leaves elliptical-oblong with a narrow and long apex, 14-32 cm. long, 6-11 cm. wide (5-12 x 2-4 in.) shiny green above, whitish below. Inflorescences on the new branches. Sepals triangular-ovate, 7 mm. long. Petals yellow with the base 3 mm. long, conchoidal; ligule spathulate, red, 9 mm. long, with a narrow base and a broad tip. Stamen with 3 anthers. Staminodes obovate-oblong, red, 8 mm. long. Ovary obovoid, with short, brown hairs. Fruit elliptical, constricted towards the peduncle, 10-11 cm. long, 5-6 cm. wide (4-4½ x 2-2½ ins.) not ridged; yellow at maturity.

Distribution: Colombia ("bacao de monte") (Pacific region)

Doubtful Species

Several species are of doubtful standing, mainly because there are not enough collections of them, or because the original specimen is incomplete or mixed.

T. kalagua de Willd., from Colombia, seems to be very close to, if not the same as, *T. simiarum;*

T. tessmanni Milbr. and *T. ferruginea* Bern., from Peru, according to Chevalier, are the same entity and probably only variations of the widely-distributed *T. sylvestris (T. subincana).*

T. glauca, Karsten, of Colombia, is known only from the original, incomplete description.

CHROMOSOME NUMBER

Muñoz *(10)* has shown that the basic number of chromosomes in *Theobroma* and *Herrania* is 10 and not 8 as counted by Heyn, Cheesman and Kuyper in certain cultivated species. In Brazil, Carletto *(4)* found 2n-20 for the somatic tissues of *T. leiocarpa, T. grandiflora* and *T. speciosa.*

Muñoz proved also that this same number *(10)* occurs in the following species: *T. cacao, T. pentagona, T. microcarpa, T. simiarum, T. capillifera, T. obovata, T. angustifolia* and *T. cirmolinae.*

The same number of chromosomes he also found in certain species of *Herrania,* for example; *H. albiflora, H. purpurea* and *H. pulcherrima.*

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CHAPTER 25

THE GENETICS AND BREEDING OF CACAO*

INTRODUCTION

Cacao is a plant in which cross-fertilisation is greatly facilitated by the peculiar structure of the flower and by the mechanisms for incompatibility that are shown by different cacao populations. For these reasons variability in its seedling progeny is to be expected. Anyone familiar with the crop can prove these facts by a tree-to-tree study in a seedling population of the differences in yield, type and color of the pods, shape and size of the leaves, resistance to diseases and pests, shape, size and color of the seeds and many other characteristics. The occurrence of a high degree of variability of characters in a seedling tree population is an advantage in selection work because the range of distinguishing features used in selection is great and permits the isolation of superior geno-types and the changing of the frequency of certain genes through selection and hybridisation.

The perpetuation by sexual means of a desirable character is impossible to achieve in cacao because the particular combination of gametes of heterozygous and unknown parentage which originated this particular character is difficult to repeat. Nevertheless, with cacao as with most fruit trees, a desirable plant can be vegetatively propagated and, in this way, outstanding geno-types can be conserved as "clones". The geno-types can then be used for crossing in order to transmit the desirable characters.

Owing to the facts that tropical agriculture is in its infancy, and that our knowledge of the caaco plant is still incomplete, the application of genetical information already acquired to the problems of cacao breeding is not entirely satisfactory. In spite of this, notable progress has been made both by selection and by hybridization.

In any breeding program, certain fundamental principles must be observed and, in the case of cacao, almost all of them are nowadays applied *(1) (90)*. These are:

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* The original version in Spanish of this chapter was written by J. Soria, Lecturer in Plant Breeding to the Fifth Cacao Course.

(1) A thorough understanding of the problems presented by the crop and a realization of which are the most urgent and what stage of progress has been reached. The objectives of the program are established on the basis of this information.

(2) A collection of germ plasm as complete as possible, including cultivars from the many diverse geographical areas where cacao is grown, and a complete collection of indigenous varieties and closely related species for use in the breeding program as a source of certain characters.

(3) A study of the variability of the characters of each of the cultivars that are available in order to ascertain their potentialities for future use in the breeding program.

Before a breeding program can be started, accurate information on the variability of the characters that are to be fixed is essential. For this purpose, a necessary initial step is to find out the size of the sample needed to establish statistically the limits of variability for the purpose of setting up selection criteria. The pioneer in cacao breeding work was F. J. Pound of Trinidad (1932) who laid the foundations of the procedure for the selection of individual trees *(71) (73)*.

METHODS USED IN CACAO BREEDING

The methods used in the breeding of cacao comprise two principal procedures, namely:

(1) Selection of the best individual plants for any particular important character such as resistance to diseases and pests, yield, bean quality, etc., and their subsequent vegetative propagation.

(2) Utilization of the best material in hybridization work which aims at combining desirable characters.

(I) SELECTION OF INDIVIDUAL PLANTS (CLONES)

Pound (1932) and Cheesman and Pound (1935) set up the first standards or criteria for selecting individual trees and tree populations of Trinitario cacao *(29) (71) (73)*. Later these original criteria had to be modified for application to populations of cacao other than Trinitario, for example, the Amelonado cacao of Africa, and others. Since then, many other investigators, working in different experiment stations, have published descriptions of methods for the selecting of outstanding trees *(2) (3) (9) (10) (11) (36) (40) (41) (56) (57) (66) (69) (87)*. These methods do not differ fundamentally from those originally described by Pound.

The essential steps that should be followed in selecting are the following:

(1) Study the variability of the characters in the populations of the area in which the breeding work is being carried out.

(2) Determine by visual inspection the most promising trees in respect of the particular character to be selected, for example, high yield, resistance to different diseases and pests, quality, etc. Personal inspection is preferable but, if the area is extensive, information supplied by the farmers who know the best trees should be used. The features of the soil and site where the tree is growing should also be noted, for example, the physical and chemical properties and attributes of the soil, in special regard to root room, water and air supply and nutrient supply. The actual space occupied by the tree should be considered, for an isolated tree surrounded by blank spaces, or occupyying a border position in a field, or near to a stream has more room to expend its root system and its leafy canopy than one occupying a more normal position in the field. The age of the tree should also be taken into account, for an adult tree generally has a higher yielding capacity than a young one *(22) (29)*. The appraisal by the recording of yields, disease incidence, etc., of the neighboring trees surrounding the tree in question also aids in its true evaluation, for, if these too are outstanding in growth and production and other characters, the site in which they are growing is probably exceptionally good and the soil abnormally fertile.

(3) Collect accurate data for each tree regarding each character. The data should be collected over a period of three or preferably more years before attempting to draw conclusions.

(A) SELECTION FOR HIGH YIELD

One of the chief objects in selection work is to obtain plants having high yielding propensity. Certain steps have to be taken to achieve this object. The most essential step is to measure "pod index" which is the number of pods needed to give one pound of dry cacao beans. The limit set for Trinidad is 7½ pods per pound. Actually the wet weight of beans is first determined and the dry weight calculated as equal to between 35 and 40 percent of the wet weight of the beans. The percentage factor varies depending on the kind of cacao and probably on the time of the year which seems to influence the moisture content of the raw beans.

When the pod index is known, the yield data are analysed in order to determine the number of pods produced per year. This simplifies the selection work and reduces in a few year's time the number of original trees to a small number of the best yielders. It is advisable to retain trees having a low pod index because these have the advantage of requiring fewer pods per tree to produce a high yield. For example, a tree that produced 50 pods a year and having a pod index of 7.5 is better than one which gives 100 pods and having index 15, because the work involved in harvesting and breaking the pods in the case of the first tree is much less than that for the second. On the other hand, a relationship generally obtains between the size of the pod and the number of beans in a pod, larger beans usually occurring in the larger pods.

After 3 or 4 years' work along these lines, three groups of trees will have resulted from the selection, namely:

(1) Trees having exceptionally high yields and bearing 300 or more pods per tree per year but having small pods of little or no commercial value though possibly useful for research work.

(2) Trees bearing 50 to 100 pods per tree per year with pod index 7.5 to 9.0, of which 90 percent of the seeds weigh, on the average, 1.6 to 1.8 g. each when dry. This is the best group for propagating vegetatively among a population of Trinitario type.

(3) Trees bearing 100 to 200 pods per tree per year with pod index 10 to 12, with pods medium in size and beans having average weight when dry 1.0 to 1.2 g. The best trees of most of the populations of the Forastero-Trinitario type belong to this group *(28) (66) (71)*.

Other characters that have been recommended for consideration are: weight of pod, length, diameter and thickness of husk, individual weight of beans, and number of beans per pod. All these data are used to determine pod index for evaluating the features of a clone. Selected clones should afterwards be tested by precise regional field experimnts, repeated in different places, so as to observe their response to variable environmental conditions of climate and soil. If the number of clones to be tested is small, simple experimental designs, such as the randomized block or the latin square may be employed but, if the number of clones is large, more complex designs should be used, such as incomplete blocks.

When planning experiments with cacao clones, the fact should be taken into account that we are dealing with a perennial plant whose performance should be considered on a long-term basis. For this reason great care should be taken in planning the comparative trials so that, not only will the information which is required be forthcoming, but also the design will be sufficiently flexible to provide any additional information that may be needed.

The importance of plot size has not yet been investigated in field experiments with cacao, but the use of small plots containing few trees cannot be recommended *(16)*. The least number of trees to be used in clonal trials is 6 or 9 *(44)* but the choice depends largely on the degree of soil heterogeneity. In the case of experiments involving trees grown from seeds produced by open or controlled pollination, plots containing a greater number of trees, or many more replicates, must be used because the trees show high genetical variability as would be expected with such populations and, in order to measure the variability, a sample of adequate size must be provided.

(B) SELECTION FOR QUALITY

The evaluation of quality in cacao is difficult because, in addition to genetical factors, other factors that have not yet been sufficiently studied are involved, for example, the effect of the curing system used. Quality in cacao is generally considered to be correlated with pale color and with the size of the bean *(7) (45) (72) (85)*. The amount of anthocyanin present in the bean has been shown to influence the astringency and the flavor of cacao to some degree, but so far a positive correlation between bean size and quality has not been proved *(6)*. Criollo, *T. pentagona,* and other types having pale-colored beans are generally considered to comprise cacao of the highest quality, whilst types having purple pigmentation, like Forastero and Calabacillo, are regarded as having low quality. For this reason, in some countries such as Venezuela, Java, Costa Rica and Mexico, selection has been directed toward the production of clones of Criollo type or closely related to it but, unfortunately, they are susceptible to attack by the majority of the cryptogamic diseases of the crop. At the present time, the world's market for high-quality cacao is limited, and for this reason the breeder must strive to select, not solely from among those types of cacao, but should try to incorporate other characters of importance, for instance, resistance to diseases and pests and high producing capacity. In addition to desirable characters like pod size and color of bean, these other characters must also be considered.

The maintenance of the traditional characteristic flavor of Trinidad cacao by growing only certain selections or clones is believed not to be feasible (26) because cacao flavor is the result of the mixing of a large number of genotypes. Best results might be obtained by growing clones that show close resemblance to the Trinidad type when tested by the flavor test, and by planting an ample mixture of different local clones. Clones having undesirable flavors or too much astringency should be eliminated although a certain amount of astringent flavor seems to be characteristic of the Trinidad flavor.

(C) SELECTION FOR DISEASE RESISTANCE

Another object of selection is to obtain types of clones that are resistant to one or other of the diseases that locally affect the cultivation of cacao. An outcome of this kind of work was the discovery of SCA 6* and SCA 12 in Trinidad and Silecia 1** and Silecia 5 in Ecuador which show marked resistance to Witches' Broom disease.

(1) *Selection for resistance to Witches' Broom:* Differing degrees of resistance to Witches' Broom disease were found to occur in trees growing in a certain plantation in Ecuador in 1937(75) and in a certain plantation in the upper Amazon in 1954 *(30) (75) (76) (77).* Seeds were collected from trees that did not show any disease infection. Tests for resistance, carried out in Trinidad afterwards and designed to determine the degree of resistance of th different ICS clones, showed that the clones SCA 6 and SCA 12, collected in Ecuador, possessed almost complete resistance to the disease but they bore small pods containing small flat purple seeds whose features are hardly desirable in a commercial cacao.

* The prefix SCA comes from "SCAVINA", the supposed name of a plantation in Ecuador where its resistance to Witches' Brom was first noticed. The name is really a corruption of "Sabina" which is the real name of this plantation (Editor).

** Silecia is the name of a plantation on the Napo River near a village called Archidona, situated in the eastern foothills of the Andes near to the Peruvian border (Editor).

Among the ICS clones, ICS 1, 6, 60, 95 and 98 are stated to be resistant to Witches' Broom Disease *(21) (48) (50)* whereas SCA 6 and 12 are nearly immune to it. At the Tropical Experiment Station at Pichilingue in Ecuador, criteria have been established and methods have been elaborated for evaluating clones and for selecting seedling trees for disease resistance *(30) (32) (33) (34) (36).*

These methods are:

(i) The collection of resistant material within areas that are severely affected by the disease. (ii) The mass selection of seedlings of resistant trees. (iii) The evaluation of resistance in the clones and seedlings. (iv) Hybridisation between disease-resistant clones and other clones having desirable characters.

The material collected is either budwood or seeds from selected trees. The methods employed for evaluation differ according to the kind of material tested. Planting material propagated by cuttings or by buddings is multiplied and submitted to disease resistance tests. One method of testing consists in artificial inoculation with suspensions of basidiospores of the fungus applied to the plants. Another method consists in planting out the plants near to heavily-infected cacao fields.

Broom-age ratio: The number of brooms produced by the trees are counted and the "broom-age ratio" is calculated *(32).* This assesses the quantity of brooms produced in relation to the age of the tree. It is obtained by dividing the average number of brooms produced per tree for all trees of the same age and of the same clone by the average age of the trees in years. In this way, the clones are separated into three groups in which immune or resistant clones have broom-age 1.0 or less, intermediate clones, 1.0 to 1.5 and susceptible clones, greater than 1.5.

The selection of plants grown from seeds of selected cacao trees is carried out as follows: (i) Plant the seeds of the known progeny of the selected trees that are highly infected with the disease. (ii) Inoculate the seedlings artificially. (iii) Eliminate susceptible plants. (iv) Transplant into the field under natural conditions the resistant seedlings remaining after 2 years of mass selection.

The field or area employed for the resistance testing should be situated near to an infected field or plantation and each broom which is recorded should be left on the tree to serve as a further source of infection. The Ecuadorean selections, Silecia 1 and Silecia 5, were obtained in this manner. They show a high degree of resistance to Witches' Broom disease. Among the clones tested in Ecuador, the following have proved to be highly resistant: Silecia 1, Silecia 5, Tenguel 20, EET 261, SCA 6, SCA 12, ICS 8.

A more rapid method for testing the resistance of cacao to Witches' Broom disease has more recently been developed *(49).* It consists in placing cacao beans deprived of their testas into a suspension of spores (200,000 per cubic centimeter) and then planting them out in the field. After 4 to 6 months' growth, the seedlings are classified according to the degree of infection that they exhibit.

2) *Selection for resistance to Black Pod disease (Phytophthora):* Little work has been done on selection for resistance to Black Pod disease of cacao. In Samoa, a high degree of resistance has been reported for clonal material derived from

a tree known as Lafi 7 which had not shown any infection for 4 years though surrounded by infected trees *(39)*. Some independent investigations have been carried out on the relationship between seedling resistance and resistance of the parent tree *(13)*. Inoculation tests performed at Turrialba, Costa Rica, showed that the pods of resistant trees become discolored at a more rapid rate than those of other trees *(14)*. In an investigation carried out at I. I. A. S., Turrialba *(63)* the dry weights of the mycelium of the fungus cultured in liquid extracts of the husks of pods of different clones showed differences between them. Clones UF 11 and UF 12 proved to be the best. Different degrees of resistance have been observed in Ghana *(89)*; the following clones were found to be resistant: Lafi 7, Clone 12 B (Camaroons) SIC 28 (Brazil) and ACU 85 (W. A. C. R. I.). At La Lola (Costa Rica) seedlings selected for immunity or low resistance to *Phytophthora* showed variable degrees of resistance to natural infection by the disease *(15)*.

A more intensive and exhaustive study of resistance to this disease, which causes such great losses in all the cacao-growing areas of the world, might result in the discovery of complete resistance. The problem is complicated by the possibility of the existence of physiological races of *Phytophthora palmivora* such as have been found to occur in *P. infestans*. In such event, the work of selection for disease resistance would be greatly complicated.

(3) *Selection for resistance to other diseases:* Investigation of resistance to *Ceratostomella fimbriata* has not been carried out to any appreciable extent, although certain types of cacao, for example, Criollo cacao and its derivatives, and the Nacional cacao of Ecuador, are known to be highly susceptible to attack *(31)*. In the case of Cushion Gall, a high degree of resistance has been reported for clones UF 29, UF 242 and UF 273 to the flowery type of gall *(51)*. A wide range of resistance to Cushion Gall disease apparently occurs in cacao. A study of this inheritance might be useful but further information is first needed concerning its cause and mode of transmission. Resistance to other diseases, for example, *Monilia, Collectotrichum* and *Diplodia,* has not yet been studied.

(4) *Selection for resistance to insects:* Certain diseases of cacao, such as Swollen Shoot, *Ceratostomella* and possibly Cushion Gall disease are associated with attack by certain insects and studies of resistance to these might yield useful results, for example, in the case of thrips, capsids and aphids.

(II) CACAO HYBRIDS

Most cross-pollinated plant species depend on outbreeding (exogamy) to maintain the vigor of their populations. The crossing of different types of cacao produces plants having greater vigor than their parents. When cacao was first cultivated, following its discovery in Tropical America, plantations consisted of more-or-less uniform populations (Criollo, Nacional, etc.) but, with increased planting, the different types of cacao that were planted became mixed together and inter-hybridization occurred, thus producing populations that, not only showed greater vigor, but also gave greater yields than the original tree populations. The Trinitario group of cacao types originated in this way and replaced in nearly all the countries of Tropical America the Criollo and Nacional populations which they surpassed in vigor, yield and resistance to cryptogamic diseases.

Many investigators from the time that cacao cultivation began have noticed the effect if inbreeding in reducing the vigor in plants that are produced by self fertilization, and also the occurrence of hybrid vigor in plants resulting from crossing, particularly between individuals of differing types and origin *(8) (27) (55) (58) (59) (66) (68) (78) (79) (81) (83) (84)*.

Not until 1943, however, were any attempts made to utilize hybrid vigor by artificial crossing effected by hand pollination *(58)*. In that year, controlled pollinations were carried out in Trinidad between the clones SCA 6 and SCA 12 with certain superior ICS clones, the primary object being to combine in the hybrids resistance to Witches' Broom disease characteristic of the first with the good agricultural features characteristic of the second. The immediate results obtained showed that these hybrids, besides having a high degree of resistance to this disease, also showed remarkable precocity by beginning to produce cacao pods when only 3 years of age, and by giving average yields that were considerably higher than those given by clones of the same age and by seedling trees produced by uncontrolled pollination *(4) (5) (37) (38) (52) (58) (59) (66) (80) (81) (83)*. The following table gives data showing the yields of some of these crosses at different ages:

YIELDS OF SOME SCAVINA X TRINITARIO CROSSES *(25)**

(Lb. dry cacao per acre; trees planted 7 x 7 feet apart)

	1954-55	1955-56	1956-57	1957-58
ICS 1 x SCA 6	853	1283	1709	1950
ICS 1 x SCA 12	797	1432	1934	2281
ICS 6 x SCA 6	1034	1461	2279	2572
ICS 6 x SCA 12	909	1410	2497	2200
ICS 60 x SCA 6	684	1036	1349	1850
ICA 60 x SCA 12	834	1504	1932	2200

A similar line of work was started later in Ecuador in which attemps were made to combine resistance to Witches' Broom disease shown by the local clones Silecia 1 and Silecia 5, and by SCA 6, SCA 9 and SCA 12 with the desirable features shown by other local clones *(37) (38) (80)*. Early information has shown that these crosses give much higher yields than other trees produced either from seed or by vegetative propagation.

Some of the hybrids, for example, Silicia 1 x SCA 6, have not shown any infection by Witches' Broom in 6 years, and their yields have been high *(37) (80)*.

* NOTE: Comparison is not shown in this table with yields given by the parent clones so that the precosity of the hybrids is not revealed by the data. Nor is it stated whether fertilizers were used nor what were the ecological features of the atmospheric and soil environment which are known to affect growth and production just as much or more than genetic composition. (Editor).

In Ghana and Nigeria, hybrids obtained by inter-crossing certain Amazonian selections, and by crossing Amazonian selections with local Amelonado and with Trinidad selections have given high yields and have shown precocity and vigor *(42) (43) (68) (81).* In West Africa, the general cacao population consists of an exceptionally uniform kind of Amelonado cacao. The reason for this uniformity is that almost all the cacao trees come from pods of a few trees introduced from San Thomé whose ancestors probably originally came from Brazil. Since no other types of cacao had been introduced into West Africa, the interchange of genes having been limited to the same kind of Amelonado cacao, the variability of the cacao population is small. Hence, when African selections are crossed with Amazonian and with Trinitario clones, great hybrid vigor is manifest in the progeny.

The discoveries described above have awakened great interest in the application of the principle of hybrid vigor which is brought about by crossing certain types of cacao, and have stimulated the production of interclonal hybrid seed for the purpose of developing cacao populations having high yielding capacity and showing great resistance to diseases and great precosity, which facilitate better plantation management. Considerable variability in yield, type of cacao and other characters occur in hybrid progenies, as in ordinary cacao populations, because the parent plants used for producing the hybrids are not pure lines but are strongly heterozygous in regard to a large number of characters. In spite of this fact, the average yields of certain of the more acceptable combinations are higher in comparison with the average yields of cacao populations developed without controlled pollination. Furthermore, a considerable proportion of individuals will have inherited high resistance to Witches' Broom disease.

The principles involved in the formulation of a hybridization program are briefly as follows.

(i) Definition of the objectives to be achieved, that is, a clear visualization of the results desired. For example, the possibility of combining in a single clone the desirable features displayed by two separate parent clones.

(ii) Collection of the necessary material within a clonal garden which is needed to produce the desired hybrids. If this material is not available locally, then it should be introduced from other areas or countries, preferably through a quarantine station. A thorough knowledge of the heredity of the characters which it is desired to incorporate into the hybrids is a great help to the breeder but, unfortunately, not much information of this sort is available at present in the case of cacao.

(iii) Applications of methods of artificial pollination.

(iv) Evaluation of the progenies resulting from controlled crosses.

The choice of methods of evaluation depends on the character or characters in question. In the case of diseases whose resistance can be gauged when the plants are young, it would be best first to eliminate susceptible plants by means of artificial inoculations carried out in the greenhouse. Later the survivors should be planted out in the field for testing under natural conditions.

The evaluation of hybrids for yielding capacity, as well as for other characters, should be carried out by field experiments in which simple yet suitable experimental designs are employed. In examining hybrid populations that are highly heterozygous, special consideration should be given to the number of plants per plot and the number of repetitions that are used. At the Cacao Center, I. I. C. A., Turrialba, a minimum of 80 to 100 plants are tested in a single trial in plots each consisting of 16 trees planted at a distance of 3 x 3 meters or less. As soon as production begins, records should be taken, for each individual tree, of yield, incidence of diseases and pests and other characters that are being studied.

The primary aim of hybridization should be to produce superior trees for vegetative propagation as new selections and for use in future breeding programs. During the time that methods for producing more uniform populations having the desired characters are being perfected, hybrid seed, produced by suitable combinations of clones, would be preferable to unimproved seed planting material for establishing new plantations.

The problem of producing hybrid seed on a large scale when one of the parent clones is self-incompatible is simple. All that is necessary is to plant alternate rows of the self-incompatible clone and of the pollinating clone within isolated blocks of other cacao. Only the seed produced by the incompatible trees should of course be used because this must be the product of the other clone. Until the time when hybrid seed gardens have been formed or in cases when both clones employed for crossing are incompatible, recourse must be made to artificial hand pollination.

ARTIFICIAL POLLINATION OF CACAO

The following method of artificial pollination for application to cacao is based on the results and experience gained by various investigators at different experiment stations *(12) (47) (74) (88)*. The materials required comprise (i) transparent glass or plastic tubes open at both ends, of dimensions 1.5 to 2.0 cm. diameter by 5 cm. length, ii) plasticine, (iii) cheesecloth, (iv) pointed forceps, (v) plastic tags or labels, (vi) rubber bands, (vii) magnifying lens.

One of the open ends of a tube is covered with a piece of cheese cloth held in position with a rubber band. The other end is placed over a flower and sealed to the bark of the tree with a piece of plasticine. By this means, insects are excluded but the circulation of air is not impeded. The flower is hand pollinated as follows.

(i) A flower bud which will open on the day following is selected from a cushion. Such a bud can be recognized by its white or whitish-green color and its swollen appearance. ii) The selected bud is protected fixing a tube over it in the manner described above. (iii) During the morning of the day following, when the flower has opened and its stigma has become receptive, pollen from the same flower or from another flower of the same tree is applied to the stigma by means of a small camel's hair brush, without first emasculating the flower by removing the stamens. This kind of pollination is termed selfing and is applicable to self-compatible kinds of cacao. (iv) In the case of self-incompatible cacao, or to make crosses, the flower must first be emasculated. This is easily effected by removing by means of the forceps the five petals to which the stamens are attached, taking care not to dislodge the pollen by unduly shaking the stamens. (v) After removing the petals, two or three of the staminodes are cut away so as to give access to the stigma. (vi) Flowers of the tree which is to be used as male parent or pollinator are collected in Petri dishes. The sepals and petals of these flowers are removed by means of the forcps, leaving the ripe anthers still attached to the stamens of the flowers. Suitable anthers are pearly-white in color and are readily distinguished from old anthers which are brown and contain yellowish pollen. (vii) The absence of pollen from the stigma of the flower to be hand pollinated should be verified by inspection under the magnifying glass. (viii) An anther of the male parent is gently rubber over the stigma of the emasculated flower so as to detach a suitable amount of pollen and to cause it to adhere to the surface of the stigma. The presence of pollen on the stigma is ascertained by inspection under the magnifier. (ix) The pollinated flower in all cases is immediately protected by placing a glass tube over it as described above. (x) Each hand-pollinated flower is labelled by attaching a tag to it on which has been inscribed the clonal number and designation of the parent cacao trees, the date and the initials of the operator. (xi) After an intervals of 3 to 5 days, the pollinated flowers are inspected to ascertain whether fertilization has taken place. Successful fertilization is indicated by a swelling of the ovary. If it has occurred, the protecting tube is removed.

In order to prevent undue wilting and shedding of the young fruits resulting from hand pollination, the following precautions are taken.

(i) Remove all other fruits that have been produced by natural open pollination.

(ii) Apply periodically a suitable fungicide in order to prevent *Phytophthora* infection.

(iii) Place a polyethylene bag around each developing fruit and tie it round the pedicel.

THE PROBLEM OF SELF-INCOMPATIBILITY IN CACAO

Self-incompatibility is a genetical character of general occurrence in cacao as well as in many other cross fertilized crops, for example, maize, onion, beet and sorghum. It is explained by the fact that the presence of certain genes inhibits the fertilization of the ovules by the pollen produced by the same plant. This means that fertilization depends on the pollen of another plant having a different genetical type of compatibility.

The first investigator to note the occurrence of self incompatible cacao was S. C. Harland in Trinidad in 1925 *(46)* and later F. J. Pound in *(70)*. Many investigators working in different areas have stressed the fact that a relationship exists between yield and degree of compatibility of cacao trees, self-compatible trees being high-yielders and self-incompatible trees being low-yielders *(17) (18)*

(19) (20) (29) (35) (64) (65) (67) (86). Numerous investigations have been undertaken to determine the causes of self-incompatibility and the degree of self-incompatibility. Self-incompatible trees having different geographical origin were found to cross easily and even self-incompatible trees from the same region were observed often to be compatible when crossed *(67).*

Th problem of incompatibility in cacao in its chemical and physiological aspects has been studied in Colombia *(60) (61) (62) (82).* Extracts made from the gynecia of the flowers of self-incompatible trees when incorporated into glucose-agar employed as a pollen-growing medium, strongly inhibited the germination of the pollen and the growth of the pollen tube. On the other hand, pollen tubes were found to grow normally in self-pollinated flowers and also in those of crosses between self-incompatible trees which suggested that the seat of the antagonism is located in the ovary *(23) (24).* Later, fusion of the nuclei of the pollen grains with those of the ovules was proved not to take place in the flowers of self-incompatible trees. Using the technique described, incompatibility can be proved by microscopic observations within 5 hours after pollination has occured *(23).* If the nuclei unite, the gametes are self-compatible and if they do not, they are self-incompatible. This method appers to be more reliable and probably less time consuming than the method which depends on the determination of the extent of fertilization by counting young pods produced by hand pollination.

The first genetical explanation that has been suggested for the phenomenon of incompatibility is that fertilization is controlled by a series of five alleles operating at the same locus. These alleles were designated S. They operate with the following order of dominance S_1, $S_2 = S_3$, S_4, S_5 *(53))54).* The presence of a sixth allele, recessive to the five others, was later proposed and of two additional independent factors which were called A and B. These latter are believed to produce some kind of substance or substances upon which the S factors act to form their respective antigens and antibodies *(24).* Only two alternatives exist for the A and B factors but many exist for the S factors. The theory was proposed that each gamete possesses its own specific antigen or antibody substance for the various S alleles present in the cytoplasm of the nuclei of both the pollen grain and the ovule *(24).* Investigations on the different possible causes of incompatibility in cacao are being continued in Trinidad and in Ghana. Greater knowledge of the mechanisms of compatibility that exist in the different clones is essential for future application to commercial plantations as well as to programs of hybridization.

SUMMARY

1. Cacao seedling populations show great variability in most of their botanical characters. This is a distinct advantage to the geneticist and the plant breeder who are endeavoring to produce new types or strains of cacao that resist diseases and pests and that yield large crops under suitable environmental conditions.

2. When a desirable type or strain of cacao has been produced, it can readily be propagated by vegetative means.

3. The procedures used by the cacao plant breeder are, (i) selection of the best clones for subsequent vegetative propagation and (ii) hybridization for the transmission of desirable characters.

4. The methods used are separately described under the headings, selection for high yield, selection for quality and selection for disease and pest resistance.

5. The design of suitable field experiments, and the size of the plot needed to give experimental precision, are discussd in connection with the testing and comparing of new cacao types or strains, both clonal selections and hybrids.

6. A high degree of hybrid vigor and marked precocity are shown by crosses between cacao genotypes that have developed originally in widely-separated areas. By crossing differing types of cacao variously characterised by resistance to diseases and pests, high yielding propensity and high pod and bean quality, hybrids having great commercial value are being produced in increasing numbers in several cacao-growing countries.

7. The possible value of inter-clonal hybrid seed as planting material has attracted the attention of cacao growers, and hybrid seed is likely to be used in increasing quantity in future new plantings and in rehabilitating old ones.

8. The principles involved in formulating a hybridization program are discussed. The primary scientific aim of hybridization is to produce superior trees for vegetative propagation and for use in cacao-breeding programs.

9. The method used in hand-pollination of cacao flowers is described whereby desirable controlled crosses are produced.

10. The problem of self-incompatibility in cacao is discussed in its various aspects.

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PART IX:

CURING AND MANUFACTURE OF CACAO PRODUCTS

CHAPTER 26

THE CURING OF CACAO

INTRODUCTION

Long ago the discovery was made that, by allowing a heap of cacao beans freshly extracted from the pod to stand a few days, the beans soon began to "sweat", liberating a considerable quantity of liquid (sweatings) and giving off much heat. At the same time, the pulp cells rapidly disintegrate and the beans become less slimy and easier to handle. They can then readily be dried and stored prior to shipment with less possibility of damage by moulds and insects. The sweatings at first contain alcohol but later this is replaced by acetic acid formed by its oxidation. Much carbonic oxide gas is envolved during the alcoholic stage and large numbers of fruit flies are attracted to the heap. These infect the beans with acetic bacteria and other micro-organisms.

Profound biochemical changes affect the components of the bean cotyledons during sweating. These changes are accompanied by loss of astringency and by the diffusion of purple pigment out of the cells of the cotyledons that contain them into the adjacent colorless tissues, including those of the radicle and plumule. At the same time, the purple coloration gradually gives place to brown, particularly when the beans are subsequently dried. The most important change of all, however, is that which produces the precursor of the chocolate flavor that particularly manifests itself when the dried beans are eventually roasted. This essential change does not take place unless certain precise conditions are observed, and it is only in recent years that these required conditions have been accurately determined. Nevertheless, by trial and error, certain standard procedures for processing cacao beans have been envolved in different countries and these will first be briefly described before further consideration is given to the biochemical aspects of cacao curing. These procedures have been variously termed "fermentation", "preparation", "processing", and "curing". They also include drying whereby the beans are finally stabilized. Strictly speaking, only the early stages should be called "fermentation" since they alone depend on the activity of living organisms, namely, yeasts in the alcoholic stage and acetic bacteria in the acetic acid stage. Accordingly, the term "curing" will be used for the whole process and it will be considered under two heads, namely, (i) fermentation mostly controlled by micro-organisms, and (ii) internal enzyme actions which do not directly involve micro-organic life.

PRACTICAL ASPECTS OF CACAO CURING

There are two main procedures practiced now-a-days for curing cacao beans, namely (i) curing in heaps and (ii) curing in boxes. The first is the simpler method and is generally used by peasant farmers. The heap varies greatly in size. In some cases, the beans are put into a hole in the ground. The heap is usually covered with banana leaves or sacking. The second (box method) is mainly practiced by large-scale growers on the plantation or in cooperative central curing stations where several batteries of curing boxes are often employed.

Generally the mass of beans is turned periodically, either by remaking the heap or by transferring the beans from one box to another. The frequency of the turning depends partly on the size of the heap or box and partly on the variety of cacao undergoing curing, Criollo cacao usually being afforded less time and fewer turnings than Forastero cacao.

(1) *Curing in heaps:* This is the method most commonly practiced in West Africa *(45) (46) (47) (48) (67)*. The size of the heap varies from 20 lb. to over 5000 lb. The heap may be left undisturbed throughout the whole of the curing period, or it may be turned once or more times by breaking it down and reforming it on the same or a neighbouring site. The rate of curing is quicker for the beans at or near the surface as compared with those at the center of the heap. Nevertheless, even without mixing, the curing of fairly large heaps of cacao beans is apparently complete within 24 to 30 hours when followed by 6 to 12 hours sun-drying *(67)*. In small heaps, the temperature of the beans on the outside is almost the same as that of the beans near the center. Even in medium sized heaps of, say, 250 to 500 lb. weight of beans, the temperature difference between the outside and the inside is never appreciable and reaches a minimum in 3 to 4 days. The effects of mixing are not accurately known in the case of heap curing, and there does not yet appear to be any great advantage in practicing it *(67)*.

(2) *Curing in boxes:* This is the method commonly used in most of the well established cacao-growing regions of Central and South America, Ceylon and Indonesia. As an example, the system used in Trinidad will be described *(7) (8) (61)*. This consists in placing the wet beans, in batches varying in weight from 400 to 3000 lb., into a strong wooden box provided with holes at the bottom through which the sweatings drain away. After standing in the first box for 2 or 3 days, the beans are transferred to a second box. During this operation, which is carried out with wooden shovels, the temperature falls appreciably and carbonic oxide gas escapes. The temperature soon rises again as the curing proceeds. After one, two or three days more, the beans are put into a third box and kept there up to a total of six but not usually more than eight days. The quantity of sweatings liberated from a 3000 lb. batch of wet beans filling a box 5 x 4 x 3 feet in dimensions, is about 40 gallons. The liquid is generally run to waste. The pulp cell sap (pH 4.0) contains citric acid and much glucose sugar which accounts for the alcoholic fermentation.

The changes in temperature that the have been recorded in sweat boxes vary appreciably in magnitude and range. An example of a typical run is given below (San Juan Estate, Trinidad) *(44)*.

PERIOD	TEMPERATURE		CONDITION OF BEANS
Beginning of day	*C degrees*	*F degrees*	
1. First box	33ºC	92ºF	Alive
2. First box	35	95	Some dying
3. First box	49	120	Mostly dead
4. Second box	47.5	117.5	Mostly dead
5. Second box	50	122	All dead
6. Second box	48	118.5	All dead
7. Third box	47	117	All dead
8. Third box	46	115	All dead

Fermentation complete: beans transferred to drying tray.

NOTE:—Other runs gave maximum temperatures of 49.5C (121ºF), 50.3º C (122.5ºF), 51ºC (123.5º) and 52ºC (125ºF). Generally, the temperature of the contents of the sweat boxes lies close to 50ºC (122ºF) after the beginning of the third day until the beginning of the sixth or seventh day after which it falls rapidly.

In a good fermentation under the Trinidad system, most of the cacao beans are dead by the beginning of the third day. A cut section of the beans just before death occurs shows an outer zone of pigmented tissue into which acetic acid has penetrated and has destroyed the semi-permeability of the cell membranes *(64)*. Soon the whole of the cotyledon tissue and that of the radicle and plumule become uniformly purple in color. The beans are now swollen and plump and are full of purple juice. Thereafter the color of the tissue becomes progressively paler and finally cinnamon brown. By the beginning of the fifth day, the cells have desintegrated and the mass of beans has become sticky. The micro-organic flora has rapidly diminished by this time, and no more carbonic acid gas is generated, although possibly some may still be liberated by oxidation of carbohydrate in the cotyledons *(45)*. The further obvious chemical changes that occur within the bean are loss of moisture, loss of astringency, deepening of the brown color, shrinkage of the cotyledons away from the testa and their separation into halves. A gradual development of aroma and flavor also takes place. These changes are continued and intensified when the beans are dried in the sun or in artificial driers. The dried beans possess a crisp break and their testas have separated from the fractile cotyledons.

Numerous factors affect the rate and completeness of cacao curing, for example, pod ripeness, duration of time between reaping and pod breaking and between breaking and putting into the box or heap, the degree of heat insulation provided by the walls of the box or the cover of the heap, the length of the curing time, the frequency of turning and the method and time of drying *(48)*. Certain of these factors can be varied within wide limits without appreciably affecting the features of the final product but others exert profound influence when altered, for example, the length of time which elapses between opening the pods and putting the beans into the box or heap which should not be much greater than 24 hours for best results *(48)*. The time of box curing can be varied from 6 to 8 days without much alteration in the properties of the product, but periods longer than 7 days are not to be recommended because of the marked deterioration that sets in, the beans emitting a smell of ammonia *(48)*. Temperature variations are greater in the heap than in the box, possibly because of variability in degree of aeration due to irregular packing, and for this reason, box curing is preferable to curing in heaps.

In the sweat box method of cacao curing, the two main variables are the depth of the bean mass and the length of time of the fermentation. The practice of filling large boxes over a period of several days is not to be recommended. When the quantity of beans is limited, it is best to use a smaller box or to subdivide a large one by partitions *(33)*. The optimum depth for a box fermentation is about 30 to 36 ins., although recently lesser depths of 6 to 4 ins. have been suggested, for example, in the Rohan tray method *(66)*.

The degree of acidity of the mass of beans changes greatly during curing. The fresh pulp is highly acid (pH 3.6) but the cotyledon tissue is nearly neutral (pH 6.6). As curing proceeds, the pulp becomes less acid (pH 4.9) and the cotyledon tissue more acid (pH 5.0) after 3 days. The acidity of the cotiledons diminishes again to pH 5.4 at the end of the curing period, and falls rapidly to pH 7.2 if curing is continued to the stage when ammonia is produced *(48)*.

THE BIOCHEMISTRY OF CACAO

In order to appreciate the significance of the results obtained by investigators who have studied cacao curing, and to understand the nature of the problems involved, something should be known about the composition of the cacao bean and the properties and reactions of its main components. The approximate composition of the parts of the beans of typical Forastero cacao is shown in the following table (Table I).

TABLE I

COMPOSITION OF CACAO BEANS

(Percent fresh weight)

	Cotyledons	*Pulp*	*Testa*
Water	35.0	84.5	9.4
Cellulose (fibre)	3.2	—	13.8
Starch	4.5	—	46.0
Pentosan	4.9	2.7	—
Sucrose	—	0.7	—
Glucose, fructose	1.1	10.0	—
Fat	31.3	—	3.8
Protein	8.4	0.6	18.0
Theobromine	2.4	—	—
Caffeine	0.8	—	—
Polyphenols	5.2	—	0.8
Acids	0.6	0.7	—
Inorganic salts	2.6	0.8	8.2
	100.0	100.0	100.0

Notes on some of the components of the cotyledons and pulp

1. *Fat, (Cocoa butter):* This is a pale yellow, brittle, crystalline substance which melts sharply at temperatures between 32º and 35ºC (90º and 95ºF) that is, just below body temperature. It consists of mixed glycerides of two saturated fatty acids (stearic and palmitic) and one unsaturated fatty acid (oleic). It is therefore a slightly unsaturated fat. Cotyledon fat contains 0.3 to 0.8 percent of theosterols, and testa fat 8.0 to 10.0 percent. Theosterols are the precursors of the antirachitic vitamin (Vitamin D) which is produced when theosterols are irradiated. It also contains 0.5 to 0.9 percent of lecythin which increases the mobility of melted cacao fat.

   The chief substitutes for cacao fat sometimes used in chocolate manufacture are Borneo tallow derived from the fruits of species of *Shorea* and *Palaquium,* and Chinese tallow derived from the fruits of *Stillingia sebifera.* These are often wrongly called "Illipe butter", which is produced by species of *Bassia.*

2. *Theobromine* (3,7 - dimethylxanthine): This is not a true alkaloid but, like caffeine of coffee and tea, it is actually a purine base. It crystallises in white needles and volatilises on heating to 290ºC. It is soluble in hot water and alcohol but not in petrol. It has a bitter taste.

3. *Proteins:* Not much is known about cacao bean proteins and their derivatives except that the pulp contains small amounts of glutamic and aspartic acids and asparagine. *(43) (17).*

4. *Acids:* The fresh pulp contains citric acid but no other fruit acid. This imparts a reaction of pH 3.9 to the first sweatings which contain 0.3 g. of citric acid per 100 ml.

5. *Polyphenols (Cacao tannins):* Cacao cotyledons contain at least ten different polyphenolic entities, as follows *(25) (27) (28) (32).*

TABLE II

POLYPHENOLS OF CACAO BEANS

(Percent oven-dry weight)

Catechins (mostly epi-catechin and 3 others)	3.0 percent
Complex tannins	2.1 percent
Leuco-cyanidins; 1, 2, 3	2.5 percent
Cyanidin glycosides; 1, 2 (purple pigment)	0.4 percent
	8.0 percent

These are all water-soluble substances having a highly astringent taste. The purple cyanidins are compounds of galactose and arabinose sugars respectively. They do not occur in Criollo cacao beans. These glycosides contain less than 6.0 percent of total polyphenols consisting mainly of colorless leuco-cyanidins, cotechins and tannins. All these substances, on oxidation, yield insoluble tasteless products having a brown color.

RESULTS OF RESEARCH ON CACAO CURING

A summary of the earlier results obtained by some 27 different investigators who had sporadically studied the curing of cacao, was published in 1948 *(35)*. The following main conclusions had then been reached:

(1) The important changes that go on within the cacao bean during curing do not begin until the embryo has been killed.

(2) The chief chemical changes comprise the enzymic oxidation of the polyphenol components of the cotyledon tissue.

(3) Cacao beans should not therefore be heated above the temperature of inactivation of the oxidase enzyme which is probably around 80ºC (176ºC).

(4) Adequate aeration should consequently be provided during the curing process.

(5) Curing brings about other important changes besides merely removing the pulp and killing the embryo.

(6) Acetic acid, produced during fermentation, penetrates the testa (shell) of the bean and participates in the killing of the embryo.

(7) Certain minor substances formed during fermentation may be important in determining the final flavor of the roasted bean. (This opinion was not held by all the investigators).

(8) The initial stages of curing *(ie.* fermentation) can be improved by inoculating the beans with certain strains of yeast. (This view also was not held by all the investigators).

Since these conclusions were reached, renewed interest in cacao curing has been aroused mainly through the interchange of ideas made possible by the convening of conferences by the Cocoa, Chocolate and Confectionery Alliance, Ltd. in London ,at which chocolate manufacturers have discussed their problems with investigators working at the chief cacao research institutes, namely, the Imperial of College of Tropical Agriculture and the Colonial Microbiological Research Institute in Trinidad, the Inter-American Institute of Agricultural Sciences at Turrialba, Costa Rica, the West African Cacao Research Institute of Tafo, Ghana, West Africa, and the British Food Industries Research Association in London, and with members of Departments of Agriculture of several of the cacao-growing countries of the world. The main findings of this more recent research will next be considered.

RESULTS OF RECENT RESEARCH ON CACAO CURING (AFTER 1948)

Germination: Some authorities have claimed that the first stage of the curing process takes place in the cacao seed between the times when it is removed from the pod and put into the fermenting box or heap *(72) (74)*. As soon as air and moisture gain access, germination begins and certain biochemical reactions, some of which are concerned in respiration, are initiated. Germination occurs in damaged over-ripe pods whilst they are still on the tree, as well as in ripe pods in the collecting heaps in the field. It ceases as soon as the temperature of the fermenting mass in the box or heap rises above 35°C (95°F). In practice, it has been found impossible under field conditions to maintain viability for a period greater than 3½ days and at the same time to prevent seedling development. *Nor* apparently is it necessary for the production of a good chocolate flavor that such a long period of rest should be maintained *(1) (46) (67)*. Nevertheless, a shorter rest period of one or two days duration seems to be distinctly advantageous. Recently, a germination inhibitor has been found to occur in fresh cacao seed pulp *(33)*. This inhibitor is a volatile substance which is capable of suspending germination for as long as 14 days of beans kept at air temperature. The benefits of a short prefermentation rest period, if any, must therefore be attributed to some other cause *(33)*.

The processes which take place in the heap or in the sweat box comprise two definite and distinct phases *(25) (29) (32) (64)*. These may be termed Phase I, Fermentation, and Phase II, Oxidation.

PHASE I: FERMENTATION (AND HYDROLYSIS)

The question as to whether fermentation of the sugary cacao pulp, involving yeasts and acetic bacteria, is essential to the final development of the full chocolate flavor, in that it possibly adds certain aromatic substances to the beans, has been answered in the negative by the results of certain experiments in which the pulp was sterilised by spraying the fresh beans with antiseptic solutions before curing and roasting in the normal way *(46) (72) (74)*. The final flavor did not differ appreciably from that of unsterilised, cured and roasted beans produced by the normal process. Nevertheless, it is reasonable to suppose that the organisms of fermentation, whilst not necessarily contributing to the development of chocolate flavor might at least add small amounts of auxiliary substances that might influence the final quality of the cured beans.

It is at present generally believed that the really important effects of fermentation proper, apart from eliminating the slimy pulp and thus rendering the beans easier to handle and to dry, is to produce acetic acid and to generate heat. These two agencies together bring about the death of the beans and prepare the way for the next stage of the curing process *(29)*.

The limited supply of air in the initial slimy seed mass allows mainly yeasts to develop rather than mould fungi. Yeasts convert the pulp sugar into alcohol and carbonic oxide gas. As the pulp cells collapse, air enters and the conditions now favor the rapid oxidation of the alcohol to acetic acid through the agency of acetic bacteria that are brought to the fermenting mass by fruit flies. By the third day of the curing process, equilibrium has been set up between acetic bacteria and yeasts *(29)*. During the second day, the beans are killed mainly through the penetration of acetic acid into the cotyledon tissues. The killing of the beans is accompanied by an increase in the permeability of the cell walls which permits the interdiffusion of the components of the cell sap. The enzymes are thus brought into contact with the polyphenols and the proteins. This initiates certain hydrolytic reactions in which the purple cyanidin glycosidal pigments are profoundly changed and the precursor or precursors of the characteristic chocolate flavor are believed to be produced *(29) (63)*. This is perhaps the most important and essential reaction in the whole of the curing process. In addition, the proteins are hydrolysed to amino acids *(17)*. Further, the leucocyanidins combine with the proteins or their degradation products during this stage *(29)*. The cyanidin pigments begin to disappear after 1½ days have elapsed and have completely disappeared in 3½ to 5½ days. The leucocyanidins at first seem to increase in amount up to 2½ to 3½ days but soon afterwards they disappear as such on combination with protein. Epicatechin remains unchanged during the first two days and after slowly disappears *(34)*. None of these reactions involves oxygen. Indeed, the presence of oxygen during this phase would be detrimental in that it might create intermediate products of polyphenolic oxidation that are known to destroy hydrolytic enxymes *(29)*. Thus once the beans have been killed by the penetration of acetic acid aided by rise of temperature, the essential part of the fermentation phase is strictly anaerobic and accordingly this phase has been termed the *anaerobic hydrolytic* phase of cacao curing *(29)*. The hydrolysis of the cacao polyphenols by glycosidase enzyme occurs best at a temperature of 45ºC (113ºF) and reaction pH 4.0 - 4.5 *(33)*.

During the fermentation phase a balance must be maintained between too little aeration, which would prevent the multiplication of yeasts and acetic bacteria with concomitant reduction in the amount of acetic acid and heat evolved, and too much aeration, which would not only allow mould fungi to develop but also would inhibit the formation of the flavor precursor. This balance is maintained in practice by suitably packing the beans in the box or heap whilst insuring free drainage and preventing undue loss of heat by employing properly-insulated perforated boxes, or by surrounding the heap with insulating material such as banana leaves or sacking. The length of time required for the beans to be killed by the penetration of acetic acid and the rise of temperature varies from two to five days, depending on the conditions under which the beans are packed.

PHASE II: OXIDATION

This phase follows the anaerobic hydrolytic phase and frequently overlaps it. The two phases can occur in different beans at different times and at the same time in different parts of a bean, depending on the method of manipulation of the bean mass *(64)*. Moreover oxidation is continued in the drying stage after the beans have been removed from the sweat box or heap and have been spread out in the sun on trays to dry or have been placed in the artificial drier. The second phase consists essentially in the oxidation and chemical condensation of the polyphenolic compounds into complex insoluble products having little or no taste. It has therefore been termed the *oxidative condensation* *phase (29).* It continues until the moisture content of the beans has been reduced to a point where enzyme activity is no longer able to proceed *(64).*

Color changes: The biochemical changes described for the two phases of cacao curing are accompanied by conspicuous changes in color of the cotyledons. The surface of the cotyledons of a fresh purple cacao bean is speckled and not uniformly colored because the pigment is contained only in one out of every ten cells of the cotyledon tissue *(64).* After the bean has been killed, only the center part is speckled, the outer part now being uniformly purple in color because of the diffusion of pigment into cells which initially did not contain it. Eventually the speckled appearance vanishes and the color throughout becomes paler through the gradual decomposition of the purple cyanidin glycosides under the influence of the anaerobic hydrolityc enzyme.

When oxygen has gained access to the cells of the cotyledons during the oxidative-condensation phase, the color turns brown at the surface and later the whole bean becomes brown throughout as the moisture content is reduced by drying and air penetrates more freely into the cotyledon tissue. The appearance of the color thus marks the transition between the first and second phases of the curing *(64).* According to these facts, the presence of a large proportion of purple beans in commercial cured cacao must obviously be regarded as a serious defect, in spite of the claim that it appears not to exert any adverse effect on quality *(66)* an opinion which, however, is not generally accepted *(71).* Although the purple pigment itself may not affect the flavor, its presence indicates that other defects are likely to occur as a result of an imperfect or incomplete curing *(64).* The permissible upper limit of residual concentration of purple pigment in West African commercial cured cacao has been set at 10 percent of the amount occuring in the fresh raw bean. When this amount is present, the concentration of the other polyphenolic substances, namely, catechins, tannins and leuco-cyanidins, varies between 10 and 60 percent of their original concentration *(66).*

The essential condition necessary for avoiding the maintenance or survival of the purple color appears to be high temperature which should not be allowed to fall much below 45ºC (113ºF) during the 6 or 7 days of the curing process. Fall in temperature can be prevented by adjusting the size of the heap or the dimensions of the sweat box and by ensuring adequate insulation by providing suitable covers or walls *(64).*

Index of satisfactory fermentation: Based on all these considerations, a useful test for the completion of the first phase of curing, and one which would serve to decide when drying should be started, is the occurrence of a well-marked peripheral brown ring on the cut surface of, say, 50 percent of a representative sample of the beans. In a typical sweat box curing, this stage should be reached at about the sixth day *(64).*

Chocolate flavor: The identity of the aromatic substance or substances that give to chocolate its characteristic flavor and which are present only in small amount in the roasted cured beans is not yet known. It is believed to be an aromatic resin rather than a volatile essential oil, in which case it should be possible to isolate it by means of gas-liquid chromotography *(29).* Present day opinion attributes its origin to the leuco-cyanidin component of the polyphenols of the cotyledons. Possibly it is formed by interaction between a leuco-anthycyanin compound and theobromine which occurs on roasting the cacao beans *(79).*

SUMMARY

The chief factor determining the success of a commercial curing is undoubtedly the time taken to kill the cacao beans. Until death occurs, the enzymic reactions cannot take place because of the separation of the enzymes from the substances which they are capable of transforming. Under a suitable balance of moisture and air, and with precautions taken to prevent heat loss, micro-organisms multiply greatly in the pulp and rapidly raise the temperature of the fermenting mass to 45° or 50°C (113° or 122°F) and the beans will be killed in less than 2 days by a combination of heat and acetic acid penetration. The conditions within the bean are then satisfactory for anaerobic enzymic hydrolysis. This reaction is partly inhibited by the presence of polyphenols and delayed by the restricted rate of diffusion of the cyanidin pigments. Nevertheless, the pigments are generally completely hydrolysed in less than 2 or 3 days after the beans are dead.

Under unsuitable conditions (for example, small bulk of beans, poor insulation, premature drying-out, sugar-deficient pulp) some of the beans may not die until late in the curing process and even then the conditions may still be unsuitable (for example, too low a temperature, too little moisture, too little air for oxidation) so that they may still retain their purple or slaty color. The proportion of purple beans in the final cured product is thus directly related to the temperature and reaction under which the process was carried out, and therefore also to the flavor of the fabricated chocolate.

The cyanidin pigments themselves do not contribute much to the final flavor since non-pigmented varieties of cacao also produce high quality cacao when properly cured. The source of the flavor component must therefore be sought among the leuco-cyanidins which liberate sugars when hydrolysed. It is less likely to be found among the other polyphenolic substances, namely, catechins and tannins.

SMALL SCALE CACAO CURING

The plant breeder and the geneticist urgently need a reliable method for curing small quantities of beans so that they may be able to test new varieties or strains of cacao when only a few pods are available. The first attempt (1935) to cure cacao in small batches made use of the solar frame *(58) (15)*. By this means, an amount as small as 40 lbs. of wet beans could be satisfactorily cured. Even this amount is too large for the purpose in view and certain basket methods that have since been suggested are unsuitable for the same reason. The real need is for a small-scale laboratory method which will deal with only a few beans at a time *(63)*. The following are the chief small-scale curing procedures which should meet the needs of the plant breeder and the geneticist *(63) (79)*.

(1) MacLean's method, 1950 *(54 (57)*

The reaction vessel is a 10 cm. Büchner funnel inserted into a flask which receives the sweatings. Arrangements are made for passing air into the flask and through the funnel. The beans from a single pod are placed in the funnel and a "starter" is added consisting of 10 g. of pulp from fermenting beans together with 2 g. of glucose. The funnel is covered with a glass lid having a central hole in which a thermometer is fixed. The funnel and flask are placed in an electrically-heated oven whose temperature is raised from 38ºC to 49ºC over a period of four days, a stream of moist air being circulated through the beans. Subsequently the beans are dried in the sun.

(2) De Witt's method, 1951 *(11 (12)*

The reaction vessel is a 600 ml. beaker placed in a quart-size thermos flask. The beaker is heated by a resistance wire wound round it carrying an electric current. The beans are exposed to the atmosphere for an hour before they are put into the beaker. Continuous aeration is provided. Natural infection by air-borne micro-organisms soon ensues.

NOTE: In both these methods, the micro-organism population is not controlled; its effect, if any, on the features of the final product may therefore be variable. The three following methods are independent of micro-organism influence.

(3) General Foods Corporation method, 1948 (U. S. Patent)

The beans are washed free of pulp and then heated in a special vessel to 55º or 60ºC (131º or 140ºF) for 24 hours, the moisture content being maintained above 12 percent.

(4) Wadsworth and Howat's method, 1954 *(72) (74)*

The reaction vessel is a sterilized beaker covered with aluminum foil and containing a little potassium hydroxide solution for absorbing carbonic oxide gas. The beans are sterilized before putting onto a raisd stand in the beaker. The beaker and contents are heated in an incubator at 35ºC (95ºF) for three days and then at 50ºC (122ºF) for three days more. The beans are finally dried in a box containing moist air at 45º to 50ºC (113º to 122ºF) by an electric light bulb.

NOTE: In accordance with the most recent information regarding the exact conditions necessary for a completely successful cure, none of the small-scale methods described above is entirely satisfactory, in that none accurately controls the two distinct phases of curing, namely, (i) the anaerobic hydrolytic phase, in which the flavor precursor is produced, and (ii) the oxidative condensation phase in which the astringent taste is removed and a brown color replaces the purple color of the fresh beans. The method next to be described seems to meet all the required conditions and at the same time to be simple to operate.

(5) Quesnel's method, 1957 *(63) (64)*

The bean pulp is first removed by agitation with a few rubber bungs in a domestic washing machine containing water for about 2 hours. A sub-sample of the pulp-free beans weighing 225 g. is then soaked in 225 ml. of a one-percent solution of acetic acid containing one percent of ethanol, both by volume. A one-pound Kilner jar containing the beans and liquid is then kept at 113ºF (45ºC) for 48 hours in an incubator. The beans are subsequently removed and dried slowly in the air.

SUMMARY

Several methods have been proposed as rapid and ready means of curing small quantities of cacao beans so as to enable plant breeders and geneticists to assess the quality of new varieties on the spot instead of having to submit bulk samples of raw beans to taste panels connected with manufacturers overseas. The most convenient of these small-scale methods is Quesnel's in which the depulped beans are killed with acetic acid and then incubated at suitable temperature for a sufficient length of time for completion of the hydrolytic precursor-forming phase. The beans are then slowly dried in air to allow the oxidative phase to proceed.

DRYING

At the end of fermentation, during which occur the essential chemical changes responsible for chocolate flavor, the moisture content of the cacao beans is about 56 percent by weight of beans. During subsequent drying, these chemical changes continue while the moisture content slowly falls to about 6 percent. If the moisture content is brought below this level, the beans become excessively brittle, but if the beans are not dried to this extent, they become susceptible to damage by mould fungi. The final stable moisture content necessarily varies somewhat depending on atmospheric conditions, such as air temperature and humidity. Since enzymes are involved in the chemical changes that occur in the early stages of drying, the process must not be too rapid, otherwise the high temperature and the low moisture content which are attained will bring about the inactivation of the enzymes before the essential chemical changes have been completed.

It has been found that artificially-dried cacao beans contain greater amounts of acetic acid than beans dried slowly in the sun, and that chocolate prepared from them possesses a distinct "fruity" flavor, presumably owing to the formation of acetic esters *(45) (48)*. The excess of acetic acid in artificially-dried beans can be removed by extending the period of the "conching" stage of chocolate manufacture, which expedites the removal of acetic and its esters by volatilization.

In most countries where cacao is grown, the fermented beans from heap or sweat box can conveniently be dried in the sun but, in some countries, the cacao harvest either coincides with the rainy season or with a period of high humidity which necessitates drying them artificially. For example, artificial driers are customarily employed in Costa Rica, Cameroons, Belgian Congo and Samoa, as well as in most plantations in Brazil.

The apparatus used for artificial cacao drying ranges from simple platforms to mechinically-rotated drums or endless belts carrying small trays. The simplest kind of drier consists of a floor heated by a flue situated underneath it. The beans are raked at frequent intervals to ensure uniform drying. Generally the drying takes 4 to 5 days for completion. Another simple kind of drier consists of a platform made of wooden slats through which a current of air, heated by a flue, rises by convection. This type of drier is commonly used in Samoa and recently it has been introduced into the Cameroons. It is generally known as the "Samoan drier" and has been fully described and illustrated in a special publication in which the practical details of its construction are clearly indicated *(5) (48)*.

The rotary type of cacao drier, such as the Gordon and the McKinnan driers, has attained great popularity in many countries. The abrasive action of one bean on another during rotation in this kind of drier generally reduces the thickness of the testa which can result in a greater quantity of broken beans *(47)*. The rotary type of mechanical drier, as well as the type in which the beans are placed on an endless belt of trays (the Büttner drier) are much more expensive than the simpler stationary driers the best of which are highly efficient and are capable of maintaining a temperature of 80ºC (176ºF) for a 14 hours' drying period without detrimental effect on cacao quality *(48) (76)*.

It has been calculated that about 1½ tons of wood fuel are needed to dry adequately one ton of fermented cacao beans *(76)*. Where wood fuel is not readily procurable, oil fuel is generally used; this is expensive and care must be taken that it is fully burnt, otherwise there may be a risk of taint by contamination of the beans with the products of incomplete combustion when direct drying by hot gas in practiced *(76)*.

SUMMARY

Drying is essential for the completion of the oxidative phase of cacao curing and for stabilizing the beans. The final moisture content should be 6 percent. Best results are obtained by sun drying but where the climate does not permit sun drying, the use of artificial driers has proved to be satisfactory, provided certain essential details of construction are observed.

IMPROVED METHODS OF CACAO CURING

As a result of the greater understanding of the chemical changes involved in cacao curing and of the conditions which control them that has been acquired in recent years, several modifications of the customary heap and box methods have been suggested and tested. *(79)* Among these modified procedures, three new processes are outstanding and will be considered first. They may be named, after their inventors, the Rohan method, the Bridgland-Friend method, and the Eden method respectively.

(1) The Rohan method (66) (67) - W. A. C. R. I., Ghana

This consists in spreading out the ripe cacao beans in shallow layers about four inches thick on slatted wooded trays arranged one above the other within a frame which holds up to 12 trays. In preliminary experiments with trays three feet square, in which a 4-inch layer of beans was insulated by a cover of plantain leaves, the temperature of the middle of the layer attained 44ºC (111ºF) in 24 hours. Fermentation was allowed to go on for 40 hours without the beans being disturbed in any way. Afterwards the beans were dried. The resulting cured product gave good-quality chocolate. The method, if generally successful, should have special value on the cacao plantation since it will reduce labor requirements. The beans are merely put onto the trays and after fermentation is complete ,the trays are put in the sun, and the cured dry beans finally put into bags, no other handling being necessary. It is thought that this short-period process should avoid off-flavors associated with over-fermentation.

(2) The Bridgland-Friend method (1) (79) - New Guinea

This consists in placing the ripe cacao beans first in a sweat box and leaving them there for 16 to 20 hours. Afterwards they are removed from the box, and spread out in a thin layer and allowed a "resting phase" of 24 hours duration in which they are stirred at 2 hour intervals. They are then put back into the box and left for 3 to 4 days more with daily turning. A rapid rise of temperature occurs during the last stage, up to 65ºC (149ºF) in some instances.

(3) The Eden method (20) - Western Samoa

This method was introduced in order to improve native cacao that had not been satisfactorily cured nor completely sun-dried so that the beans were somewhat mouldy.

The particular feature of the method is the interruption of a kiln drying process, followed by a final drying in a rotary drier during which further oxidation of the fermented beans occurs, resulting in a greatly improved product. It is aptly described as "a system of reconditioning by oxidation", and it has now become standard practice throughout the territory of Western Samoa. It was based on a method advocated in 1908 by Schulte-im-Hofe who found that cacao beans which had been fermented in boxes for two or three days, then dried to 15 percent moisture content and afterwards returned to boxes heated by steam coils to 40-50ºC (104-113ºF) produced, on drying out, a product that possessed much better flavor than beans cured in the ordinory way.

The whole process is briefly as follows. The ripe beans are fermented for 5½ days in boxes housed in well-ventilated rooms whose air temperature is about 29ºC (84ºF). The beans are turned after the first 12 hours and afterwards daily. They are then put through a washing drum, drained, then dried in a stationary hot-air drier. After 12 hours, the heated air is turned off and the partly-dried beans are allowed to cool. They are then fully dried in Mc-Kinnon rotary drum driers in which the temperature is about 93ºC (200ºF) for the first 6 hours but is decreased slowly as the cacao dried out.

DISCUSSION

The main object in the Rohan method above mentioned is to exploit the "surface effect" observed in heap fermentation with West African Amelonado cacao *(66) (67)*. It has frequently been shown that, in heap fermentation, there is normally a sharp rise in temperature to about 45°C (113°F) during the first 24 hours, during which time most of the beans in the top four inch layer of the heap are killed. If the beans are left for 6 hours more after they have died and are then dried, a good-quality chocolate can be made from the cured beans. Apparently the flavor-precursor is rapidly developed on the death of the beans, and six hours later, if the beans are dried, the concentration of cyanidin pigment has fallen by about 90 percent, an amount which is usually associated with cured cacao of good quality *(66) (67)*.

In a large heap of fermenting cacao, the death of the beans in the center of the heap is usually greatly delayed through slowness of temperature rise, although cases of the reverse condition have been reported. The fact that sometimes the temperature of the surface layer is higher than that of the center of the fermenting mass and sometimes lower, obviously depends on the relationship between the rate of heat production and the rate of heat loss by conduction, convection, radiation and as latent heat of evaporation. This, in turn, depends on the size and shape of the mass of beans* and on the degree of compaction which decides the degree of aeration. It also partly depends on whether the beans are contained in a box, basket or hole in the ground or are piled in a heap, and whether they are covered with an insulating layer of banana leaves, sacking or wooden boards. Possibly also, the variety of cacao, whether it be Amelonado, Criollo, or other kind, is important, since these varieties differ in the proportionate amount of pulp that surrounds the beans in the pod. Finally, the condition of the surrounding air in respect of its capacity for absorbing heat, that is, its temperature, humidity and movement, affects the rate of cooling, and so affects the heat balance. The varied experience of those who have carried out curing trials of cacao can doubtless be satisfactorily explained on these general principles.

In the case of the Bridgland-Friend method *(1)* the main aim apparently is to ensure a rapid attainment of high temperature lethal to the bean, and also to ensure constancy in the "temperature pattern" which is essential for the production of uniform high-quality cacao. The beans are presumed to remain viable during the first two stages and part of the last stage. They are not wholly dead until they have been in the sweat box for at least 8 hours of the last stage.

SUMMARY

The newer knowledge of the curing process has suggested certain modifications in the customary heap and box methods. Three of the most promising of these are described, namely, the Rohan, the Bridgland-Friend and the Eden methods.

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* The larger the heap, the smaller is the ratio between its surface area and its volume, and the smaller the heap the larger the ratio. Thus, a large heap should lose heat at the surface more slowly than a small heap and the temperature of the fermenting mass should rise more quickly in the interior although the surface layer may cool rather rapidly.

CURING METHODS USED IN DIFFERENT COUNTRIES

Based on the results obtained by circulating a general questionaire among cacao growers of the chief producing countries, the following information was obtained and published in "Cacao", issued by the Cacao Center of the Inter-American Institute of Agricultural Sciences, Turrialba, Costa Rica, for October 1956 to October 1957, Vol. 3, No. 12, at pp. 2-3. Replies were received from twenty-two different countries. The following note is mostly a summary of the replies, prepared by W. G. C. Forsyth and V. C. Quesnel.

Four general methods for curing cacao are at present practiced, namely:

(1) Curing on the drying platform
(2) Curing in heaps on the ground
(3) Curing in baskets
(4) Curing in boxes.

These different methods are in common use in different countries as follows:

(1) Curing on the drying trays is chiefly in vogue in Ecuador for processing high-flavored "Arriba" cacao. The beans are heaped at night and any fermentation that occurs must be regarded as merely accidental. In recent years, with the introduction of clonal material into the plantations, other methods of curing are coming into use in Ecuador.

(2) Curing in heaps is the usual process employed in West Africa. The heaps vary in size. The minimum weight that can be successfully cured is about 20 lb., although many authorities consider that 100 lb. is the smallest weight needed to give good results *(64)*. The heap is generally covered with banana or plantain leaves.

(3) Curing in baskets is confined to West Africa and appears to be a useful and convenient method for the small farmer who cures his wet cacao in batches weighing from about 40 to 400 lb. The duration of the treatment is usually 6 to 7 days. The baskets are lined with banana leaves and a temperature of 50ºC (122ºF) may be attained by the third day, even with small batches. The beans are often turned or stirred daily at every second day to ensure uniformity of product.

(4) The use of wooden boxes for curing cacao seems to be generally favored in most countries (eg. *(53) (59)*) and four out of every five cacao growers who were questioned apparently used this method. Widely divergent sizes of boxes are evidently employed, usually in batteries of two or more boxes. The average size is 6 x 5 x 3 ft. approximately. The larger boxes are often slotted and provided with movable wooden panels so that they can be divided into smaller compartments. In this way batches varying in weight from 60 to 12,000 lb. in weight of wet beans can be handled. The practice of filling large boxes over a period of several days with small lots of beans is inadvisable. The boxes should be furnished with holes at the bottom to allow free drainage of the sweatings.

The main function of the box is to provide insulation for the anaerobic fermentation, but there must not be either too much nor too little air or else moulds will form in the first case and undesirable organisms, producing foul odors, in the other case. The degree of aeration can be controlled by the amount of insulation, as well as by the tightness of packing and the frequency of mixing or transferring the beans from one box to another. The depth of the layer of beans, which can easily be controlled, also partly decides the degree of compaction. Opinions vary as to the optimum depth of the layer of beans in the box. Many authorities consider that 35 ins. (90 cm.) is the permissible limit of depth. The best depth is about 30 ins. (75 cm.) though recently much shallower depths have been advocated *(67)*.

The length of time of curing by the box method varies from one to eleven being associated with Criollo types of cacao and the longer period with Forastero types. A positive correlation exists between length of time in the box and degree days. The favored periods are 2 to 3 days and 6 to 8 days, the shorter period of temperature reached during the fermentation. With a Criollo fermentation, the temperature rises to 40º - 45ºC (104º - 113ºF) and with a Forastero fermentation, it rises to 46º - 52ºC (115º - 126ºF).

QUALITY OF CACAO

The factors that determine the quality of commercial cured cacao beans can be subdivided into three groups, (A) heredity, (B) environment and (C) curing *(18), (41)*. Within each group they may be further subdivided according to whether they concern external or internal characters *(14)*.

(A) HEREDITY FACTORS

Broadly considered, cacao beans of commerce belong to one of three main groups, namely, (a)Criollo, (b) Flavor cacao and (c) Amelonado *(71)*. Beans of the first group are large and plump and have white cotyledons which cure to a cinnamon-brown color. They have characteristic flavor features and are used only for special purposes. The second group comprises beans of varieties grown mostly in Central America and the West Indies. The beans are variable in size and shape and have dark purple cotyledons which cure to pale to dark reddish-brown. They have strong flavor and are mainly used in blending. The third group is mainly produced in West Africa and Brazil. The beans are small and flat and have purple cotyledons which cure to dark reddish brown. They do not posses especially strong flavor but they form the main bulk of the World's commercial cacao. The cacao market at present needs only about 10 percent of the total output as Criollo and Flavor cacao, the rest being basic Amelonado cacao which is chiefly used for making milk chocolate.

Knowledge regarding the genetics of quality in cacao at present is almost nil, although it is believed that characteristic flavors, such as the flavor of Trinidad cacao, probably results from the intermingling of a large number of individual genotypes *(18)*. Since, however, flavor is partly dependant on curing and cannot be assessed by any external plant characteristic, the problem of selecting and crossing cacao varieties for quality presents many great difficulties.

(B) ENVIRONMENTAL FACTORS

Lack of adequate supplies of water and nutrients in the soil is known to reduce the size of the pods and of the beans produced by a cacao tree. It also brings about significant variations in the biochemical composition of the cotyledons, for example, in the amount of protein produced. Experimental evidence has been adduced which indicates that nitrogen metabolism in the cacao plant is sensitive to the environment *(42) (43) (18)* and that the beans of cacao trees grown in a soil rich in available nitrogen or treated with nitrogenous fertilizers contain appreciably higher amounts of protein which, if excessive, impart undesirable flavors to the cured cacao *(17) (18)*. It also seems likely that a deficiency of certain minor elements, notably copper, can prevent or diminish the formation of polyphenol oxidase enzyme which is involved in the second phase of the curing process *(13)*. This results in the retention of astringency during curing.

(C) CURING

The quality factors determined by curing are by far the most important of all the desirable attributes of commercial cacao. It is generally agreed that chocolate made from unfermented cacao beans does not possess either true chocolate flavor or aroma *(71) (70) (3)*. It is also generally agreed that the full chocolate flavor and aroma develop only when the properly-cured beans are roasted *(3)*. The following main features are characteristic of unfermented and underfermented cacao beans.

EXTERNAL FEATURES

1. The *size of the cured bean* is one of the most important external features, because the magnitude and constancy of the contents of shell (testa) and of fat vary greatly with bean size *(71)*. The average mass of a large cacao beans is over one gram; undersized beans weigh between 1.0 and 0.5 gram and waste beans weigh less than 0.5 gram *(14)*. The amount of shell in a large bean is about 10 percent and seldom varies by more than one percent, whilst that of a small bean lies between 12 and 16 percent and is much more variable. Small beans contain 3 percent less fat than large beans *(71)*.

2. *The shape of the cured bean* varies from round and plump to flat and shrivelled. Round beans give a more uniform roast than flat beans.

3. The *external color* varies from dark red-brown and shiny in Trinidad beans that are "danced" during drying, to pale brown in washed beans from Pacific countries *(14)*.

4. The *aroma* is pleasant in well-cured beans but distinctly acetic in incompletely fermented cacao. It is musty, earthy or fishy if not properly dried, or if stored in humid surroundings. Cacao that has been dried in smoky driers has a hammy flavor which is highly undesirable *(14)*.

5. Germinated beans usually have a hole at one end where the radicle has dropped off during curing. This exposes the beans to fungus and insect attack in contrast to beans having whole shells which are seldom attacked internally by fungi or insects. Surface mould does not affect cacao quality and most beans possess more or less of it, but mould that has penetrated into the cotyledons produces unsaleable highly tainted cacao *(14) (71)*.

6. Broken beans are characteristic of cacao that has been thoroughly washed, because washing makes the shells brittle *(71)*. Broken beans are readily attacked by insects and furthermore they are difficult to roast. Beans that have been damaged by the cutlass during pod opening are also readily attacked by insects and fungi. They often comprise as much as 3 percent of the number of beans in a commercial sample of cacao, and even in unwashed and well cured cacao their amount is 0.5 percent or more. Whole beans are nearly immune to insect attack *(71)*. In the storehouse, however, both the cigarette beetle *(Lasioderma)* and the cacao weevil *(Araecerus)* are able to attack sound cacao, although they are not able to do so when the moisture content of the beans is less than 8 percent *(14)*.

INTERNAL FEATURES ("Cut test")

1. The color of cut sections of well-cured cacao beans is dark to pale brown according to the amount of purple pigment originally present *(14)*. On the other hand, the color of undercured beans is either purple or mottled blue-grey or slaty*. Such beans produce chocolate which has a dull grey color and is entirely lacking in true chocolate flavor, being bitter and astringent or having liquorice or floral flavor *(71)*.

2. The "break" of well-cured beans is crisp. The cotyledons are not adherent to the shell nor to one another and separate easily. The consistency of under-cured beans is cheesy and the cotyledons adhere to the shell and to each other. The shell is also tough and leathery and difficult to remove by winnowing after roasting *(14)*.

3. Roasted undercured beans do not readily yield up their fat and its amount is about 2 percent lower than that of well-cured beans. Their only real use is as a source of cocoa butter and theobromine (71).

4. Mould in cacao beans, generally caused by infection by *Aspergillus* species, is the most undesirable internal feature of all. Thus, 3 to 5 percent of mouldy

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* *Purple beans* are beans in which the cell membranes have lost their semipermeability so that their polyphenols have diffused throughout the tissues but have not been oxidised because the enzymes have been inactivated by too rapid drying. *Slaty beans* have not lost the semi-permeability of the cell membranes and the polyphenols have not diffused nor left the pigment cells, nor have they been oxidised because of enzyme inactivation by rapid drying. In either case, the cause of the characteristic appearance is too rapid drying, in the first case after the cell structure has broken down and in the second case, before this has occurred. (Personal communication, W. G. C. Forsyth; V. C. Quesnel).

beans in a commercial sample of cacao is sufficient to render it useless for the manufacture of chocolate *(14) (71)*. Mould infection takes place through punctures in the shell (testa) and the fungus develops rapidly when the moisture content of the bean is above 10 percent. Mouldy beans contain free fatty acid produced by the action of mould enzymes on cacao fat. This greatly reduces the quality of the fat *(71)*. *Chocolate* manufactured from mouldy beans is liable to develop mould under poor storage conditions *(71)*.

5. *Diseased or "velvety" beans*, affected, for example, by *Phytophthora*, usually do not have any pulp and therefore do not provide sugar for fermentation. Their presence in the sweat box or heap consequently retards rise of temperature and results in undercuring. This causes an increase in purple beans. The fungus induces the breakdown of cacao fat into glycerol and fatty acid whose amount in badly affected beans can be as high as 40 percent *(71)*. In this respect, pod diseases resemble moulds and they are just as objectionable on account of the earthy flavor which they impart to the cured product.

Analysis of flavor: The characteristics of flavor are most difficult to define, describe and assess. The following components of the flavor of cured cacao have been suggested among others *(3) (79)*.

(a) Bitterness (due to theobromine), (b) astringency, (c) aromatic flavor,
(d) tannin body flavor, (e) nutty flavor, (f) fruitiness and (g) roast effects.

Tasting panels: In order to compare cured cacao produced by different clones or by different methods of cultivation or curing, or to assess the value of a sample for different commercial purposes and for the manufacture of various kinds of confections, special tasting panels have been created *55) (56) (57) (79)*. Such panels have recently been established in most chocolate factories in the United Kingdom and the United States, as well as in the research institutes of Trinidad and Ghana. Up to the present time, however, there has not been much co-operation between them *(3)*. A statistical procedure has been divised in Ghana (incomplete block design) for reducing the tasting errors *(55) (56)*. Details of the working of a taste panel, set up for flavor assessment of cacao clones and hybrids in Trinidad, have also been presented and described *(16)*.

SUMMARY

Quality in cured cacao is considered in relation to the needs of the chocolate manufacturer who requires beans having the following main features:

1. A red-brown color, loose shell (testa) separated cotyledons, crisp brittle break.

2. A strong chocolate flavor and aroma developed especially on roasting.

3. A low shell content (below 10 percent) but the shell must be strong enough to protect the cotyledons from breakage.

4. A high fat content (above 60 percent).

The beans should be free from the following defects:

a) Internal mouldiness
b) Slaty color, denoting undercuring.
c) Off-flavors, denoting improper fermentation
d) Smoky or hammy flavor, denoting faulty drying
d) Germination
f) Breakage or damage by insects
g) Shrivelling or flatness

GRADING CACAO

In most cases cacao grading merely consists in picking out flat and broken beans. Sometimes the cured beans are sifted in a rotary sieve into size grades which are bagged and marketed separately. Occasionally grading on external color is practised, or slaty beans are eliminated *(31)*. Only few cacao producers attempt a thorough assessment and grading based on a systematic study of representative samples according to external and internal characters like those set out in the last section. For most purposes, however, it is sufficient to divide the beans into "good", "fair", "bad" and "mouldy", as based on the cut-test *(14)*, thus:

Good: Brown beans, with crisp break

Fair: Brown beans, cheesy or hard to cut; cotyledons adhering

Bad: Purple or white beans (according to variety) cheesy or hard to cut

Mouldy: Fungus mycelium usually originating at the micropyle and spreading between the cotyledons.

A sample consisting of 100 to 200 representative beans is generally used for the assessment, and the percentage of insect and mechanically-damaged beans, the weight distribution, and the percentage number of beans that fall into each of the classes defined above is carefully ascertained. The color and aroma is also examined. The sample can then be graded and described on this information *(14)*.

(A) In Trinidad, four grades of commercial cacao are favored *(62)* namely:

1. *Super-grade* or *Special Plantation;* comprising the best cacao commanding a price premium.

2. *Plantation;* well-cured and dried, sifted of flat and broken beans and having not more than 5 percent of defective beans.

3. *Mixed Estates;* ordinary less well-cured, having not more than 10 percent defective beans.

4. *Sub-standard;* improperly cured with a high percentage of defective beans.

(B) In *Ghana,* three grades have been suggested *(57):*

Grade I: containing none of the defects listed in the cacao-grading regulations.

Grade II: with 10 percent defective beans.

Sub-grade cacao.

A taste panel operates according to a schedule of flavor assessment in which marks are assigned to the various flavor characteristics *(57).*

(C) In *Nigeria,* four grades were suggested in 1947 each commanding a particular price, as follows *(36):*

Grade I: Less than 5 percent improperly cured beans and less than 5 percent defective beans.

Grade II: Less than 10 percent improperly cured beans and less than 10 percent defective.

Grade III: Less than 20 percent improperly cured beans and less than 10 percent defective.

Grade IV: No limit for improperly cured beans and less than 10 percent defective.

Since 1947, it has been found possible to discard Grades III and IV because of the great improvement in curing practiced by the farmers, largely as a result of the incentive provided by grade price differences *(3i) (37).*

(D) *U. S. A.* A scheme of assessment recommended in 1952 for use by members of the Association of Cocoa and Chocolate Manufacturers in the United States of America utilizes eight characteristics, each of which is afforded an appropriate mark, thus:

1. Ripeness and goodness of cure: Not less than 98 beans to 100 grams weight of sample. Plump, brown beans.	— 1.5 marks for each one percent.
2. Waste: Assessed on a one-kilogram sample.	— Expressed as percent.
3. Slaty beans: One half of cut surface slaty.	— 1.0 marks for each one percent.

4. Mouldy beans in interior only. — 2.0 marks for each one percent.
5. Wormy beans, any attack. ...... — 1.5 marks for each one percent.
6. Broken beans, if over 5 percent. — 0.5 marks for each one percent.
7. Flat beans. .... — 0.25 marks for each one percent.
8. Purple beans, neither brown nor slaty. .... — Marks increase from 1 to 9 for percentages between 6 and 40.

The marks for each characteristic are added and the total is subtracted from 100. This provides an index of bean quality, expressed as percentage.

SUMMARY

Various grading systems based on the assessment of quality factors, employed by cacao buyers in Trinidad, West Africa and the United States of America are described.

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CHAPTER 27

THE MANUFACTURE OF CACAO PRODUCTS

The chief operations involved in the manufacture of cocoa* powder and chocolate are:

1. Sifting in order to separate impurities (cleaning)
2. Roasting the whole beans
3. Breaking into nibs (granules)
4. Separation of the germs (radicles and plumules)
5. Grading the nibs by sieving
6. Winnowing to separate the shell (testas)
7. Blending the nibs by mixing
8. Milling (grinding) of the nib to make cocoa mass (chocolate liquor).

Cocoa mass is used for making cocoa powder and chocolate. In order to make the powder, fat must be extracted from cocoa mass, and in order to make chocolate, fat must be added to cocoa mass.

Changes on roosting: The main changes that occur on roasting cacao beans are (a) water and acetic acid are driven off and (b) the characteristic aromatic substances of chocolate are produced, or their formation completed, from the precursors developed during the anaerobic hydrolytic phase of the curing process. The roasted beans contain about 2.5 percent of water but only small traces of the aromatic substances. The total amount of loss on roasting is about 6 percent. The temperature of roasting is 120ºC (248ºF) and the process is complete in ¼ to 2 hours.

The old form of roasting apparatus consisted of a horizontal cylinder or sphere of steel which rotated slowly over a range of gas burners. Small studs or rods of metal on the inside of the vessel helped to conduct heat into the mass of rotating beans and thus to ensure uniform heating. The charge varied in weight from a few hundred pounds to over a ton. The more modern apparatus employs hot air as heating agent. The hot air is passed upwards through a tall vertical cylinder furnished with baffles which cause the beans, introduced at the top, to fall slowly so that by the time they reach the bottom they are fully roasted.

* The suggestion has been made that the term *cacao* be applied to parts of the tree and to all products up to and including the cured bean, and that the term *cocoa* should be reserved for the products of the factory.

Separation of germs and winnowing: The quantity of crisp shell in roasted cacao is about 12 percent and of germs, about one percent. Separation from the cotyledons is effected by first cracking the beans to form nibs, and then passing these through a rotating cylinder provided with a series of grading sieves. The fractions are subjected to a regulated current of air which removes the shell by suction.

Manufacture of cocoa powder: First of all, a part of the fat contained in the cocoa mass is expressed in a special press consisting of a series of iron cones which fit into one another. The pressure applied is about 3 tons per square inch. The fat content is thereby reduced from 55 to 24 percent. The expressed fat is used for making chocolate or is sold as cocoa butter. The residue or cake in the press is finely ground and sifted through silk gauze of 0.0015 inch (0.038 mm.) mesh. (Unless some of the fat is removed from the mass, it could not be ground and sifted). Sometimes potassium carbonate is added, up to 3 percent in amount, to neutralise acidity, to intensify the brownish-red color and to render the product more easily "soluble" in water. The cocoa powder is packed mechanically into standard paper-lined tins.

Manufacture of bar chocolate: (a) The cocoa mass, mixed with sugar, is ground in a mill known as a melangeur which consists of two granite rollers rotating in opposite directions over a rotating iron pan having a granite bed. A steam coil is provided to keep the fat molten but the heat developed by friction helps in the melting. Sometimes lecythin is added to increase the fluidity. (b) The mass is further ground in a "kneading" machine or high-velocity mill whose rollers are cooled internally by water. Absorption of fat by the added sugar proceeds at this stage. (c) The mass is now ground in a refiner consisting of two sets of rollers moving at different speeds. This stage greatly reduces particle size.

(d) The next stage is known as "conching". The conch consists of a shell-like saucer of polished granite over whose surface a crank-driven granite roller moves slowly to and fro, pushing the mixture over the bed. The temperature of the conch can be regulated by steam coils. It is 70º to 90ºC for ordinary bar chocolate and 40º to 60ºC for milk chocolate. The period of conching is long, varying from two to four or five days. The main object of conching is to develop the characteristic "velvety" texture. It also releases the last traces of acetic acid and its esters, as well as other gaseous impurities.

Various flavoring substances, such as vanilla, cinnamon, lemon essence, nuts, etc., are added at this stage. Extra cocoa fat is added during previous operations, (c) to (d). The finished chocolate is cooled slowly in the conch and stored until needed for making bars or for covering purposes.

Chocolate bars are made in steel moulds which are violently jarred or agitated on a vibrating steel table in order to expel bubbles of air. The moulds are slowly cooled in a refrigerated chamber. On solidification, the chocolate bars have a smooth polished surface.

Composition of ordinary chocolate: Chocolate consists of about 33 percent of cocoa mass, 13 percent of added fat, 53.7 percent of refined sugar and 0.3 percent of aromatic substances.

Manufacture of filled chocolates or bonbons: The centers of these consist of caramel, nuts, ginger, marzipan, etc. These are dipped by hand into semi-liquid chocolate or mechanically "enrobed". They are then cooled in a refrigerated chamber and finally packed in layers in fancy boxes from an endless belt.

Manufacture of milk chocolate: Dried milk or milk powder is incorporated into chocolate at stage (c) of the process used for making ordinary bar chocolate. Sometimes, condensed, evaporated or concentrated milk is used instead of milk powder. Milk chocolate was invented in 1876 by M. D. Peter in Switzerland.

By-products of chocolate manufacture: These are (i) cocoa butter and (ii) cocoa shell (seed testas) which is used as stock-feed or manure, or furnishes a source of theobromine and shell fat which are extracted from it by appropriate volatile organic solvents.

Cocoa shell contains Vitamin D produced during the drying process when the beans are exposed to direct sunlight. Both the theosterol of the shell fat and the sterol of any remaining yeast cells that adhere to the shell serve as source of Vitamin D on irradiation.

Composition of cacao products: The following table gives the approximate composition of cocoa powder and of ordinary bar chocolate, as well as that of cocoa nib derived from cured and dried beans and of the fresh kernel or cotyledons, based on oven-dry ash-free weight.

COMPOSITION OF CACAO PRODUCTS (OVEN-DRIED)

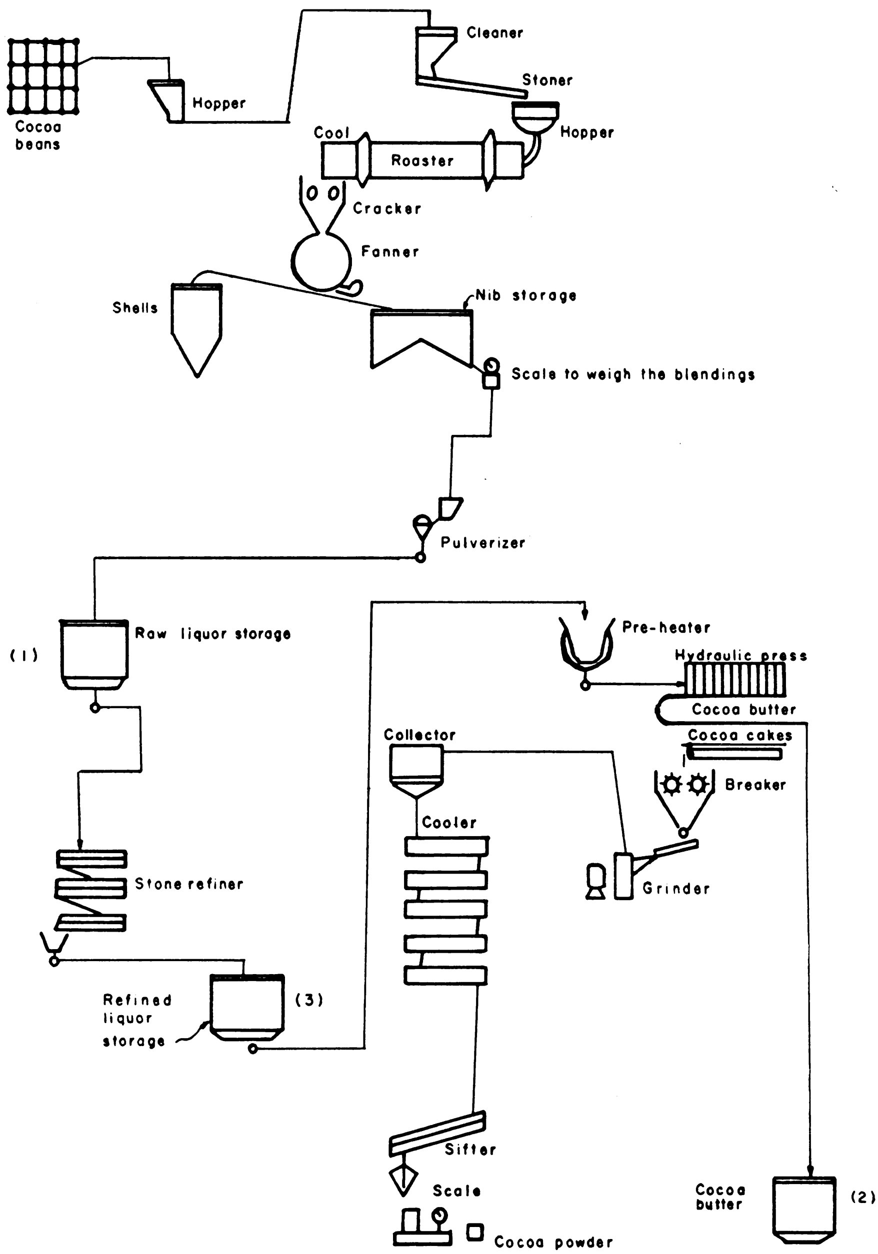
	Fresh kernel	*Cured and dried nib*	*Cocoa powder*	*Bar chocolate*
Fat	54.0	57.3	26.5	29.1*
Sugar	1.8	0.7	4.3	54.4*
Starch	7.7	7.4	22.2	4.1
Protein	14.8	6.7	22.2	1.5
Theobromine	2.3	1.7	1.3	1.1
Other substances	19.4	26.2	23.5	9.8
	100.0	100.0	100.0	100.0

* In part added

SUMMARY

The stages in the manufacture of cocoa powder and ordinary bar chocolate and milk chocolate are outlined. The effects of roasting are considered. The composition of fresh cacao kernel, cured and dried nib, cocoa powder and bar chocolate is tabulated. The by-products of chocolate manufacture (cocoa butter cocoa shell, theobromine and shell fat) are briefly mentioned.

(A) MANUFACTURE OF COCOA POWDER



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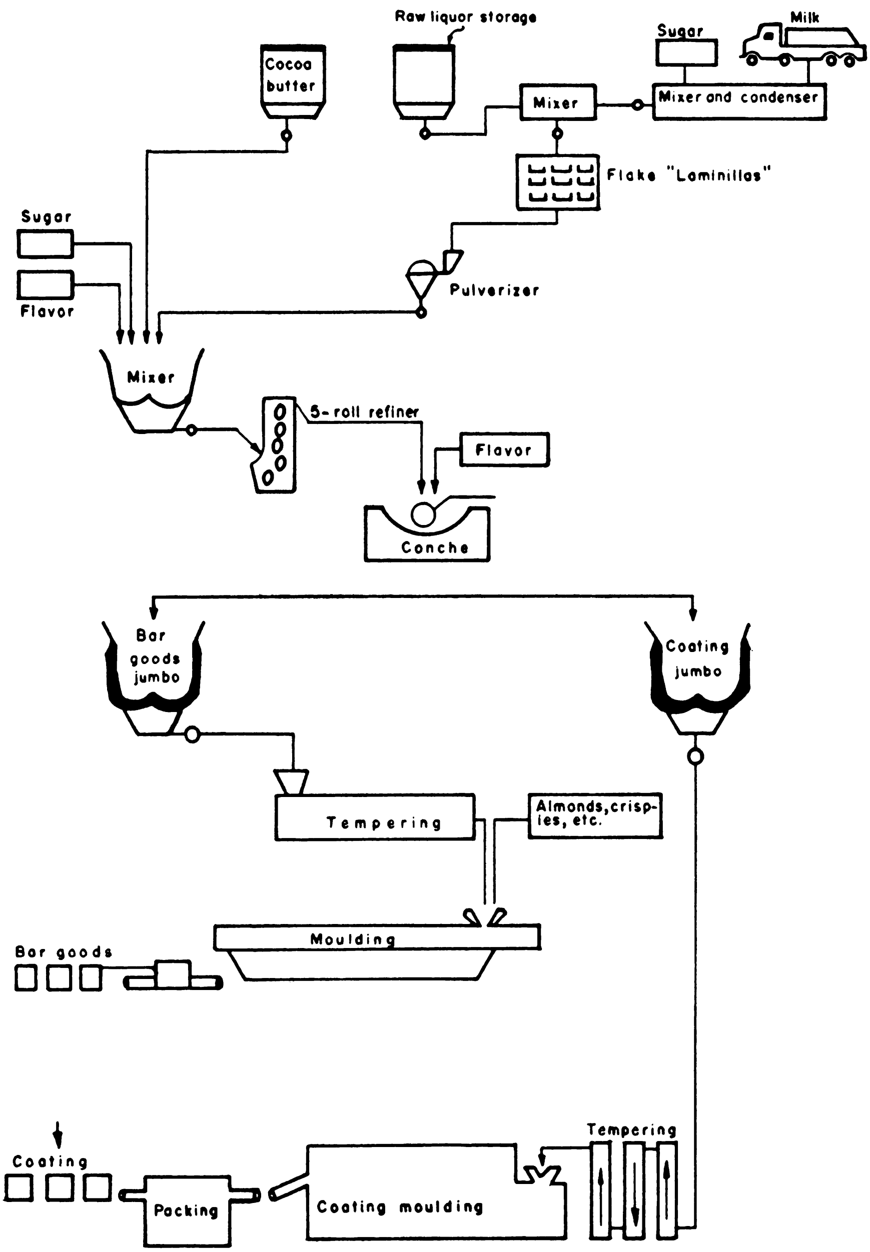
(B) MANUFACTURE OF MILK CHOCOLATE

(Bar and coated)



CHAPTER 28

THE MARKETING OF CACAO*

(A) GENERAL CONSIDERATIONS

(1) HISTORY OF CACAO PRODUCTION

Cacao is the only agricultural commodity whose post-war shortage has not yet ended. World prices are likely to remain remunerative for some time to come *(3)*. Post-war development is a complete reversal of the trend that had been in evidence for half a century previously. The steady growth in cacao production during pre-war years stimulated a corresponding growth in consumption which was manifest in all industrial western countries. Cocoa nowadays is no longer a luxury but an article of common diet. The cocoa industry has based its marketing policies and its prices on the premise that supplies of raw cacao will continue to expand. Restricted post-war development has compelled complete re-orientation of industrial policy. Whilst cacao production has risen by only 5 percent since 1934-38, the population of the ten most important cocoa-consuming countries has increased by 15 percent. On a *per caput* basis, supplies during 1953 to 1955 were 10 percent lower than during the pre-war years *(3)*.

Long-term trends between 1900 and 1939: The total increase in cacao production during the period 1900 to 1939 was more than six-fold, from 102,000 to 750,000 tons. The average annual increase was 16,000 tons. No other crop except rubber has shown such a rapid rise *(3)*. Two fundamental changes in the geographical aspects of cacao production took place during this period, namely:

(i) Up to the year 1900, South and Central America produced 85 percent of the world's supply of raw cacao. At that time, African exports of cacao had amounted to only 15,000 tons. By the outbreak of the Second World War, Africa had produced four times as much cacao as had been produced by the whole world up to the turn of the century *(3)*.

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* This chapter is mainly based on lecture notes for the Cacao Course compiled by A. Helfenberger.

(ii) Up to the year 1900, Central America was responsible for about 35 percent of the continental American output but, by 1939, its share had declined to 25 percent, mainly owing to the great expansion of cacao-growing in Brazil which almost doubled cacao production in South America.

Export developments: In 1893, the Gold Coast (now Ghana) produced only 2 tons of cacao beans whereas, in 1900, its production reached 545 tons. During the decade following, exports increased forty-fold and, in 1911, the Gold Coast was the world's largest exporter of raw cacao. For the first time, it surpassed Ecuador and Brazil by shipping 40,000 tons of cacao beans, or 17 percent of the total world production. Ten years later, the Gold Coast production had reached 130,000 tons and, in 1926, 235,000 tons, or 49 percent of the world's output *(3)*. It was 320,000 tons in 1959.

In subsequent years, the Ghana production rose still further, although its proportionate contribution to world output declined. Nigeria's development was almost as rapid as that of Ghana. Considering that this increase in output of West African cacao was all owing to the industry of peasant farmers, it provides a remarkable example of a high degree of economic consciousness, energy and initiative *(3)*.

The production of over 300,000 tons of raw cacao by West African farmers involved the partial clearing of 3.5 to 5.0 million acres of forest land which is a large area to be developed in cacao by a rural population which, in 1921, amounted to 2.2 million people. All the cultivation was carried out by hoes and cutlasses or machetes *(3)*.

The drastic fall in cacao prices that took place between 1900 and 1939, mainly as a result of the impact of this large quantity of African cacao on the world's markets, ruined the cacao industry of Central and South America and the Caribbean region where the cost of production was higher than in West Africa and the damage caused at that time by pests and diseases was less *(3)*.

Long-term trends since 1939 (1) (3) (5) (6): The 40 years of great expansion mentioned in the last section, from 102, 000 to over 750,000 tons of cacao annually, ended at the outbreak of the Second World War. The average annual world production during the next 10 years was 13 percent lower than that of the previous 5 years' average. The reasons for this decline were (a) the disorganisation of shipping which lost the European market to cacao growers, (b) the low prices that prevailed and (c) the increasing demand for labor for war-time activities. These causes were augmented by certain agricultural factors, for example, the increasing age of the cacao plantations and the spread of pests and diseases, notably the swollen-shoot virus in West Africa *(5)*. Nevertheless, world production had reached pre-war figures in 1948, although it was actually only 5 percent higher than during the previous decade. The production of cacao in West Africa has seriously diminished and it did not recover so as to attain the pre-war level until 1957. *(See Table)*. By contrast, production in Central and South America and in Asia and Oceania, especially New Guinea, had increased appreciably. By 1955, the level of international trade in cacao and its products had reached nearly 600 million U. S. dollars a year *(3)*.

Future outlook: The cost of production of raw cacao has substantially increased in recent years. The present cost of establishing and bringing into bearing is:

	Per hectare	*Per acre*
On the plantation basis	U.S. $ 800 — 500	U.S. $ 320 — 200
On the peasant farmer basis	U.S. $ 300 — 200	U.S. $ 120 — 80

The shortage of supply in relation to consumer demand is likely to continue. Prices will probably remain favorable to the grower *(3)*. This should not be taken to imply that cacao cultivation should continue to be confined to extensive exploitation since, with the possibility of a diminishing area of suitable easily-accessible forest land, the prospect of growing cacao cheaply in this way is likely in future rapidly to diminish. Instead, increasing attention should be given by cacao growers to intensive methods made possible through the ecological, horticultural and genetical researches that have successfully been accomplished during the past 30 years.

On the basis of the present trends in the growth of population, the estimated increase in world demand for raw cacao, assuming that the commodity will be available in sufficient quantity and at reasonable price, is 16 percent for 1960, 37 percent for 1970 and 65 percent for 1980 *(9)*. If sufficient quantities of cacao are not forthcoming at reasonable price, not only will these increments fail to materialise, but also current consumption of cacao products most likely will diminish.

TABLE: WORLD PRODUCTION OF RAW CACAO

(Thousands of tons)

	PRE WAR	POST — WAR PRODUCTION										
Country	1938 -39	1949 -50	1950 -51	1951 -52	1952 -53	1953 -54	1954 -55	1955 -56	1956 -57	1957 -58	1958 -59	1959 -60
Africa	539	480	511	450	508	471	492	521	577	443	555	693
Central America	15	16	14	16	17	22	27	24	25	28	32	30
South America	183	204	221	114	203	224	209	233	221	224	242	244
Caribbean West Indies	49	49	50	49	47	47	49	44	51	53	48	53
Asia Oceanica	11	7	7	7	11	10	9	11	12	13	17	18
TOTAL	797	756	803	636	786	774	786	833	886	761	894	958

During the present year (1960) world consumption will probably be around 900,000 tons of cacao beans in the price range of 25 to 31 cents per pound, c. i. f. *(2) (9)*. In subsequent years, a steadily increasing consumption, within the same price range, of 10,000 to 20,000 tons anually is possible, because of increasing population and increasing *per caput* income *(2)*. This may even be a low estimate, in view of the fact that certain previously underdeveloped countries, and also Russia, are likely to become important consumers of cacao products in the future.

World production during the past two years has only been 14 percent above pre-war production, which is less than the percentage population increase in the cocoa-consuming countries during the same period *(10)*. As a result, a considerable rise in prices has occurred, greater indeed than that of most other agricultural commodities, and indications lead to the conclusion that high prices will continue for some years. High production over a successive number of years, however, might cause a serious price reduction *(10)*.

Lack of proper raw materials inhibits the expansion of any industry and forces the manufacturer to search for substitutes. In the case of cacao, the chief of these would be substitutes for cocoa butter, such as certain natural vegetable fats and industrial fats, and for cocoa flavor, such as mixtures of various essential oils and aromatic substances that can be synthesized by the chemist. Indeed, the problem of making satisfactory alternative fats has already been solved although the making of artificial cocoa flavor has not yet been accomplished.*

High rise in price endangers the development of the cacao industry because chocolate is in constant competition with the products of the powerful sugar industry. Should the children of U. S. A. prefer to eat sweets instead of chocolate for one generation only, the damaging effect on the cacao industry would be exceedingly large.

Prices of raw cacao have fluctuated greatly since the beginning of the century *(See graph)*. During the decade immediately proceeding the Second World War, cacao sold for 4 cents up to 13 cents per pound, but during the 8 - year period following the war (that is between 1946 and 1954), prices ranged from 13 cents up to 50 cents a pound *(4)* but they fell again after 1954 to around 25 cents a pound which is perhaps too low to be profitable to the grower *(2)*.

(2) PRICE MOVEMENTS

The variations in the price of raw cacao and the details of trading transactions carried out at the New York Cocoa Exchange are recorded in certain newspapers. The following is an example:

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* To make 100 tons of milk chocolate requires about 73 tons of cacao beans, of which about 11 tons go to make the color. The remaining 62 tons is used to make cocoa butter. Thus, six-sevenths of the beans are used to make cocoa butter. Suppose the world consumption of milk chocolate is 75 percent of the whole then, from a world crop of 800,000 tons, 600,000 tons will be used to make milk chocolate. If the cocoa butter were replaced completely by alternative fats (as can now be done) then six-sevents of 600,000 = 514,000 tons of beans would be released (11).

New York, Feb. 17th. Today's futures* for cacao closed at an increase of 15 to 28 points; 290 contracts were sold. The firmer trade reflected the strength of foreign markets and specially the number of the local grindings. Cocoa afloat towards the U. S. A. from Africa and Brazil amounts to 114,386 bags, including 14,400 bags from Brazil. The dealers follow these shipments closely since they are a sort of a guide for the availability of cacao for the delivery of March futures contracts.

On another day, the news indicates a decline in prices. For some persons these fluctuations mean a loss in earnings, for others, a gain. The questions therefore arise (i) what protection can be procured against the rise and fall of commodity prices, and (ii) what advantages can be gained from a constant change in price levels? The answer to the first question lies in some kind of insurance guarantee which will protect the merchant against fluctuating prices. Such protection is afforded by the procedure known as hedging *(8) (7)*. The answer to the second question concerns the business of the speculator. Both kinds of activity are manifest in the marketing of cacao.

The cacao industry, as any other industry whether it concerns producing, selling, buying, manufacturing or consuming, resolves around *price*. The producer and the seller desire a high price, the buyer and the manufacturer desire a stable price, the consumer desires a low price, but the speculator prefers rapid fluctuations in price. Prices fluctuate as the result of the operation of the law of supply and demand. At the beginning of a crop year, the simplest form or balance sheet between supply and demand is the following *(8)*.

Supply	*Demand*
Carry-over from the previous year	Estimated consumption
Estimated production	Estimated imports
Estimated exports	Reserve supply needed for next year's carry over.

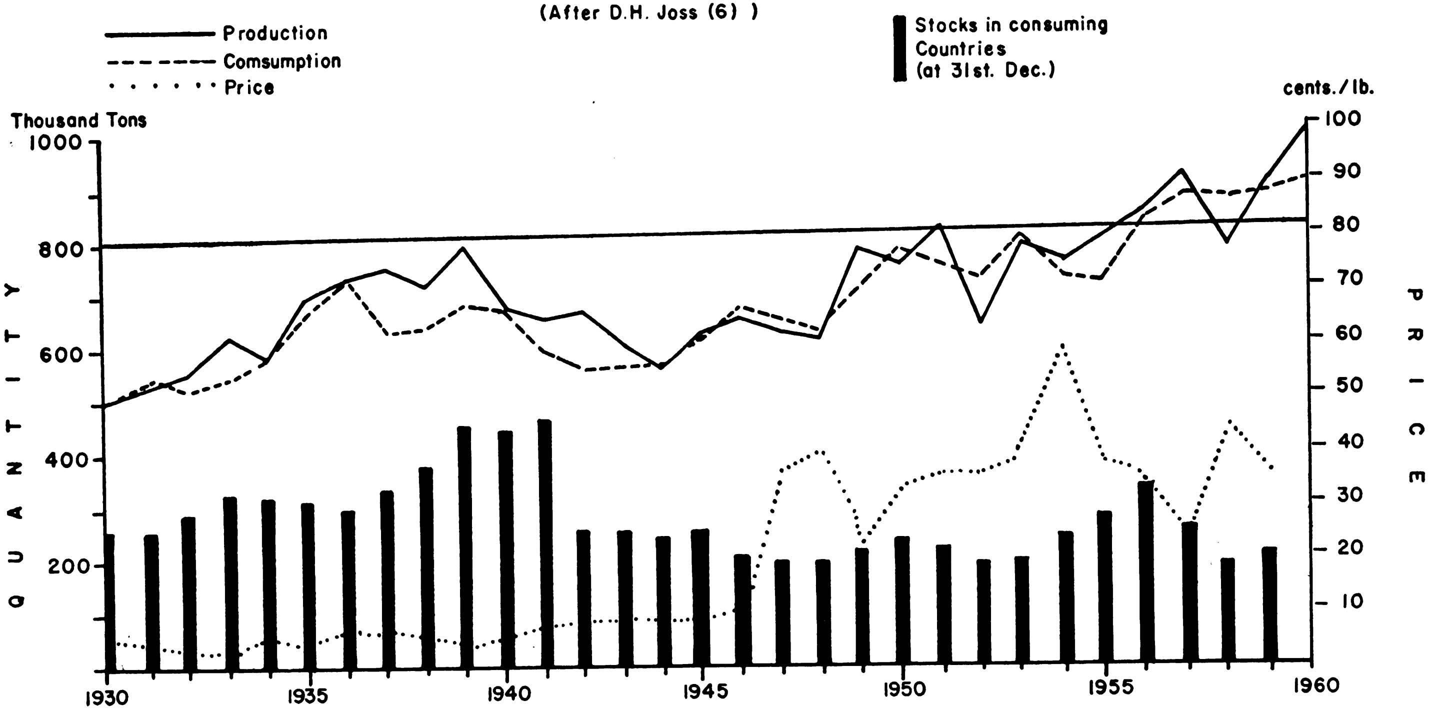
At the present time, the margin between the supply and the demand for cacao is not sufficiently wide to encourage large expansion of the cacao industry. A vicious circle has become established. The producer fears that, if he increases production, prices will fall. The manufacturer cannot work at full capacity with a shortage of supply of raw cacao. Nevertheless, the needs and desires of the consumer finally decide the price of cacao. A period of high price would stimulate production and growers would extend or intensify their cultivations. This, in turn, would allow the manufacturer to work at higher capacity and with greater efficiency and so enable him to sell his products at lower price to the consumer. The real need therefore is the establishment of a smooth and constant flow from the plantation to the consumer such as will satisfy the demands of both the producer and the manufacturer, for example:

* A "futures" contract is an agreement to buy or to sell a commodity at a future date in accordance with certain conditions laid down and agreed upon under the rules of the contract market for that commodity (4) (5) (7) (8).

WORLD PRODUCTION, CONSUMPTION, PRICE AND STOCKS OF CACAO

1930 – 1960

(After D.H. Joss (6))



Producer	*Manufacturer*
1. Produce more cacao at a lower price per unit and improve the quality.	1. Increase the output of cacao products at higher efficiency and improve the quality.
2. Increase research activities and develop an effective extension service.	2. Increase propaganda and advertising.

Scientific research on cacao production has expanded rapidly during the last 30 years. In several countries ,cacao experiment stations and model plantations have been estabilished in which scientific methods of growing cacao are being applied. Much more could be done to co-ordinate extension services with the work going on at the centers of scientific research and teaching, so that the growers will be kept constantly informed of the latest developments in the science, art and business of producing marketable cacao.

(3) PROPAGANDA FOR INCREASED CONSUMPTION OF CACAO PRODUCTS

Chocolate manufacturing companies spend large sums of money for propaganda purpose and advertisement, in one case almost reaching five million U. S. dollars per year.

The media used for propaganda comprise:

(1) The press (newspapers, magazines, comics, etc.).
(2) Television (net-work and spot)
(3) Radio (net-work and spot).

The cost of these services is exceedingly large, as is shown by the following figures:

Television	*Time*	*Animated*	*Live*
Movie pictures for televising	1 min.	$ U.S. 9,000	$ U.S. 4,000 — 5,000
	Time	*Network*	*Spot*
Television movie (Time costs)	1 min.	$ U.S. 30,000	$ U.S. 6,000

Note: For each television appearance in U. S. A., possibly as many as 12 million sets are tuned in.

Magazines	*Circulation*	*Production cost*	*Space cost*
"Life"	6,000,000	$ U.S 9,448	$ U.S. 79,000

Largely as a result of effective propaganda, the sale of cacao products has greatly increased in U.S.A. in recent years. Thus, in the case of one proprietory product, a semi-sweet chocolate, the consumption was 43 percent higher in 1958 than in 1952 and, in the case of another, a soluble chocolate, it was 253 percent higher.

(B) THE COCOA EXCHANGE, NEW YORK

The Cocoa Exchange of New York, U. S. A., is a public market where prices are registered and published. The Cocoa Exchange does not create prices nor is any change in price profitable or adverse to the Exchange, which is merely a place where buyers and sellers meet in person or through their respective brokers *(4)*. Changing prices are created when buyers agree to pay more for cacao or sellers agree to se'l for less than the price that had been established by preceding transactions. The actual trading is carried out by the members of the Exchange. Non-members may trade by opening an account with a broker member. Thus the Exchange is truly a public market place where any individual or firm who wants to buy "futures" can carry on business transactions. The persons who negociate business deals at the Exchange comprise producers, dealers, manufacturers and speculators. The transactions which they make sometimes amount to several millions of dollars in a single day *(4)*.

Functions of the Cocoa Exchange: The New York Cocoa Exchange is a membership organization that maintains the cocoa futures market without in any way gaining by price changes. It maintains its premises by dues paid by the members.

The membership of the Exchange: The membership of the Exchange is limited to 183. If any person wishes to become a member, he must first purchase his membership from some member who is willing to sell. A membership committee then decides whether the applicant has a good character, a good business reputation and sound financial standing. Finally the applicant is elected by vote of the Board of Management *(4)*.

Trade information by the Exchange: In addition to providing a place for trading, the Cocoa Exchange gives publicity to all transactions concluded, as well as full statistical data and information about the current crops. A daily printed report of all transactions is issued *(4)*.

Economic functions of the Exchange: These include (i) a broad futures market which permits large-scale hedging or price insurance operations, (ii) a reliable "barometer" or index of current and future values, (iii) a continuous market for futures which makes cacao a "liquid" commodity *(4)*.

How and why the Exchange was founded: The Cocoa Exchange of New York was established in 1925 to fill a vital need. At the beginning of this century, production and consumption of cacao increased rapidly. The process of moving raw cacao from distant producing areas to the consuming countries involves a great financial risk for any one trading in cacao. Consequently, the necessity for the creation of a futures market, similar to that which already existed for wheat, cotton and coffee, became evident. The effects of the post-war boom in cacao prices demonstrated the disastrous consequencies of reckless speculation that occurs when buyers and sellers of important commodities do not have a well-organised exchange system *(4)*. Cacao became an attractive medium for speculation for persons who did not have any special knowledge of the commodity. These speculators bought large quantities of cacao 'under cover" awaiting further advances in price. Consequently, chocolate manufacturers were forced to buy cacao at greatly inflated prices. As the supplies dwindled and became smaller and smaller, prices increased rapidly until, in 1921, banks suddenly ceased to give credits and began calling in their loans. This caused the speculators suddenly to release their hidden cacao, and to put it onto the market which by this time was devoid of purchasers. The losses thus incurred by importers, merchants and manufacturers were just as heavy as those sustained by the speculators. The Cocoa Exchange was founded to prevent subsequent repetition of this drastic sequence of events *(4)*.

Creation of a cacao market: The affairs of the Cacao Market at first did not run smoothly. The main problem was the establishment of a system of futures contracts which would permit unrestricted trading in all kinds of raw cacao beans. The system that was eventually devised is based on a few standard growths with premiums and deductions in price for all other sorts. The plan is to award premiums for cacao that is better than the standard types and to subtract deductions for cacao that has many defects responsible for low quality *(4)*.

Futures contracts: Commercial transactions at the New York Cocoa Exchange are easy to make because all futures are identical except for price and time of delivery. The price becomes part of the contract when agreed upon at the time of the transaction and the time of delivery is determined in advance by the buyer before he places his order. The current month, or any one of the ensuing 14 months, can be designated by agreement between buyer and seller. When a buyer purchases a futures contract he agrees to buy in unit quantities of 30,000 lb. weight of cacao beans at an agreed price and at a given date. On the other hand, when selling a contract, a seller agrees to sell in units or to another buyer who is willing to pay the price. Under Exchange rules, every buyer of a futures contract has the right to enforce delivery and every seller has "lots" of 30,000 lb. weight, and he can sell at any time before the contract matures the right to make delivery and demand the price agreed upon *(4)*.

The New York Cocoa Exchange opens daily for trading between 10 am. and 3 pm. except Saturdays, Sundays and prescribed holidays.

Margins: Non-members of the Exchange are obliged to open an account with a member or member-firm who will require a deposit (margin) to be paid *(4)*.

Unit of trading: This is 30,000 lb. weight of raw cacao bean, and is called one "lot". It is the smallest quantity that can be bought or sold on the Exchange *(4)*.

Market fluctuations: The least fluctuation that is taken into account in trading in cacao is 1/100 of a cent U. S. per pound. This is called "one point". Each acknowledged change in price is therefore equal in value to $ U. S. 3.00 per lot. Thus, if a buyer purchases a contract and the market price then advances by 10 points he gains $ U. S. 30 per lot, or if it advances by 100 points, he gains $ U. S. 300 per lot or 1 cent per pound, when he sells it to another buyer. An exception is made to this rule for "spot months" during which limits are not imposed *(4)*.

Commissions: The following minimum commissions have been established for non-members of the Exchange, both-buying and for selling.

Price		*Commission (Non-member rates)*
Below	10 cents	$ U. S. 35.00
Between	10 and 14.99	$ U. S. 40.00
Between	15 and 24.99	$ U. S. 50.00
Between	25 and 34.99	$ U. S. 60.00
Above	35 cents	$ U. S. 70.00

The trader is informed by invoice of the amount of the commission for each futures transaction made *(4)*.

Example of a transaction: The following theoretical example may clarify the procedure. A non-member cocoa manufacturer has opened an account with a broker-member and wishes to buy a March futures. The broker notifies his agent on the floor of the Exchange to buy one March futures. When the market opens, one broker bids "one March at 25.50" and another broker offers "one March at 25.51". The agent accordingly turns to the second broker and makes is purchase before the price changes. Although a written contract has not been made between the brokers on the floor, the oral contract is regarded as fully binding, though it will subsequently be confirmed by telephone and by letter. The purchase is duly recorded on a blackboard on the Exchange floor, and the information is immediately broadcast on the ticker telegraph system *(4)*.

Kinds of transaction: The kind of transaction described in the last paragraph is called a "market order". Another kind, called a "limited order", is a futures contract that can only be bought when prices have reached certain levels. These orders are valid only for one session unless specifically marked "G. T. C." (good till cancelled). Change of a futures of a former month to a futures of a coming month is called a "switch", and the only cost to the transactor is the payment of commission. When a broker buys and sells at the same time, he is said to have effected a "straddle" *(4)*.

Hedging: This is a procedure which has been devised to reduce to the lowest level the losses incurred in trading when unusually large fluctuations in market price are taking place *(7) (8) (4)*. Hedging is applicable mainly to futures markets. It is not automatic and its successful application requires expert knowledge and a thorough understanding of the market. It means taking protective action *(7)*. Hedging essentially comprises converting cash into commodities *(4)*.

The folowing are the main operations involved in hedging:

(i) The *sale* of one or more futures contracts in order to lessen or eliminate the possible decline in value of a purchase of an equal amount of cacao. This is called a "short" hedge.

(ii) The *purchase* of one or more futures contracts in order to lessen or eliminate a possible loss brought about by an increase in the value of the cacao needed to fill a forward sale of the commodity or of any of its products. This is called a "long" hedge *(4)*.

Short hedges protect the purchaser against a decline in the market price and are ideally suited to the producer who sells futures against his crop. Similarly they protect the exporter who sells futures against the cacao he has bought, hoping for a buyer overseas where the factories are situated. They also protect the manufacturer who sells futures against his purchases of cacao which he afterwards resells as chocolate and other cacao products *(4) (7)*.

Long hedges protect the producer, exporter, importer and manufacturer who want to insure themselves against unforseeable advances in price *(4) (7)*.

Delivery: Many cacao merchants are interested only in trading in futures contracts and do not desire to take delivery of actual cacao. In this case, they take advantage of warehouse facilities which provide storage, and accept delivery of their purchases in the form of a warehouse receipt *(4)*.

Classification: Cacao quality is assessed by licensed graders who operate at the Cocoa Exchange and inspect sample beans by the cut-test. Cacao tendered by sellers must conform to standard requirements. If the quality of the cacao differs from the standard, the buyer either pays a premium or receives a deduction in the price offered *(4)*.

Standard growths: The standard growths which are accepted without premiums or deductions are: Accra (main crop) Bahia, San Thomé (fine) Ivory Coast (main crop) Costa Rica (fermented) and Panamá (fermented) *(4)*. Maximum addition for particular growths is ¼ cent U. S. per pound and maximum deduction is one cent U. S. per pound.

Clearing house: The New York Cocoa Clearing Association, Inc., is a clearing house or central agency set up by the Cocoa Exchange throungh which the transactions made by its members are cleared and financial settlements are effected *(4) (8)*. Its members mostly comprise members of the Cocoa Exchange. Among its other duties, the Clearing Association announces the date when cacao futures mature *(4)*.

SUMMARY

1. This article deals first with general considerations regarding certain aspects of cacao marketing, namely, (i) the history of cacao production, both before and after the Second World War, (ii) the causes of price movements, (iii) the methods of propaganda and advertising employed for increasing the sale of caaco products and the cost of these methods.

2. The article deals secondly with the Cacao Exchange of New York. The origin, functions, rules of membership and other aspects of this institution are briefly described. The meaning and purpose of futures contracts, margins, trading units, commissions, types of transactions, hedging and kinds of hedges, and standard growths of cacao are explained.

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CONCLUDING STATEMENT

THE ECOLOGICAL VIEW POINT

Most of the chapters of this Manual have stressed the importance of the environment in the growth and production of cacao. When attempting to study cacao growth problems, the procedure advocated was first to enumerate the different ecological factors influencing growth and production, both atmospheric factors and soil factors, and then to attempt to assess each of them quantitatively. Assessment should be made as many times as feasible during one or more growing seasons, so as to obtain, so to speak, a cinematograph picture of the fluctuating environment rather than one or two snapshots. Asssessment should at least be attempted at the critical periods in the growth of the plant, for example, near the end of the dry season and near the end, or at the height of, the wet season. From the results of the assessments, the identity of the factor or factors that are limiting growth and production should be easy to decide. Subsequently steps should be taken to modify, or to rectify, the effect of the limiting factor by appropriate means, for example, by drainage if lack of aeration or inadequate root room, owing to a high water- table, is the limiting factor, or by irrigation, if it is lack of soil moisture. Shade trees can be introduced to reduce light intensity. Fertilizer applications likewise can be used to correct inadequate or unbalanced nutrient supply, and so on. The application of corrective measures must, of course, be economically sound and profitable. In order to ascertain whether or no this is likely to be so, corrective measures should be applied cautiously, preferably on an experimental scale, before being fully accepted and applied generally.

The interaction of the various ecological factors is extremely complex and doubt may be cast on the validity and justifiability of the approach advocated in the above discussion. Nevertheless, part of the tradition of science "is deliberately to separate for purposes of study and contemplation single aspects of complex phenomena and the results on the whole have justified the technique. The practice, however, has its dangers, for it almost invariably leads, sooner or later, to a conventional presumption that these detached aspects, these abstractions, are true objective entities*". This warning implies that the complex actions and interactions of the various environmental growth factors must not be underestimated. Apart

* Harry Roberts, in "Spectator", London 1 st June, 1954.

from the great practical difficulties and expense involved in the application of the dynamic principle to the study of the ecology of a crop plant such as cacao, the results so far have indeed justified the means, as is proved by the real advances made in our knowledge of the effects of atmospheric temperature on the physiological processes that go on in the cacao tree, described in Chapter 3, and of the water and air relations of the cacao tree which were realized only when this particular method of investigation was followed, and which led to a better understanding of the significance of cherelle wilt. The customary procedure followed in carrying out a simple factorial pot-test or a factorial field experiment, designed to determine fertilizer requirements of a soil, is also an example of the ecological approach herein advocated. Many improved management practices are based on information acquired by ecological researches on the cacao crop, and a better understanding of the relationships between diseases and pests and their host plant has been acquired also by this procedure.

Another procedure which has been applied in the climatological study of plant responses to the fluctuating environment is the method of controlled growth in which the plant is grown in specially - constructed chambers. In these chambers, air temperature, air humidity and light are accurately adjusted separately and severally and the behavior of the plant is observed under various combinations of these three atmospheric growth factors. Considerable success has been achieved by this method in the Clark greenhouses and the Earhart Plant Research Laboratory which have been established at the California Institute of Technology, Pasadena, California, U.S.A.*

Recently, the construction of three air-conditioned growth chambers has been started at the Imperial College of Tropical Agriculture, Trinidad, for the study of the cycles of leaf flushing, flowering and fruiting in cacao as affected by temperature, humidity and light. By suitable modifications, the study of nutrition and of water and air supply in the soil in which cacao plants are being grown under controlled atmospheric conditions should also be possible in these growth chambers.

At the First FAO Technical Cacao Meeting, held at Accra, Ghana, in February, 1959, a paper was presented which discussed the ecological method in cacao research**. It was written by an entomologist. The following is a somewhat plagiarized transcript of it.

Cacao research in Ghana has been dominated by pathology: the tree in its total environment has been neglected. Spectacular capsid control now shows the need for a common ecological approach to research and management. Apart from the control of capsids, the use of powerful insecticides and the removal of shade trees have upset the balance of nature. Cacao in Ghana is grown in the forest which harbours pests. Competition with the forest depresses the vigor of

* 1—The Experiment Control of Plant Growth.
F. W. Went, Chronica Botanica Co. Walthan, Mass. USA, 1957. pp. 343 with plates.

2—Crop Production and Environment. R. O. Whyte, Faber and Faber, Ltd. London.

** "The ecological approach to cacao research in Ghana". C. G. Johnson (Deputy Director and Head of the Entomology Division, West African Cacao Research Institute, Ghana, West Africa).

the cacao tree. When the forest trees are removed, the capsids that they harbour attack the cacao. When capsids are controlled by means of insecticides, shade can then safely be reduced. The vigor and the yielding capacity of the cacao tree consequently increase greatly. Certain Lepidoptera then become pests, however, and when other insecticides are used to control them and to reduce the ant population which attends the virus-transmitting mealybugs, the pod-husk miner *(Marmara)* then becomes a pest, presumably because its predators and parasites have been destroyed. Removal of shade, by altering the cacao micro-climate, favors the increase of other mealybugs that are less susceptible to the insecticides that control the virus vectors. Furthermore, shade removal and the application of fertilizers also change the pattern of flowering of the cacao tree and this affects the process of pollination.

Capsids, mealybugs, virus, insecticides, hybrids, soil, shade-trees, have all been 'abstracted from their overall ecological context" and made the objects of departmental study. Their interactions have been ignored. "This is the single factor approach". Opposed to it is the multiple factor approach in which disease is regarded as the resultant of the interaction of many factors which are either climatic, edaphic or biotic. All this is well known, yet research is not organised accordingly. The fact that Ghana is generally considered to be an ideal country in which to grow cacao really means that "economic cacao grows here in spite of its being riddled with disease, blasted by capsid, smothered by shade and crowded by forest. The ideal environment (for cacao) is not known, never having been analysed and arranged optimally. Maximum yield, disease resistance and early bearing are all unknown for any cacao variety, and "health" has merely implied the absence of disease. We lack orientation to the overall ecology of cacao and a common background for all departments. The relevant factors need integration into a tentative system, showing the tensions in the ecological fabric as a whole".

The compiler and editor of this Cacao Manual, as a concluding gesture, can do no better than recommend these ecological sentiments to the serious student of cacao-growing, and to suggest to directors of cacao research that they be given due consideration when programs of investigation are being formulated.

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