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COFFEE

WORLD CROPS BOOKS

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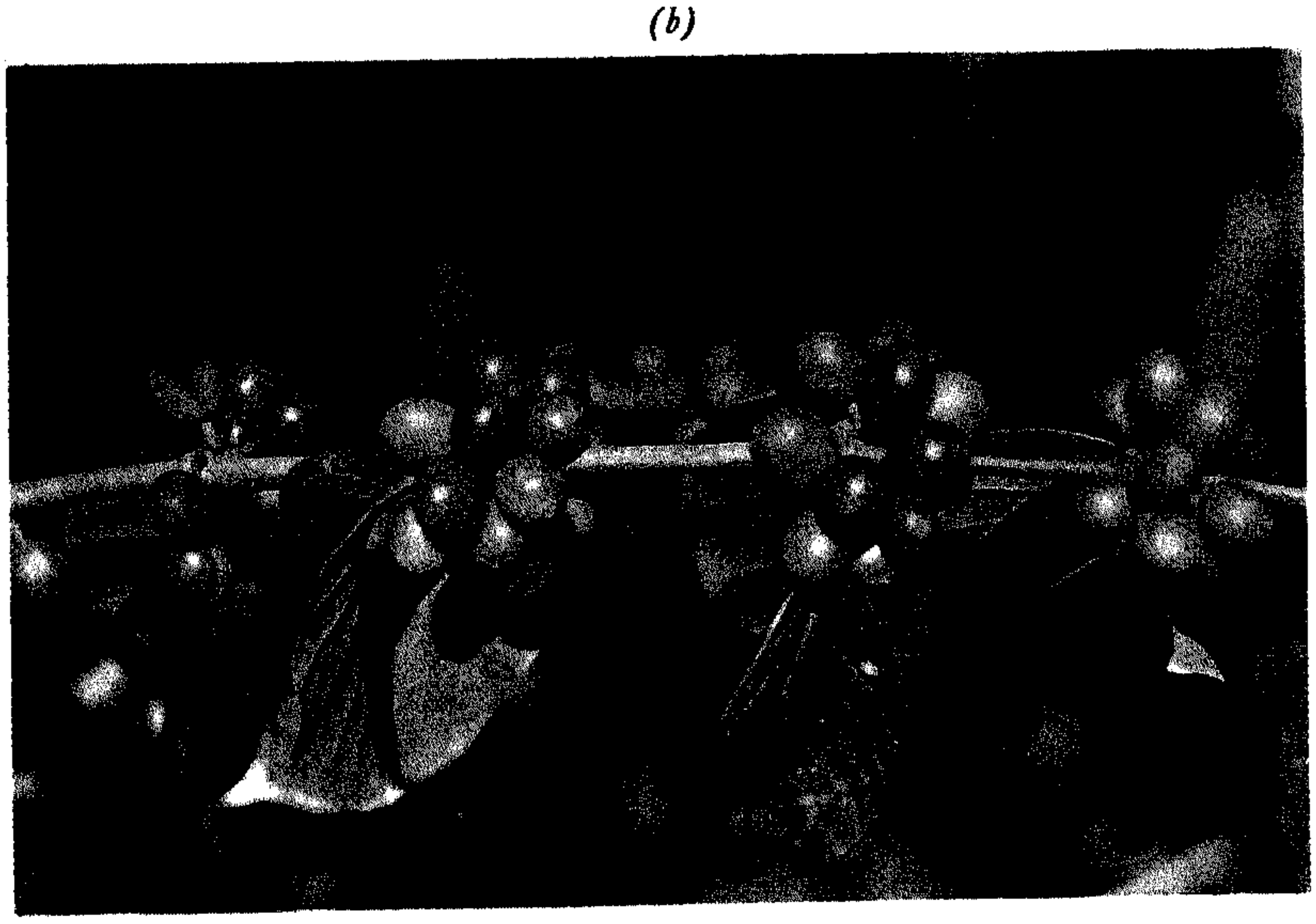
(a)

PLATE 1.—(a) Coloration in tip leaves of *Coffea arabica* mutants. On left, bronze flush of Typica; in centre, the green of Bourbon (most mature leaf about 12 cm. long), and on right, the slightly smaller purplish tip-leaves of Purpurascens. I.A.I.A.S., Costa Rica.

(b) Coffea arabica cherries on fruiting branch. Fruits are shown in several stages of maturity, somewhat loosely borne at the nodes. (Fruits averaged about 11 mm. in diameter.) I.A.I.A.S., Costa Rica.

(b)



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COFFEE

Botany, Cultivation, and Utilization

By

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CONTENTS

PREFACE

THE study of coffee and the problems it presents is an attractive life experience. The legends and stories of its early history are more like fiction than fact. In its production, the part human beings have played extends from what was done by aborigines and unwilling slaves to that performed by imperial order and by special touch of kings and religious teachers. There are strong scientific challenges in the reasons why the crop succeeds, and just as challenging is the solving of why it may have failed in some regions. It has summoned and attracted great scientists in their times.

During the period that agricultural science has been developing in the tropics, coffee has been the great cash crop there. It has paid for much. It has had an incalculable influence on the evolution of institutions for research and learning, and of institutions for finance and communication. For the tropical lands and their advancement, coffee has been, and still is, of vital consequence. An almost unbelievably large proportion of science, in the equatorial part of the world, has had its inception wholly because of necessary studies on coffee.

The one who is professionally involved with coffee finds an aura about it quite distinct from that of any other tropical crop. It seems to be in, what might be termed, a senior position. One reason is that, in coffee countries, much the greatest percentage of world exchange depends upon it. It is through this force that many tropical lands are economically attached to the temperate zone. Another reason is that growing of coffee has been a success in man's struggle to harness nature. Those dealing with the culture of coffee have gained confidence in what they can do with the jungle. This is a truly admirable achievement. The potent leadership furnished by such men has been important and freely given to the advancement of backward lands.

Coffee was grown as a new crop in some countries, while in many cases it later gave way to such crops as cacao, sugar cane, bananas, tea, cassia, rubber, oil palm, cinchona, fine cabinet wood trees, and pasture grasses. To grow these, farmers have unhesitatingly employed basic information already secured for coffee. It may not be fair to say, in all instances, that other tropical crops would have been failures without the scientific knowledge gained because of coffee. Yet it *is* fair to say that, for information about growing many tropical crops, more has been borrowed and gained from coffee research than is often admitted. If all that has been learned from work on coffee in the general field of tropical agricultural research were to be taken away, it would be a calamity indeed.

In certain lines, outstanding research has been done on coffee. More is now in progress as the increasing technology requires. It is widely-realized that more research than ever is necessary, if the crop is to continue in its status as the prime world commodity that it is. In spite of this knowledge, in certain countries there continues to be a dangerous lag in coffee research. In thirty years of watching, it is amazing to see, in places, how little change has been made in growing methods. Certain old-fashioned systems, that go back into the last century, still prevail. On the other hand, in other parts, there have been great advances in coffee cultural practices in the last ten years.

To make coffee a sounder investment, and to insure its future, new lines of inheritance from the wild plants are needing to be incorporated into the crop. A clearer knowledge of the botany and reappraisal of species not commonly used in commerce is also needed. The crop is being studied as never before, especially in Africa, but we are still far behind in research on coffee. There are numerous, much less important plant productions that, in special fields, have had a great deal more scientific study than coffee. It is astonishing to realize that there have been more trained pathologists working on the diseases of such an insignificant crop as celery in its very limited regions in the United States, than pathologists working on all the disease problems of coffee in all of Latin America. It is entirely probable that, at the present time, there is more study of the physiology of the winter vegetable crops in the one state of Florida, than is being done on the physiology of coffee in all the world. There has been more detailed work on herbicides for tea in one part of India than on the herbicide possibilities for coffee in all the world.

There has been more study of fertilizer placement for potatoes in Germany, for example, or the State of Maine in the United States, than has been done in all of the research on coffee fertilizing since fertilizers were first used on coffee over half a century ago. There is more study of time for application of fungicides on one of several of the small fruit crops in such a limited region as England, as in coffee all over the tropical world. More is known about the genetics of disease resistance in the cabbage crop of one small area of southern Wisconsin in the United States, than is known about the genetics of disease resistance to all the diseases of coffee in all the world. More study by trained specialists is being given to farm management problems in a half-dozen counties in a state like Illinois, or Indiana, or Iowa, in the United States, than is being pursued in all the length and breadth of the coffee farms of Tropical America. These are just a few examples.

Still, coffee has continued to progress. Planters have done what agriculturists do anywhere—carry on their own tests and studies. The successful *finquero* or planter has to be, in his way, a practising scientist. He runs his own experiments, and upon their outcome depend changes in his husbandry practices. These farmers have also gone farther.

They are, more and more, demanding the development of services of researchers from governments or associations. This was an old system that paid handsomely in the Netherlands East Indies for a long time. It is being practised in many countries now, while only just being established in some other parts of the world. They are wise who are doing it; for the mistakes that can be made from dependence on findings in far-distant places are often costly. Where good research goes on locally, making needed changes in the adaption of others' findings and developing new techniques, the future of coffee is more nearly assured. Eventually, it is the place where coffee is studied the most that will produce the most and the best.

The old type of exploiting coffee farming is still practised, but the areas where this is still possible are fast disappearing. Planters do not relish costly moves that used to be a recurring experience. It is more than ever imperative to solve growth difficulties, and not to run away from them. The findings of scientific agriculture are being sought to solve the problems, and, in the long run, scientific agriculture is not characterized by failures.

It is not only in its help in scientific agriculture or in its civilizing of the jungle that coffee has had its influence. There are features about the drink that are not easily matched. One great advantage is the combination of something that has both flavour and stimulus, yet can be prepared from a relatively stable, concentrated product. It is popular because of 'the kick and the push', the awakening and the sustaining, that comes from the drink. Many human beings seem to need that stimulus. Who can tell to what extent coffee has effected the impetus of our modern civilization ? What inventions of new fabrics, new colours, new food products or means of caring for them, or new electronic devices, have been the fruit of the mental spur from coffee? What new physical comforts, new transportation, new explosives, and new progress towards peace, have been propelled through the last 'ounce' of mental effort generated by the extra thrust from coffee?

No one has actually said that any war has been won on coffee. But who knows ? In aviation, the test pilots, the bombers, the servicing forces have kept acutely awake on cups of coffee. Night watches on land, on water, and in the air, have been sharper because of coffee. No one can well estimate or judge to what extent, for many years military success has been due to a last effort or follow-through by the winning side because of its supplies of hot caffeine drink.

Coffee is of value in its effect on many sides of life. Authors write into cold grey mornings with sustaining cups of coffee at their elbows. Artists and their models, for the endless search in the expression of beauty, are notorious users of coffee in the Greenwich Villages, the Latin Quarters, the Montmartres of great cities. There is no easy way to assess the part coffee has played in thought and aesthetics in the past or plays at present.

It is difficult to know the full influence of such a thing as the mid-morning and mid-afternoon coffee breaks in business, thereby easing office strains and relaxing petty annoyances. Coffee is known to help in the clarification of clouded and smouldering thoughts, and to make bearable and even pleasant, otherwise deadly and routine tasks. Not least, but last, should be mentioned perhaps the greatest service of all from coffee: its benignant use in the home. It is the early morning blessing, the pick up, and the source of comfort, friendliness, and happiness during the rest of the day—*par excellence.*

It is such things as these, and more, all combined, that make it worth the effort to write a book on coffee, even though it may be lacking on some points. Many phases are under active study at present, some are newly begun, and some are far from deserving much more than mention. Another book can include them. It has been with a great deal of satisfaction and pleasure that I have written this book. It has been an interesting thing to do, and I wish to thank Professor Nicholas Polunin for leading me into the task.

ACKNOWLEDGEMENTS

IN particular, as related especially to preparing this book, my indebtedness is great to the never failing help and clarification of thinking about the coffee crop from Dr. Pierre G. Sylvain, Physiologist and Coffee Specialist of the Inter-American Institute of Agricultural Sciences. His help should never be blamed for features I have presented of controversial nature. Among other things, he freely furnished me photographs, of which special mention should be made of those he obtained while on assignment in Ethiopia and Yemen with the Food and Agriculture Organization of the United Nations. My library work could never have been accomplished in the way it has been, but for the interested and selfless dedication, and the special service and help, of Miss Angelina Martinez and Miss Noel James, Librarians of the Inter-American Institute of Agricultural Sciences. I also wish to express my appreciation to the Library of the United States Department of Agriculture for the loan of some special books. Especial recognition should be given my wife for the inestimable and active assistance she has given with the manuscript. Much as that has been, she has added still more by her patient and helpful concurrence in the lone stretches of time that are ordinarily ours together but which I have spent working toward this book.

I owe a debt of gratitude to Dr. Ralph H. Allee, Director of the Inter-American Institute of Agricultural Sciences of the Organization of American States, for his continued help and unfailing encouragement. In especial measure, I wish to acknowledge the early and constant help of Mr. Claud L. Horn of the Office of Foreign Agricultural Relations of the United States Department of Agriculture. It was he who initiated me into certain of the more difficult horticultural problems of coffee and its world relations. In retrospect should be mentioned the great pleasure I always had in working with the late Mr. James T. Mitchell, Photographer and Visual Aids Specialist, Office of Foreign Agricultural Relations of the United States Department of Agriculture. It is a satisfaction to acknowledge the aid he so freely extended from the photographs he made and from which I have used many. Special thanks should also be given to Plant Protection Ltd., 61 Curzon Street, London, for the opportunity they furnished me to work in the libraries of Kew, the British Museum, and the Linnean Society.

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FIGURES IN TEXT

LIST OF ILLUSTRATIONS

PLATES

INTRODUCTION

COFFEE is a well loved drink. Several characteristics of coffee make it good to man. There is its rich golden colour, its inimitable bouquet, its delightful fragrance, its miscibility with additives such as cream and sugar and sometimes spices and certain alcoholic liquors, its welcomed warmth, and the strength derived from its mild and good stimulus that suffuses the person who has had a cup. It is habitually drunk not only in the early mornings but as a refreshment with all meals, and possibly between them. Often it assists in work, and eases the tension of powerful activity, whether physical or mental. It may begin meals; but it is also the last fleeting aesthetic touch to dining, whether it be an informal luncheon for one or two, or a large banquet of hundreds, with the wealthy, the noble, and the great in attendance. How much one would like to know what part the cup of coffee has had in the true carrying on of a maturing civilization, in the winning of wars, and in the developing of philosophy and art! Whatever else may be conjectured, it is the pleasing source of a mild stimulus—harmless but most remarkably important to a large body of civilized men and women.

A great many of those who drink coffee give little thought to its origin. Some scarcely realize that it comes from trees *(see* Pls. 2 and 3), and comparatively few know what part of the tree is used. The trees vary in size; they grow in the tropics and are mostly handsome evergreens with leaves that are dark green and waxy surfaced. In some, the leaves are as large as those of the magnolia, in others as small as in the plum. Depending on the species, the plants of the genus may be vine-like or shrubby and some are dwarf, bush-like growths with stems no thicker than a finger and less than hip-high. There may be dwarfed to small or medium-sized trees, or large forest trees with trunks having a diameter as thick as or thicker than a man's waist, and reaching well up into the 'high parts of jungle growth. However, the main coffees of commerce come from the medium to smaller-sized trees. Their fruits vary in colour: they may be pink but are mostly brilliant red, some being nearly purplish, other dark brownish-red or yellow, and they all bear inside them two nut-like seeds. On picking and drying the fruits, hulls are shelled off and the hard kernels are roasted to a brown colour and then ground. It is from these ground and roasted kernels, or beans, that an extract or infusion is made with hot water. This is the decoction that is the end product, that goes to make the fragrant drink.

Pl. 1 *(Frontispiece)* shows examples of what might be called the original raw-materials, the foliage and fruits of coffee.

THE BENIGN STIMULANT AND ITS IMPORTANCE

Coffee has become an important part of the dietary plan of many civilized peoples, and of many we class as aborigines. Because of its taste, coffee has come to fill a most important place as a beverage. Flavour is there in good quantity; there is good colour, and a healthy stimulus which, if reasonably indulged, is a valuable aid to good living. This makes for a mild habit formation that is easily erased. Its use is, in only very rare cases, of an injurious nature. It is well recognized by the young and old, by labourers, thinkers, and dreamers, that it helps mightily in the carrying on of services, and in the course of their living as a part of the world's population.

The true purpose of the best beverage, which is to stimulate with good but harmless effect, is to be a pleasure to drink, to have dietary recognition but not necessarily to add to caloric intake, to have long-time acceptability, to be the kind of a thing that will appeal to human beings repeatedly, and one that they can have recourse to over the years of their lives. Coffee accomplishes all this and, in addition, it does not result, as in certain other stimulants, in great elation followed by a ruinous feeling of depression. The effects of the coffee are benign but highly effective.

According to studies by the U.S. Army and others, beverages fall into three natural categories: the thirst quenchers, the stimulants, and those that are nutritious. Coffee has been classed in the second category as a stimulant of the first magnitude, and commercially it is the most important of the group that are infusions or decoctions. According to medical men, stimulants such as coffee are considered better, both physiologically and psychologically, than either tobacco or alcohol. It is significant that, in world commerce, coffee takes first place as one of the enjoyment goods, surpassing alcohol, tea, or tobacco.

For some time coffee has been, and continues to be, among the five most important agricultural commodities in international world trade, the others being cotton, wheat, sugar, and wool. In many of the coffee-growing countries, business with the rest of the world depends on coffee. In Latin America this is especially true, for here seventeen independent republics and several dependencies grow large amounts of coffee. In at least eight of these western repubHcs, and in at least four countries of Africa, it is the principal commercial crop. It is a main, and some say the most valuable, complementary agricultural product imported into the United States of America. This is, to a slightly lesser degree, the case also in certain countries of Europe.

There are over 125 countries that consume coffee, and there are about half that number producing it. A list of what might be called important coffee-producing countries is as follows: Angola, Brazil, Colombia, Continental French Africa, Costa Rica, Dominican Republic, El Salvador, Guatemala, Haiti, Honduras, India (southern), Indonesia, Kenya, Mexico, Nicaragua, Tanganyika, Uganda, and Venezuela. It can be seen that these make up a group having locations in the great geographical divisions of the globe, namely Africa, Asia, Caribbean Islands, Central America, North America, Oceania, and South America.

During the years 1953, 1954, and 1955, exports of green coffee from producing countries became the second largest in world export trade and were exceeded only by petroleum products. The Pan American Coffee Bureau review of the world coffee situation has shown that, as an export commodity, it is of the greatest importance in thirteen major producing countries. In some, of course, it is much more critical than in others as a source of world exchange. This ranges from 2 per cent for Venezuela to nearly 90 for El Salvador. There are some changes occurring in coffee trade that are of considerable significance. These will be discussed more fully in another chapter, but there is a tendency in a few countries for coffee production to become more stable. At the same time in other parts of the world there is little of this tendency to be seen. In Brazil expansion is going on rapidly, but finding some limitations. In the East, both in Africa and in Asia, where coffee production has been so low for so long, it is once more increasing. Consumption is, perhaps, gaining in Europe, while in North America it is tending towards a relatively fixed rate, increasing slowly with population growth.

It is fairly obvious that coffee is an agricultural product of considerable world value and renown. Yet, over the years, it has had a minimum of attention from the standpoint of gathering together known facts about it in a unit where they can be reviewed or consulted. There are a few old, widely scattered books on the subject that can be obtained in libraries here and there. In the main, these are out of print and mostly they do not present the results of newer findings from the last few decades of study and research. There are a few books of more recent publication on special aspects of coffee.

When I was asked, and then consented, to write this book, I did not do it because I felt that I knew more than anyone else on the subject; far from it. I have done no more experimentation than anyone else. I have written the book because it is a challenge, and I felt that possibly it would be of service in helping others to know coffee, and that it might assist the development and modernization of research on a great world crop. It is recognized that, while these very words are being written, new discoveries are being made that will soon supersede some of those here recorded. In addition, there are new problems just now arising to be solved. Therefore, this book is only a step. But it may be a reasonable step in the progress that has gone on to further an understanding of the problems related to this crop, and maybe to some of tropical agriculture in general.

This book has not been prepared as a manual of detailed information on every possible jot of knowledge about coffee. The most important thing: borne in mind has been to present the plant or the coffee tree, and the drink. The book has been written with the hope that significant coffee problems, and phases of those problems, will be indicated. It is, moreover, hoped that it directs attention within its pages to some of the serious lacks and weaknesses in accepted knowledge and research results of coffee. Coffee has a fascination about it. It has a romantic background, and It is produced in some of the most picturesque and fantastic parts of **the** world. It is of paramount significance as a world crop. It is of such consequence that it needs to be understood by the economists who deal with international relationships. It has serious political influence, both within countries and internationally.

This book is written in the hope that it may be interesting not only to the coffee producer, importer, exporter, and average student, but also to the one who drinks coffee and to the scientist who is interested in it. Care has been taken to make of it an authoritative account through adequate attention to world literature. In this connection, it should be pointed out that the tropics is not an easy part of the world in which to accomplish scientific work. In these lands we are behind the temperate zones In scientific advancement and libraries, for numerous physical and sociological reasons. Anyone who accomplishes a major piece of scientific work In the tropics, especially on a crop with random backing, such as is often the case with coffee, is to be highly admired. To publish it for posterity is even more admirable. This is what takes the blood and the years. And so, at this point, I want to give special recognition to those who have written. It is on these writers, whether the names are of those long gone into history, still living, or at work in the present, that our agricultural science dealing with such a great crop as coffee must depend. My hope is that I have included at least a modest part of what I should.

To all who work in science, especially in the tropics, it is well known that sound, original publication is not child's play. Tropical workers realize that it is more arduous than for their colleagues of the relatively more comfortable, luxuriously manned and equipped centres and institutions of the temperate zones. However, real presentation in print of original research or observation is precisely what separates the professionals from the lesser amateurs. It has given me some concern just how much should be done towards recognition of the professionals working on coffee. A complete listing and reference to all writings on coffee could not be done in this book; in it, instead, are listed only those publications that I have cited. These are not necessarily the only ones on their subjects, and may not always be the best ones. They seem, however,

Photo James Mitchell

PLATE 2.—Tree of Arabica coffee in blossom in the Guatemalan highlands.

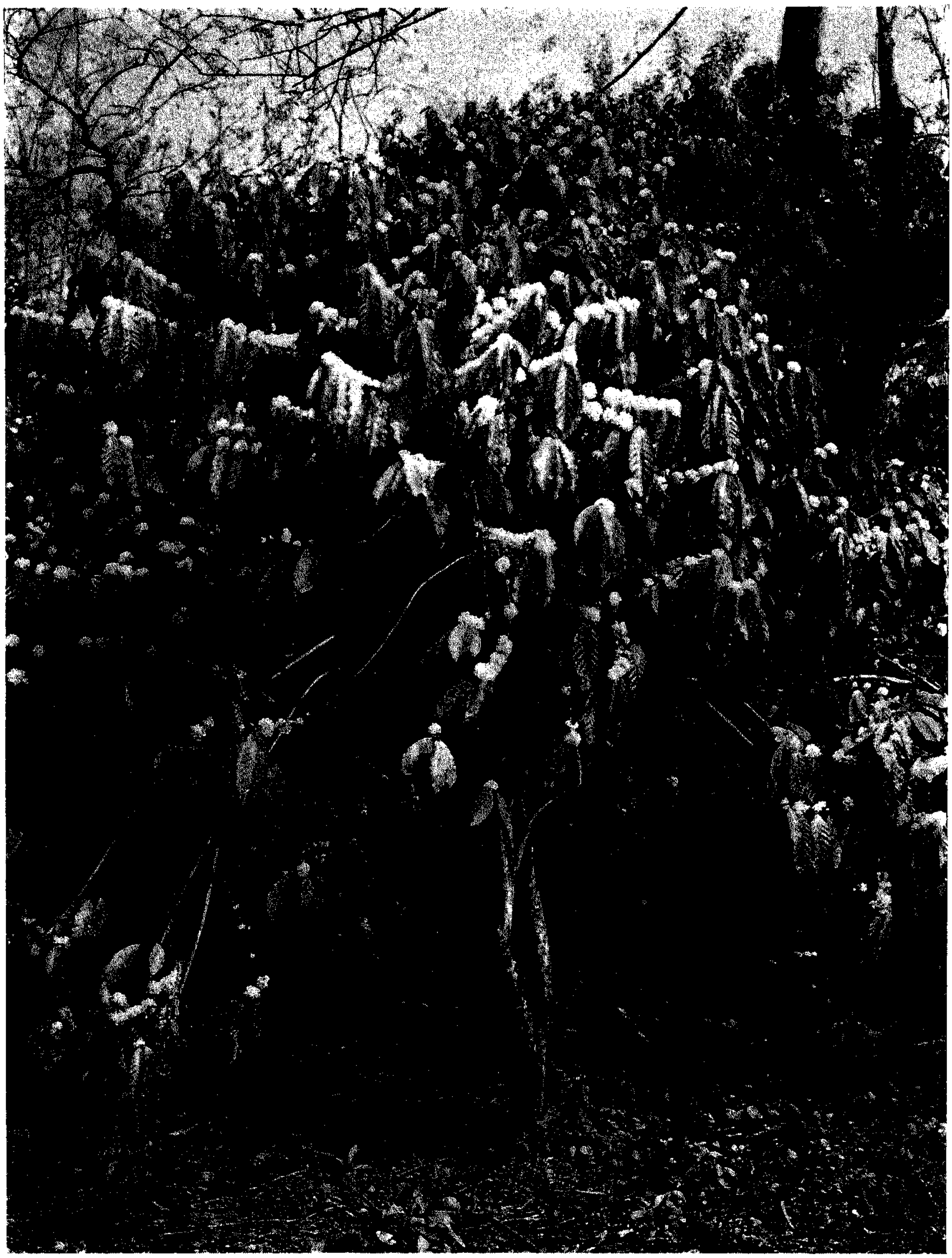

Photo James Mitchell

PLATE 3.—Young trees (over 2 m. high) of the Canephora species of coffee in blossom. It is from this species that Robusta coffee was developed. Guatemala.

important publications, and perhaps readily obtained in libraries. Some few were included only for historical reasons. Many were selected because, in addition to the body of the articles, they contained good appended literature lists.

There are some thousands of citations on coffee, but an exhaustive recording of them would hardly serve the purpose of this book, which is not a literature review. There is, inevitably, duplication of presentation in the literature. With a subject of such world-wide interest as coffee, writings have appeared in many languages. In connection with coffee-growing alone, I have found articles in Spanish, Portuguese, Dutch, German, French, Walloon, English, Latin, Chinese, Arabic, Italian, and Swahili. There must be others, such as Russian, Japanese, and Umbundu. It can be readily understood that many translations have to be made to carry newly secured results to many people. Many of the people needing information most are growers who may not readily understand the first language in which results appeared. Sometimes the original authorship is traced with some difficulty, as translations may have been made primarily for extension and adult education purposes, and without much consideration of the ethics of credit. However that might be, it is believed that the major portion of the best coffee literature is gathered together in this book.

One of the things that must be noted is that my scientific interest in coffee began with the pathology of the coffee tree in all of its stages. It is true that I have had to know the growing problems to deal with reducing losses from diseases and pests. However, because I specialize in diseases, I have been interested in the whole gamut of crop difficulties. I may perhaps be accorded the privilege of presenting a fair amount of description and discussion of these difficulties which, to me, are such an interesting and crucial part of all tropical crop production. Furthermore, as the reader goes through these pages I hope he will see, as I have realized after writing the book, that my philosophy has been to proceed on the basis of an understanding of troubles, whether of pests, of techniques of growing, of diseases, or poor ecology. To me, the stimulus lies here, such an approach always having a healthy conclusion as its logical end.

F. L. W.

II

SOME LEGENDS AND EARLY HISTORY

THE coffee drink has become everyone's drink, but it has always had about it, not only a certain aristocratic but, as well, a religious atmosphere. There is something ceremonial in its use. The stimulating effect of its aromatic beans has made the crop desirable in a way that ordinary food products do not satisfy. It is no wonder that legends have developed around it. Fig. i shows the areas of the world in one or more of which coffee must have originated, as they are the areas inhabited by the wild plants.

SOME EARLIEST HISTORY OF COFFEE

Classic writings from Egypt and from the early Greeks and Romans have no mention of coffee. It is curious that there has never been any proof of its use in the Ancient World, nor in centuries later in Greece and Rome, or Byzantium. There have been some authors who have thought that the nepenthe, which, it is recorded, Helen of Troy brought out of Egypt for surcease from her sorrows, was, in all probability, coffee mixed with wine. It was believed by the religious Linnaeus (1763) that coffee was spoken of in Arabic scriptures of about A.D. 900 and that, historically, it went back even farther. He believed that in his Old Testament there was a story (I. Sam. XXV) that the beautiful Abigail, the calculating but peace-loving wife of Nabal, took roasted grains of coffee to the then emerging King David and thus not only negotiated peace between two opposing camps, but, on Nabal's death, charmed David to make of her one of the first of his numerous wives.

Since the time of Linnaeus other students of the Old Testament have thought a possible reference to coffee was in the first chapter of Genesis. There the red pottage of fame is mentioned, for which the hairy Esau sold his birthright. The colour red has a very ancient relationship with coffee, and the Bible is quite clear that, in one case, the pottage was red, while in the other it was spoken of as being of lentils. There is no proof that these stories refer to coffee, and there are those who question the likelihood.

One of the interesting things in the history of coffee is the, perhaps somewhat legendary, story of its introduction into that region of Arabia called Yemen or Yaman. It will be recalled that, during the latter part of the Sassanid dynasty of Persia, there was an invasion of Yemen. It was

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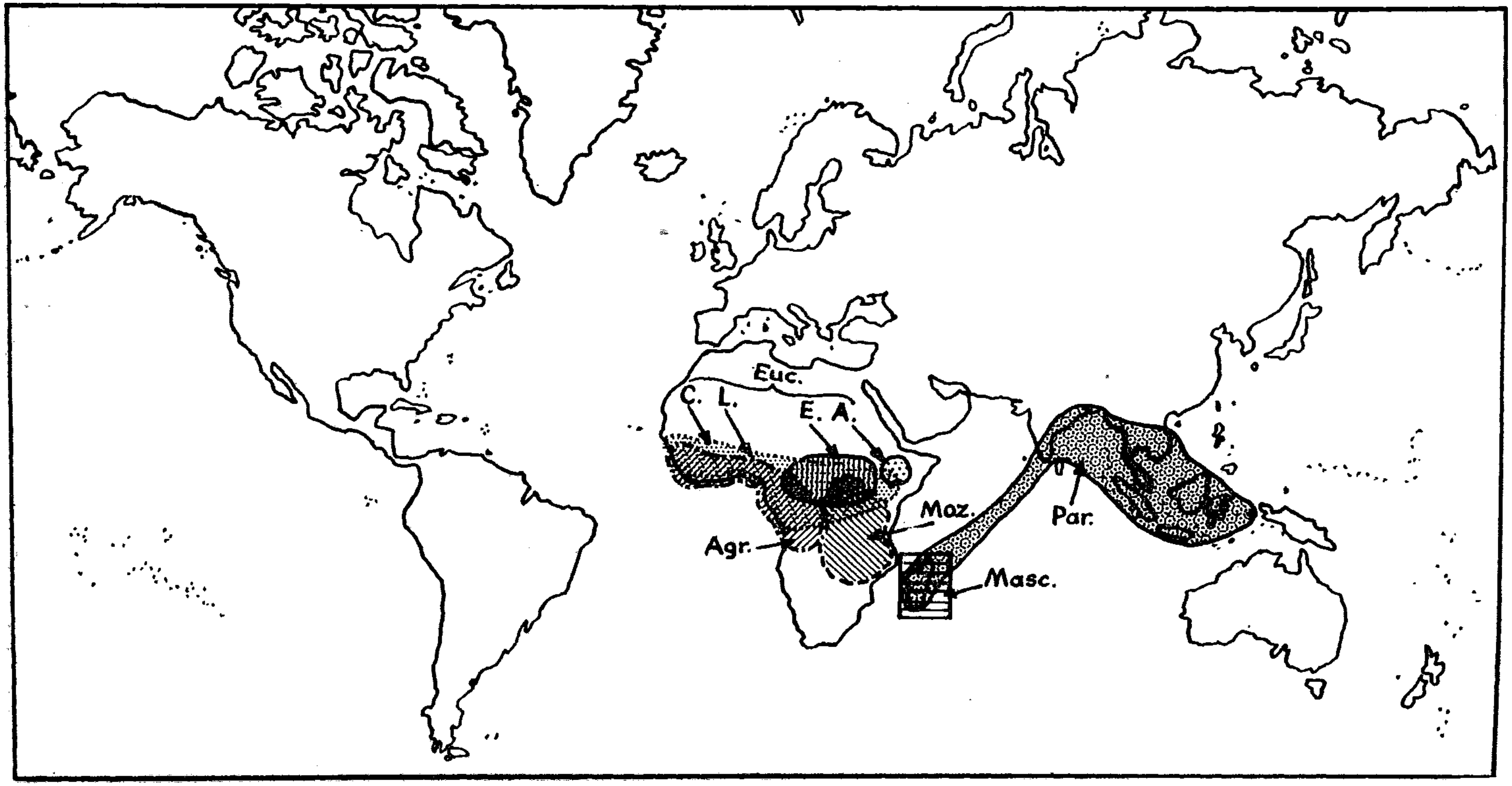


FIG. I. Approximate outlines of Areas of Origin of Coffees, Agr.—Agrocoffeas; Euc.—Eucoffeas, main species; *A—Cqffea arabica*, G—C. *canephora*, E—*C. •exceka*, L— *C. Mbmca;* Masc—Mascarocoffeas; Moz.—Mozambicoffeas;Par.—Paracoffeas* one of the invasions that occurred with the slow progress of the conquerors travelling overland from Persia and up the Nile valley. The armies stayed long in the territory they won, and from it there were forays into the fabulous highland country of Ethiopia. Even then, it was a rather short over-water trip to Arabia across the Red Sea. During this time the Persians took with them the things that interested them most

Since before the Persians even began to record their doings in cuneiform, they were great travellers and prodigious lovers of luxury. They searched in every corner for perfumes, spices, and stimulants, old or new, common or exotic, to enrich their proud civilization. No one knows exactly when the first coffee came to Yemen. It has been variously estimated at about A.D. 575. It was probably brought along as part of one of the culture-carrying invasions of those Sassanid conquerors. So it seems the probabilities are that, in the beginning, the first move of coffee outside of its native habitat was by adventurers, devotees of Zoroaster, and themselves admirers of the good things of life.

However, long before the Persian conquerors, there is sure knowledge that the first use of coffee was by the aborigines of the African forests. The most complete and scholarly historical studies have been those of Ukers (1922) and Chevalier (1929), but the works of Bradley (1716), Keable (n.d.), Abendroth (1825), Cramer (1957), Cheney (1925), and Porter (1833) should also be reviewed in this connection.

It is believed by some that the Ethiopians, who were related to the Egyptians but had been a separated part of that stock for some millenia, had at one time-travelled out of Africa, across the narrows of the Red Sea, to Arabia Felix. This was the better watered part of Arabia, with gardens green enough to relieve the monotony of the harsh" desert vegetation. Since ancient times, long before Mohammed, there had grown up a Sanctuary in Arabia Felix, that later became known as Mecca. For very long a separate kind of civilization flourished there, specializing in religion and in the arts of peace. Early in their prehistoric wanderings, it seems that Ethiopian adventurers and religionists visited, and settled in, the outskirts of this favoured place. It is believed that some of these brought there the first coffee seed from Ethiopia. It is not unlikely that from there the camel trains and first merchant ships took small bags of the coffee beans to Persia, and thence northwestward on the ageless caravan routes. PI. 4 shows an opening in an untouched coffee forest in Ethiopia.

LEGENDARY STORIES OF ITS DISCOVERY

Those earliest coffee beans for human consumption almost undoubtedly were chewed. An example of legend, connected with the first coffee use, is the story of Sheikh Hadji Omar which, although well known, deserves repeating. This dervish was an early Moslem, exiled, for peculations, from the Arab parts of the city of Mocha, which is far distant from Mecca.

He was taken away and set outside the reaches of cultivated lands. There he lived in misery and alone in more desert than garden, with only his bare hands to get him food. Nearly dead from hunger and illness, he discovered small coffee trees growing in an out-of-the-way place. He found on chewing the buds and fruits from them that he had wholesome relief from his miseries. He must have been a good person, for he told others, and soon the sick and weak came to him from all around. They chewed his seeds and drank his coffee medicines, and they returned to Mocha much improved in body and soul. His fame spread. He was pardoned, was brought back from his wilderness isolation, and continued to dispense his coffee medicine. A grateful populace built him a monastery, where he lived and died, and, long after, his disciples carried on his good works.

There are different versions of another story, the tale of the Arabian goat-herd, Kaldi, It has changed much in re-telling, but one of the oldest versions is as follows. Kaldi, it seems, found his animals dancing and cavorting after eating fruits and branch-tips of certain bushes. He was curious and tested the fruits one day and was so refreshed and greatly stimulated as to dance along with his goats in the Arabian hills. Below, in the flickering heat, at a far distance, lay slumbering the age-old, wide sanctuarial space where grew up the city of Mecca. Here was housed and protected the population that lived to minister to aged bands of religious visitants and mendicants, that came there even long before the time of the Prophet of Allah. It so happened that a drowsy monk from below was passing by and admired the wakeful herd-boy and talked with him. Kaldi told him his secret, and asked the monk to try the fruits. The monk then ate of the fruits, seeds and all, and was quickly a better man because he was reinvigorated and could pray longer without sleepiness. This soon became not only a fad but of great value to the Most Faithful in Mecca, and spread to other parts of the world where the Faithful prayed.

It was also believed by Moslems, generations ago, that an angel came down from heaven and taught the virtues of coffee to a True Believer, who gave the secret to the world, and, although unnamed, his memory was forever to be praised.

Another story is told, but without much detail, that special votaries were to be offered by The Faithful to two Arabian monks, Scialdi and Ayduis, because they first introduced coffee to Moslems. During the fifth century, a common Arab worker, Schehabbedin Ben Abdalgiafar Almaleki, is supposed to have taken coffee from Africa to Arabia Felix, and another worker, who was also a priest, Gemaladdin Abu Abdallah Muhamid Bensaid, was the first to bring it to the city of Dhabar in Arabia Felix. Their names have long been cherished as being among the great benefactors to the human race.

There are many old references that show how important coffee has been in Arabian civilization. There is even a passage from the Koran that is believed to refer to coffee. In English translation it goes this way: They shall be given to drink an excellent wine, sealed; its seal is that of the musk.' The term musk in this connection is said to refer probably to the solid nut that would contain the drink or wine. In other words, the coffee bean. There have been reports that Arabians made an alcoholic beverage from the expressed juice of the pulp from coffee fruit. However, any alcohol is prohibited by the Koran, and, besides, one who has been so unfortunate as to have tasted experimental coffee pulp wine, knows the unattractive, poor quality drink that results. On the other hand, the infusion from the seed itself was a stimulant so good, harmless, satisfying, and so well enjoyed that it became, and has remained, a significant feature of Moslem civilization. It is most probable that the Arabs were the first who really perfected preparation from roasted coffee for a drink.

NAMES FOR COFFEE

The Arabs were great users of coffee, to such an extent that the English-speaking world often called it 'wine of Araby'. In connection with the crop, it is important to consider briefly the names for it and the drink. The name 'coffee' may or may not be originally Arabic, although it has been used in Arabia for a long time. The Arabic word 'kahwa' probably had remote connections, for it seems related to the Sanscrit word 'katu', meaning impetuous. The more oriental Dravidians used the name 'kadu' for it, and the name 'karwa' is Hindu. In discussing *Coffea arabica*, Linnaeus (1737, 1763) published such common names for it as 'arbor bon', 'bunchos arabum', 'bun', 'bon', 'bunchum', 'bon vel ban', and 'buna'. His generic name, *Coffea*, is a Latinization of one of the Arabic names 'caova', 'cova', or 'kahwah'. Prior to this time, Chamberlayne (1682) stated that, in all of the wide flung Turkish dominions, the drink was called 'coava' or 'chaube', and that it came from the 'bon' or 'bun' bean. Another early writer, Bradley (1716), reported the coffee fruit as called 'buna' and the drink as 'caova'. He also said the tree was known as 'bon vel ban arbor', but was simply called 'coffee' by the 'Aethiopians'. He quoted from Jacob Cotovicus who, in his *Travels to Jerusalem* published in 1598, saw the coffee drink being much used by Turks and Arabs. He said the latter called it 'cahua', while others used the words 'bunna' and 'bunchi'.

Considerably later than Linnaeus, there appeared a work on coffee by Abendroth (1825). He gave names for the coffee drink in Arabia alone as 'kahwa', 'kaw-wat', 'cavet', 'cohvet', 'cofe', 'cohue', 'cahue', 'cophe', 'chaube', 'chahave', 'cahovah[5], and 'chohava', while the tree was called 'bon' and the fruit 'buna'. A long time after Linnaeus, coffee was being called 'boon bija' in the cottage gardens of India (Meppen, 1938). This was known there as the ancient name handed down over 200 years before from Abyssinia, where it was called 'boon'. According to Chevalier

(1929), 'bun' was an Arabic name, although the Amharic word was 'bun' and the native Oromo tribe used the word 'buna'. In these modern days it is often called 'buni' and 'mbuni' in Africa. And speaking of the 'bean' of coffee, the name may well have had its origin from this word 'buni' or 'bun'.

In addition to the word 'buni' and variants of it still used for coffee by Africans and Europeans, there are many native dialects which have their own designations. These are little known by Europeans but indicate the indigenous and very ancient use of the crop. Chevalier (1929) found in north-east Africa, largely Ethiopia, that a coffee leaf infusion, twice steeped, was called 'tchambo' among the people of the Golla tribe. Leaves mashed and mixed with butter were called 'greffe', and the plant itself was known as 'dukke' by the Ometo people. According to a report of the Royal Botanic Gardens, Kew (1915), the vernacular names in Nigeria for either wild or cultivated coffees are 'murian bambe' and the similar 'muria ubambe', which may have slightly different connotations. In the West Coast region, the natives use certain of the wild types, and they mostly have their own peculiar names, a few examples of which are given by Dalziel (1937). The native words 'benim akpano' are used for the wild-growing C. *rupestris*. The name 'yonembei' is used for C. *stenophylla,* and they call *C.jasminoides* both 'pegbie' and 'ma-gbel'. This last is used as a source of medicine for application to circumcision wounds during their secret rituals. In the Congo, the Turumbu dialect name for the wild C. *lebruniana* is 'yabukula esendi' (Germain & Kesler, 1955).

EARLY USAGES AS MEDICINE AND DRINK

It would be, indeed, an extremely unusual thing if a plant of such surprising and stimulating characteristics as coffee, did not have many unusual uses. It had been known in early medicine in Arabia, in Europe, and in America, for many and diverse purposes. It has been suggested by Chamberlayne (1682), Bradley (1716), and others that coffee infusions may have been the so-called ancient *Jus Nigrum Spartanorum,* or the Black Broth of the Lacedemonians. This deals with the age of mythology and, of course, would be hard to prove. Medicinal usages, of not more than two-and-a-half centuries ago, indicated coffee to be of a so-called drying quality; it was said to have comforted the brain, helped pains in the head, lethargy, and cough. It was supposed to be a cure for consumption, swooning fits, and rickets, although it was not advised for the paralytic nor for those troubled with 'melancholy vapours' nor 'hot brains'. However, it was useful in sobering people saturated with 'fumes of wine'.

It was supposed to help digestion and 'rarified the blood'. It prevented sleepiness after eating, and was administered to 'provoke urine and catamenea'. Arabian women used it for alleviation of discomfort of 'periodical visits' with 'good results'. Its administration was 'prevalent in such as had Running Humours, Sores, and King's-Evil'. It was also considered useful against rheumatism, gout, and intermittent fevers. For children it was said to be effective against worms, and it was a strong anti-hypnotic. Since those early days coffee entered the more modern Pharmacopoeas, and a cup of black coffee is, even today, a medical prescription in certain cases. Of recent years, it may be more commonly prescribed as purified caffeine in compounds, but is well recognized as a most valuable nerve stimulant. Such uses as drink were from the bean, or of purified caffeine from it.

Going back into ancient times, a number of authors have given scholarly evidence that the first coffee drink, antedating medical use, was probably an infusion from the coffee leaf. Both Barrett (1928) and Burkill (1935) describe a common method of preparing coffee leaves to make a tea-like drink. This method was old when it came to Malaya, Java, and Sumatra, but is still used. Young leaves and succulent stem cortex is stripped, permitted to wither slightly, bruised, allowed to stand a short while, and then basket-dried over a bright fire. When it is broken in small pieces and infused like tea, it makes a palatable and refreshing drink.

This ancient drink is from foliage, and it would seem likely that later, green 'cherries,' picked whole and dried so that they could be stored, were steeped and resulted in an even more stimulating beverage. The use of dried coffee cherry pulp is described by numerous writers, especially Bradley (1716), Southard (1918), Burkill (1935), Taunay (1935), and Sylvain (1955). In this method, the dried skins or hulls are prepared like tea and yield a tasty, stimulating drink. It was long ago, and still is, called 'quixr' 'qixr' 'kixr' 'kishr', and variants of these. Very recently Sylvain found 'kishr' in popular use in Yemen, while, interestingly enough, he also encountered use of a tea-like drink made in exactly the same way from dried coffee fruit hulls in Bolivia.* It was his personal experience in Yemen that kishr was a rather pleasant and stimulating drink, and the people were quite critical of the various qualities of kishr, paying accordingly. The seeds left after kishr production are crudely propessed in Yemen, dried, and sent away to outside markets. Very little roasted coffee is consumed there, while kishr is popular. Kishr is used also in parts of Africa lying opposite to Arabia, and Taunay (1935) reported that the Somali negroes, in addition to the Caucasians, drink kishr in Somaliland.

COFFEE AS A SOLID FOR FOOD AND EXCHANGE

From time immemorial, Africans have employed plant products from coffee for food. They have also recognized the exhilarating and good effect which comes from drinking and eating the leaves, fruits, and seeds

• Personal communication from P. G. Sylvain after consultant trip to the country of Bolivia.

Photo Pierre G. Sylvain

PLATE 4.—An opening inside an untouched coffee forest. A clump of the small trees of *Coffea arahica* form part of the lower storey. District of Limu, Province of Jimma, Ethiopia.

Photo Pierre G. Sylvain

(a)

PLATE 5.—(*a*) An improved Arabica coffee forest in Ethiopia: shade reduced, underbrush cut, ground litter undisturbed, and stand of wild coffee trees thinned.

(b) Typical Arabica coffee growing in small plots on ancient man-made terraces in Yemen (old arabia felix). Between the small plots of trees are grown annual subsistence crops tor human consumption and forage for camels and other domestic animals.

(b)

Photo Pierre G. Sylvain

of the many different forest and jungle trees, bushes, and shrubs belonging to the genus *Coffea.* It is logical that they probably first ate the ripe red fruits. The pulp is sweet and contains stimulating caffeine. This alone was refreshing, but when the fruit season ended those who had developed a taste for pulp had to wait another year for more. Ingenious persons found dried fruit hanging on branches and picked them for chewing.

Evidence of coffee use as a solid among the aborigines goes back a long way into prehistory. It was introduced from Africa into Arabia in pre-Islamic days, where it was eaten as a compressed product much as chocolate bars are consumed in Europe and the United States in modern times. According to Keable (n.d.), such coffee bars were used as a sort of iron ration in the famous crusade of Caleb Negus, when his forces went to punish the Himyaritic ruler Yusif Yarush in Yemen, who had been unusually cruel in his persecution of early Christians.

It was about this time that the Abyssinians first used it in solid form. Camel drivers and others took it as pressed cakes on their caravan trips and ate it with dates. It was believed (Thurber, 1884) that the original inhabitants of Central Africa never drank coffee. Rather it was eaten as a solid, a mass being ground and mixed with animal fat and pressed into a round form about the size of a billiard ball. On, safari, such a ball was sufficient to supply nutrients and energy for one man for one day. These, and similar masticatories, are usual caravan and hunters' foods in parts of Africa. They serve to refresh heavily laden foot carriers over long trails where extraneous impedimenta are at a premium. There are still places where pay-load and weapons to keep away dangerous and marauding animals are more important than bulky and fresh foods. Chevalier (1929) reported that the explorer Speke found coffee in the Lake Victoria region used in a sort of soup. The settled appearance of these jungle uses are such that they probably extend into distant times and may have been habitually handled in this manner for no one knows how long.

Taunay (1935) tells of the Galla tribes of more modern times who have an important travel diet, with a coffee base, for use on long safaris. The coffee is roasted, ground fine, and mixed with butter or other edible oil. It is formed into rather oblong balls about the size and shape of almonds, and these are eaten as a source of concentrated energy. Coffee was consumed as a preferred solid food and considered a necessity for home use among the Somalis. It was roasted in the villages and combined with cereal grains, likewise roasted. Today in several parts of Africa, good quality buni is used for chewing, has wide popularity, and brings good prices in native markets. Indeed, in some African regions no processed and shelled coffee beans ever appear for local sale.

The British Museum in the spring of 1956 exhibited modern African handicraft ware, among which were pieces suggestive of the present use of coffee by the native peoples. Two displays, obtained in 1939 and 1950, were from the Hinda tribe of the Bukoba district in Uganda. These were labelled as 'Baskets to hold coffee beans which are chewed like chewing gum'. From Somaliland was shown a modern wooden mortar for grinding coffee. Some artistically finished, beautifully woven objects obtained in 1943 were included from the Zifa tribe, living near Lake Victoria. These were labelled as 'Two small baskets of the kind made by princesses, to hold coffee beans, which are chewed like sweets'. A handsomely made flask of woven grass had been secured from the Ira tribe in the Ankole district, and described as 'Plaited grass bottle to hold coffee beans, which are chewed like sweets'.

While in Uganda in September 1952, I saw in village markets small packets of spiced buni. I ate some of them according to directions. In consistency, at first they were flint-like, but, held in the mouth, the outside soon softened, was chewed off, and the two beans soon became softer and in condition to chew. This required a little time, but the taste was good, almost describable as savoury. One did not need many of these buni to be highly stimulated, at least judging from effects on me. They came from large, wild 'King Trees' of *C. canephora* that were later pointed out to me; they were picked green, when over half-mature, and steeped in water with sweet grasses and several native spice herbs. On drying carefully, they were packaged in grass and were ready for consumption. Hung in the huts and houses of the people, they were said to keep well for a long time. I have not seen any record of all the places where buni are eaten in Africa, but their use is widespread. I learned of their consumption in Angola, and buni have been a staple in the Gabon for an exceedingly long time.

Coffee has also acted as a means of exchange. The employment of cocoa beans for money among indigenes of the Americas has been well publicised. It is not so well known that African peoples have done this with coffee. This is still said to be the case in some isolated tribes. It was reported by Bradley (1716) that he knew of coffee used as money in Arabia: 'Counting so many Berries to an Asper (a small Turkish coin worth about three farthings), in proportion to the Value, or Price settled by the Bashaw.' This latter personage was a sort of export-import commandant who settled the price of coffee according to business conditions.

COFFEE IN RELIGIOUS AND MARRIAGE PRACTICES

Buni and other solid preparations of coffee for chewing and eating are not all the uses made by the Africans. There have long been religious features involved as well. I have never read any published material concerning certain of these religious employments, but I have been told about them a number of times. They are said to be a special part of 'blood brother' ceremonies. Blood of the two pledging parties is mixed and put between the twin seeds of a coffee fruit and the whole swallowed, in some cases covered with clay beforehand; or it may be placed in an old burial chamber; or, again, the seeds may be beaten together with the blood drops and eaten in a ceremony. Grains are also said to be used in certain witchcraft and fertility rites among midwives and barren women.

The old Arabian savants drank coffee but were kept so busy copying, repeating, and perpetuating nearly lost knowledge of the past millenium, that they did little more than describe coffee medicinally and give it to their holy men. It was consumed in centres such as Mecca for its fortifying use among the professional prayer-men of the time.

As the Moslem faith became established and spread, coffee had apparently an important influence on visitors to the Tomb of Mohammed. With the great Mohammedan expansion over the old continent of Europe, coffee played its part as a stimulus for the Faithful. At first, it was used only in religious ritual and the holy men tried to restrict it to church purposes. But its use soon spread and the free thinkers, hedonists, and lovers of good things took it to the public of the Middle Ages and on down to modern times. The Arabs had brought coffee to the Island of Ceylon at about the close of the thirteenth century. The Renaissance had started, and European exploration went into new and little-known places.

The Arabs early had a kind of veneration for coffee, even in secular use. Only men were allowed to prepare coffee up to some twenty years ago (Keable, n.d.), and there was other ceremony regarding it. After roasting it in a special pan it was ground fine with a mortar and pestle, or in a brass grinder. An exact measure of powdered coffee was put into an exact quantity of boiling water. This caused the boiling to stop, and as soon as the mixture started boiling again it was taken away from the fire. When it had cooled slightly, it was put back and this was repeated until it had boiled and stopped three times. The result was a perfect drink with a slight froth on top, appetizing to view, rich in aroma, full of flavour, and strong in stimulus, with no bitterness. This was poured into a specially prepared cup.

This cup, along with others, had been pre-rinsed with freshly made hot coffee, poured from one cup to another, and the rinse coffee finally dripped onto the ground as a libation to the coffee saint, Sheikh esh Shad-hilly. Cups were then ready to receive the coffee and were only half-filled. To present a full cup or much less than half was an insult. Never more than two cups were offered, unless it was to an enemy. The saying was: The first cup for the guest, the second for enjoyment, and the third for the sword.' There was also a coffee tradition at Arab weddings, something like the Western game of throwing rice at the bride and groom. They poured newly made coffee in front of the bride's feet, to propitiate coffee saints and thus predispose the spirits in the bride's favour.

Coffee has been, and still is, of high value in the later married life of certain Eastern brides. For example, in times past in Turkey, it had been only necessary for a man to say three times to his wife 'I divorce thee' and the separation was done. However, the distaff side had a hold on this thing themselves, and should husbands refuse coffee to their wives or neglect to have coffee readily on hand, it was legitimate cause on the woman's side for divorce. Men also made solemn promise, witnessed at the marriage ceremony and feast, never to let their wives be without coffee.

In these last paragraphs we have mentioned the drinking of coffee. No one knows just when the first coffee was drunk. There is clearly a transitional stage between solid and liquid in the typical modern Turkish brew. This is from very finely ground roasted beans, and the powdery solid is infused carefully in boiling water, after or during which a great amount of sugar is added. The powdery solid is drunk with the liquid, and a small cup of this is believed to be stronger than a big cup of coffee made in other ways. There has been a considerable amount written about how it came to be drunk, some of which is highly imaginary. However, old observations and records have been preserved by Arabian scholars and have been translated and may be referred to in works such as those of Bradley (1716), Thurber (1884), Ukers (1922), and Keable (n.d.)

EARLY DRINKING AND USE IN THE LEVANT

The first drinking of coffee in Aden took place about the middle of the fifteenth century. It soon spread to other great centres, and in another century was so popular in Grand Cairo that there were about a thousand coffee houses in that city. Alpinus reported in his *Plantis Aegypti* of 1591 that it was drunk in Turkey, Egypt, and Arabia. Another old writer, Cotovicus, reported having seen coffee drunk in the East in 1598. This was considerably before it came to Europe. About the same early date a man, Sandys, who was a traveller in the Turkish Empire, found it in Constantinople, where it was sold to the public. He was critical of it, and described the Turks as sitting and drinking it most of the day, whiling away their time chatting and sipping of the drink 'in little China Dishes, as hot as they can suffer it; black as Soot, and tasting not much unlike it'. After several years of scholarly research on the matter, Ukers had this to say about the early use of coffee: 'Toward the close of the fifteenth century (1470-1500) it reached Mecca and Medina, where it was introduced, as at Aden, by the dervishes, and for the same religious purpose. About 1510 it reached Grand Cairo in Egypt, where the dervishes from Yemen, living in a district by themselves, drank coffee on the nights they intended to spend in religious devotion.' Meanwhile, the virtues of coffee became known to secular members of society, and there grew up the first coffee houses, called just that, 'kaveh kanes' or 'kahwahs', in Mecca, Medina, Aden, Cairo, and Constantinople.

Another of the first dates we can be reasonably certain about in the history of coffee is A.D. 1600. There is a fairly well recognized story, with documentary evidence that can be found for corroboration, about a holy man named Baba Budan who went to Mecca for his required pilgrimage. While there, he met and had dealings with all manner of people and ate and drank all manner of things. Of all these, he was most drawn to 'quahwah', and he managed to go up into the hills and secure some fresh seeds of the magical tree. It is said that he came home to south India as rapidly as he could with 'his seven seeds' bound to his belly. There he planted his treasures near the cave in which he dwelt in the hills, up from the little city of Chikmagalur. Those special seeds germinated and grew into trees, and from these plantings the tree was spread farther, going into Mysore, the Coorg, Goa, the high gats above Coimbatore, up as far north as Berar in the Central Provinces, and down to Travancore and the regions in the hills west of Tuticorin at India's extreme south tip.

As early as 1503, the first coffee plants were taken to Ceylon by the Dutch. In 1616, a single living plant had been transported to Holland from the ancient port of Mocha or Mokka, off the coast of Yemen. Meanwhile, coffee beans became an exotic importation from Arabia into the emerging Europe. The business-minded and ever adventurous Dutch, after their subjugation of Portuguese overlords in Ceylon, saw a future in coffee for the coffee-house trade of Europe. Forthwith, they began to multiply the scattered plants in Ceylon and by about 1658 they had brought them under a cultural pattern, so that they were doing well by 1690. Coffee was grown for profit by Europeans in Ceylon and India, and this began to break the dependency of Europe on coffee from Arabian ports and started wider use of the beverage as well.

Meanwhile, in the countries of the Levant, the coffee house became a most important adjunct to their civilization. The first recognized date for a coffee house in Grand Cairo, Egypt, was 1500, but prior to that they were common and old in Arabia. In Constantinople the first coffee house opened in 1554, but the drink had been used in all of the important Near East cities for centuries before it became a matter of public sale. The drink was always strong and black, and often spiced. To sit in these kaveh kanes was the mark of being in the great metropolis.

Because he could get nothing else, the trader, or master camel driver, had to drink his herb infusions and teas on his long wild caravan treks between the grand bazaars of the ancient cities; it was when he arrived at the gates where he could smell the grateful fragrance of coffee that he knew he was at civilization's door. Coffee houses eventually came to Greece and to Italy. It is difficult to determine when coffee became an article of common commerce in Persia or Syria, but it seems to have been some time in the sixteenth century. In all these countries, oriental-type coffee houses were immediately successful. They were furnished in the rich artistry of those lands, with their low stools, luxurious cushions, handsomely made braziers, carved bric-a-brac, rich carpeting, thick rugs, and beaten-metal ware. There are still such characteristic establishments in some of the countries of the Eastern Mediterranean.

Some of those coffee houses were institutions of great charm. Many were elaborately designed, lighted, and adorned. In some, the service was delicate and exquisite, while in others it was more utilitarian. Some brought fine singers and dancers and declaimers to amuse and please the customers. The classics were read aloud to the restrained clink of coffee cups, and in some such houses there was *risque* entertainment and stories told purely for masculine laughter. These were part of a man's world. In some of them, there grew up groups who came together solely for the joy of argument, some where laughter was almost continuous, while in others there was deep thought and great philosophy. A drink that had once been a religious adjunct became something for carnal pleasure, and the coffee houses were thought by some to be ever the source of dangerous reasoning against the existing order. The Mohammedan church and state recognized their disquieting influences. The Sultans and other leaders, more than once, had the coffee houses closed, but they were always subsequently reopened due to the basic good sense of the rulers, overriding uncertainty and prejudice.

ATTEMPTS AT ITS SPREAD AND THE 'NOBLE' TREE

During the latter half of the fifteenth century the drink became a much desired luxury of royalty and nobles, and the taste for it spread among the wealthy and even those of lesser station. Its monetary value increased tremendously. It was inevitable that attempts should be made to take coffee from the tropics, where it flourished in some of the cooler corners, and try to produce it in the milder agricultural regions of southern Europe. For example, in France they even attempted to grow it in the fields of Dijon, but it could not stand frost. To this day the coffee growing in Europe is wholly in glasshouses. However, the practical Dutch, seeing its excellent production and development in Ceylon, and the wealth it brought, sent their colonizers farther afield into the tropics. Some others followed their example. While many countries sent their warriors out to bring back gold and other wealth from distant lands, the men of Holland became planters in far tropic isles, and shipped from there to Europe their teas and spices and coffee. They were the ones who obtained, from the Malabar Coast in India, the first coffee plants to be taken to Java. This was done first in 1696, but through flood and earthquake, these plantings were destroyed. Three years later the Dutch repeated the work and this time a few bushes lived. This same Malabar coffee descended directly from the 'seven seeds' brought, nearly a hundred years before, from Mecca by the Baba to Chikmagalur in India. These trees were said to be the progenitors of coffee in the East, and of the burgeoning Dutch East Indies.

Shortly after the establishment of the Chikmagalur coffee in Java, there was much interest awakened in scientific aspects of the plant, and a strong desire among potentates, botanists, and the curious to see it growing. Seeds were sent from Batavia in Java to Amsterdam in Holland, but they repeatedly died during the long ocean voyage. In the year 1706, from a group of a very few plants growing from seed secured in Yemen, one was put aboard a Dutch ship and taken to Amsterdam where it grew successfully in a glasshouse in the Amsterdam Botanical Gardens. Seeds from this Amsterdam-grown tree subsequently went to conservatories in several countries in Europe.

This part of the world had been in great ferment and numbers of meetings were held of representatives of nations in the hope of bringing about an end to strifes, settling boundaries, and equalizing influences. It culminated in the famous Treaty of Utrecht, in Holland, with its many signatories who were national representatives present during the years 1713 and 1714. Coffee played its part in this. It indicates the rare favour and the extrinsic, as well as intrinsic, value accorded to coffee, that a living tree specimen was considered an eminently satisfactory royal gift. Because of the profound respect in which Holland held the greatest of all kings in Europe, King Louis XIV of France, the Dutch tried unsuccessfully to get a coffee tree to him in 1712, as a small sign of their appreciation of his help in bringing peace. The next year they tried again and this time the tree lived. It was a healthy specimen, 5 ft. high and growing in a handsome container. It turned out to be the tree of pre-eminent importance in the history of this crop. There are, however, other stories of how Louis XIV came to get his coffee tree, though they report the same result.

This tree came as a seedling from a living mother-tree shipped direct from the port of Mocha, via Batavia, where it stayed a few months, and thence to Amsterdam where it produced its first few progeny. The best of these was growing in an Amsterdam glasshouse and the burgomaster there, Nicolas Witsen, sent it with a special attendant to the greatest autocrat and imperious sovereign of contemporary Europe. King Louis XIV accepted it and was immediately intrigued, as he was a great taster of good coffee and annually spent large sums on it for his household and courtiers. With his habitual intelligence and the shrewd regard for his people that characterized him, after one day of feasting his eyes on it, he put the tree in the hands of young Professor Antoine de Jussieu, the new but well trained and competent curator of the Jardin des Plantes in Paris. The Emperor King ordered an immediate study of the tree, which was to be gathered into a memoir within a year's time, and that every effort be made to cajole this royal gift to grow well, blossom, and mature fruit. It was presumed to come from tropical Arabia and the first glasshouse ever built in France was quickly constructed for this tree. Such attention was it accorded that it could only be interpreted as of major importance. It was from a study of Jussieu's work and from examination of dried specimens and living direct descendants of this tree in European glasshouses, gardens, and herbaria, that Linnaeus named the genus and its Arabica species.

It seems worth while to point out again that this most notable coffee tree originated from seed of a tree in Yemen. It was, in all probability, a direct descendant of the same line as that brought years before to India by the old saint, Baba Budan, who went back to living in his cave in the Chikmagalur hills. It grew well in the imperial glasshouse in Paris, and seeds and seedlings from it were sent to far corners of the French Empire. The first introduction from Paris out of the noble tree was in 1715, when it was sent to the French Antilles in the Caribbean ; the Island of Bourbon, on the other side of the world, received it the same year.

Search of much literature (for example, Ukers, 1922; Cheney, 1925; Chevalier, 1929; Cramer, 1957; Sprecher von Bernegg, 1934; Bradley, 1716; Linnaeus, 1763; etc.) shows that this same tree was destined to become the progenitor of billions of the coffee trees now growing. Progenies were first grown in the old French colonies, such as those of Bourbon or Reunion, of Indo-China, of the Antilles, and of continental Africa. Some of these were planted in acknowledgement of the imperial edict of Louis XIV, others resulted from the common sense of colonial developers. Others were also sent into parts of India, to d'Ougly near Calcutta, and, on the Coromandel Coast, to the enclave of Pondicherry. By 1799, coffee could be found in the nearby French holding of Talicherry and was being grown in some of the British parts of India. It seems inevitable that from those centres it should have been spread by colonials and missionaries throughout the West Indian islands, from there to Mexico, Central America, South America, British East Africa, Central Africa, South Africa, and to many other places—even into Australia and southeastern China.

During this time, coffee was being studied by medical men and botanists, and de Jussieu had given it a scientific name, *Jasminum Arabicum,* in about 1717. However, when the plant came to be studied by Linnaeus, he found it could not be included among the Jasmines. Thereupon, he erected the genus *Coffea,* a description of which he published in 1737 in his famous work *Genera Plantarum.* It was years later (Linnaeus, 1753) that he published the epochal *Species Plantarum,* in which he described the full species *Coffea arabica,* which he believed came originally out of Arabia. His simple, lucid, and unmistakable Latin description, and the characterizations he gave centuries ago, still stand.

SPREAD OF ARABICA COFFEE

Certain of the details of the story of the spread of *Coffea arabica* L., even aside from the sketch just preceding, are remarkable and, it is believed, worth gathering together. Some of the story may be romance, but the outlines are correct and it gives an idea of the near-veneration in which the crop is held. One of the tales is of the Frenchman Gabriel Mathieu de Clieu, who brought a seedling from Paris to the Island of Martinique where, it is said, 50 years later it had 19 million descendants growing *(see* P. 34).

In 1718 the Dutch introduced coffee from the same original source as came the tree of King Louis XIV, into Paramaribo, capital of Surinam. There it multiplied, was grown with great care and kept continually under guard, but it never did very well. In spite of that the Dutch would not give away seed. It seems that there had escaped to Surinam from French Guiana a man named Mourgure, wanted for serious law-breaking, and he longed to return to his home. He made a secret pact with French authorities in Guiana and contracted, in return for his freedom, to bring coffee from the well guarded Dutch gardens. By studying the guards and using stealth, he filched what he wanted, and took seeds with him and won his repatriation in 1722. This became known, and as coffee had increased in value, very soon a somewhat similar attempt was made to take coffee from Surinam to Brazil, but the theft was discovered and those seeds did not leave Dutch hands. There were several such unsuccessful attempts by adventurers from Brazil. The introduction that was finally successful was brought off by a Brazilian Emperor's romancing emissary named Francisco de Melho Palheta.

Meanwhile, a British botanist, James Douglas, had gathered more information about the noble tree, the *Jasminum Arabicum* of de Jussieu. Douglas wrote what, for the time, was a fine monograph. Compatriots of his had introduced the tree into Jamaica by 1730. Ten years later some Spanish missionaries, who had been training in Java, took coffee seed from there to the Philippines where they established the crop. By 1748 it had reached Cuba from the part of Santo Domingo that is now Haiti, where it had been introduced many years before by edict of Louis XIV. During all this time the Dutch were industriously growing and shipping coffee to Europe. By the year 1750, the Dutch had imported living plants from Java into Bali, up through the Macassar Straits, and settled them in the Celebes. All these introductions expanded into billions of trees, and all of them, wherever found, were from that same noble parentage; all could be traced back to the original stock of the King's tree itself that Louis XIV had accepted at his court one day in 1713. Study shows that it was largely between the years 1714 and 1800 that *Coffea ambica* of this strain was being most rapidly and widely spread in the tropical world.

The Dutch, Portuguese, Spanish, French, and English were moving and reaching out and making the most of territorial discoveries and conquests all over the world. If, where empires touched or were close, they could pay for strategic holdings with some production—and often it was a tropical product such as coffee—there was extra reason for pride, and from its sale there was money to pay for garrisons and navies. Coffee began to be wanted for growing in many places. It was purchased widely. It was a time when cheap labourers could be exploited by anyone, of whatever nationality, who could get to a place first. These workers were on a long-suffering, more or less slave basis, whether white 'indentures' or lowly peasants called by other euphemisms—including untutored peoples from Africa, Melanesians, Pacific Islanders, yellow men, or the indigenes of the Americas. Production of coffee was fairly easy, based on the husbandry they knew, and with ample hands to carry it on. PL 5 shows scenes of modern coffee growing in Ethiopia and Yemen.

COFFEE HOUSES OF EUROPE, ENGLAND, AND THEIR PROGENY

In our interest in the moving around of the tree, there should be no neglect of attention to the progress in use of the beans produced, from which the favoured drink was made. It was during these early years that the cup of coffee began its ascendancy in Europe. It had romance about it, it was something of witchery from the Orient, and it had also its own wonderful flavour and fine stimulus. Coffee houses or cafes became immensely popular. They were places of marvel, entertainment, and great mental relaxation. Coffee was brought to Venice in 1615 by traders from the Near East. In a few decades there were numbers of coffee shops in that city principality. In 1711, the first small consignment of coffee produced for commerce in Java, was shipped to Holland for European trade. It had grown in popularity before this, and was specially appreciated and sought after in England during the time of Charles II. The first English coffee house was opened in Oxford in 1650, by a Lebanese. Others soon came into being and it is notable that they flourished near centres of learning. Of special note was Tillyard's, near All Soul's College, where there gathered daily a group who played an important part in the Restoration. They were known as The Oxford Club, and were the start of what later became the Royal Society. None of these emporiums, at first, were in London, but the idea soon arrived in the big city.

There has been some argument as to the earliest record of a London coffee house. It appears that liquid coffee *(see* Cheney, 1925) was served as early as 1651 in a London 'cophe house' known as the Sultan's Head. It was said by Bradley (1716) that a Mr. Daniel Edwards, who was a Turkey merchant, and his servant, Pasqua Rosee, made coffee, the first time it was drunk in London, in 1657 in his house in St. Michael's Alley, Cornhill. In any case, the drink was soon much favoured, and a big business of import was built up around it to serve the coffee houses, many of which had reasons for fame. For example, in 1688, a Mr. Edward Lloyd started a coffee house in the Royal Exchange building, where he kept track of ship movements and numerous other mercantile matters for his customers. The house became known both for good coffee and dependability of information, and grew into what is now the greatest insurance institution in the world, operating practically everywhere, the present-day Lloyds of London.

Coffee houses of England became the centres for a certain intelligentsia and social set. There was so much argumentation and discussion in the houses that spies returned to King Charles with black stories of the seditious nature of those places. He was advised, and attempted to have them closed. One year there was a royal order to that effect, but within 11 days it was withdrawn because lawyers pointed out that it curbed the basic rights of man. The King then countered with a heavy tax on the drink sold publicly, which resulted in a situation like some other similar governmental prohibitions, tremendous ingenuity being expended to reduce the tax burden and still allow coffee for the houses.

Such deterrents did not stop the popularity of coffee from increasing, or the establishment of larger numbers of coffee houses. During this period there were some 3,000 of them in London, and, of course, very many in other large cities of England. It was during the seventeenth and eighteenth centuries that coffee houses attained their height of sophistication and popularity in England. Names of some of the important ones during this golden period were Man's, Rota, The Grecian, Old Man's, Lion's Head, The Cocoa-Tree, The Folly, Turk's Head, Will's, Child's, and St. James. A very well known name was Tom's, and another was The Rainbow, but probably the most famous of all was The Cheshire Cheese.

These housed the loitering and fierce geniuses of the time, who made of them their sounding boards of chit-chat, philosophy, elegant poetry and drama, art criticism, legal pronouncements, doggerel, political broadsides, stories of every colour, or finest thoughtful essays. Names of some of those old *habitues*, reached back into the lists of great users of the English language, such as Dryden, Pope, Pepys, Addison, Harris, Ben Johnson, Sir William Petty, Milton, Macaulay, Steele, Samuel Johnson, David Garrick, Boswell, Oliver Goldsmith, Gibbon, and Adam Smith. Those were great days. English art and literature were in flower, British ethics was being evolved, the Restoration was accomplished, the mature idea of the Commonwealth was coming into being, and the fitful meetings of Parliament were becoming more regular and fruitful Who can possibly gauge how much influence the coffee house played in all this!

During these centuries, coffee houses in other countries also were the centres for intelligent gatherings. The drink had been seen in insignificant amounts in Paris homes as early as 1657, and the first small shipments for that city came out of the bazaars of Constantinople in 1664. In 1669, the Souleman Aga, Turkish ambassador to the court of the great Louis XIV, introduced coffee with much pomp, ceremony, and luxury among nobles and the royalty there, and the King soon became a great devotee. It was given as a special mark of favour to nobility all over Europe, and became the rage. The earliest date for a French coffee house seems to be 1671, when one or two were set up in the port of Marseilles. More were soon established. The sailors and sea captains, and their girls, as well as the better classes, gathered in them. The cup of strong black coffee was soon well at home in France, and in a few years more coffee houses were appearing in Paris. There they multiplied rapidly, occupied enclosed gardens, the sidewalks, rooms under roof, cheap and dark recesses, and the most expensive and well-lighted places. They seemed to be everywhere. These were mostly called 'cafes', a name that has stayed and has later become stylized to designate the restaurants and eating places found there and in many other countries.

Numbers of the first French coffee houses were little more than a congregation of rough chairs and rickety tables, and in questionable parts of the city. They were mostly for the lower classes, not places for people of high fashion. Soon there were a few, more elegantly appointed houses, and they immediately gained popularity. By 1690, there were over 300 cafes in Paris and during the course of 150 years the number arose to 3,ooo. Writers have said that, at one time, old Paris centred around one vast continuous coffee house that never slept. Men and women came from all walks of life, and from all over the world, to revel in and listen to the tall talk of Paris cafes. Probably the most noted of the coffee houses of all Europe or the Americas was in Paris, and it still exists there. This is the Procope at 13 rue de FAncienne Comedie.

The Procope was, at one time or another, the gathering place of the greatest among the dreamers and thinkers and doers of France. During their hours they held audiences about its tables. The names are many but among them were Voltaire, Rousseau, Beaumarchais, Hugo, Zola, Marat, Robespierre, Danton, Balzac, Desmoulins, Napoleon Bonaparte, Paul Verlaine, Bernhardt, Clemenceau, and others. The Paris coffee house was a field of most fiery debate and seething excitement during the French Revolution. It was the rendezvous for a large number of the heroes of the period. There were hundreds of other coffee houses in Paris, some of the names being Magny's, that afterward became The Royal Drummer, the Eldorado, Scala, Bonner, Folies Bobino, Concert Europeen, and one of the best known, the Cafe de la Regence. Many changed, were sold, moved, made different. But the cafes of Paris are still there, one of the charming features of the city.

It was from the Oriental coffee houses that Europe received some of its most romantic ideas about the drink and its service. These added greatly to its popularity and the public's amusement and enjoyment. It was especially true in England and France, where the mystery of the Orient was given much attention. In Holland, the first coffee houses were started in Amsterdam in 1666, and they came into Germany and Austria some 20 years later. Coffee as a drink appeared in Vienna about 1683 on the heels of a war with the Turks. It did not take much time after that for coffee houses to become common in the Austrian capital. Here they flourished, but were never so characteristically Viennese, nor so filled with the famed *Gemutlichkeit* that was the heart and soul of the beer garden.

It was precisely during the period of their arrival in Vienna and Berlin, that coffee houses were introduced to Colonial America. Those were stirring days there, and coffee houses appeared in one British colony after another in North America, all faithfully patterned upon the design of the well-accepted English and European establishments. Some of the most famous old Colonial establishments still have a nostalgic ring to their names. There were in Boston, The London, Gutteridge's, The Red Lion, King's Head, Indian Queen, and Cole's. In New York City, the first coffee house was the King's Arms, opened in 1696. It was located on Broadway, between Trinity Church and Cedar. Many more came in, including, later, the well known Exchange Coffee House. About 1737 was established in New York the most famous coffee house in America, the Merchants. Here was much transaction of business and politics, by leaders in the early days of the United States.

In other parts of the American Colonies, coffee houses were also found. The old Quaker, William Penn, is said to have introduced them into both Pennsylvania and Delaware. They spread westward after the Revolution into the larger centres of population, such as Chicago. These all had their heyday and decline. They are not found now in their old form, but have become restaurants and liquor-dispensing establishments in addition to selling coffee. Of late years the great popularity and increasing acknowledgement of the good effects of the mid-morning and afternoon 'coffee break' is making a change in the United States. The semblance of true coffee houses is reappearing, and it is possible that they may again be widely popularized in that country. It is said that the same thing is occurring in England.

Typical coffee houses today exist all over Paris and more are flourishing in many of the other European capitals. Portugal is a country in modern Europe where metropolitan coffee houses carry on in a manner worthy of the best tradition. In Lisbon, there are many sturdy old houses, wonderful to see, whose antecedents go into the past centuries. In them, men of affairs come to discuss things, to transact business, and to recuperate from tensions of competition. Some of those establishments are beautifully appointed, some of them sombre and old, and some of them glitteringly new. There are places where tables are reserved for special people, and places where certain of the notables of Europe may be seen to pass an hour. There are also typical sidewalk cafes, some modest, others more ostentatious, and offshoots and annexes to regular coffee houses.

Again crossing the ocean, it will be found that much of Latin America is dotted today with thriving coffee houses. In very many of the little, even backward, villages can be found 'tienditas de cafe'. Some are small, with crude furnishings, but the air is charged with the vapours of roasting coffee beans. Pots of the drink are always in preparation over wood-fed fires in sheds behind the place where it is served. In some of the capitals and main cities the coffee houses may be larger and more sophisticated.

Sidewalk cafes can be found that are comparable with those in Europe. For example, the port of Guayaquil, in Ecuador, has long been noted for its sidewalk cafes, and there is a growing fondness and increasing popularity for adaptations of these in such cities as San Salvador in El Salvador, and San Jose, Costa Rica. In most of the important towns and cities, coffee houses make a highly valued contribution to the social life of a community. In the countries of Colombia and Brazil, 'tinto' or 'cafezinho' is served in small cups numerous times a day, in favourite coffee houses at convenient corners within a few steps of large businesses and social clientele.

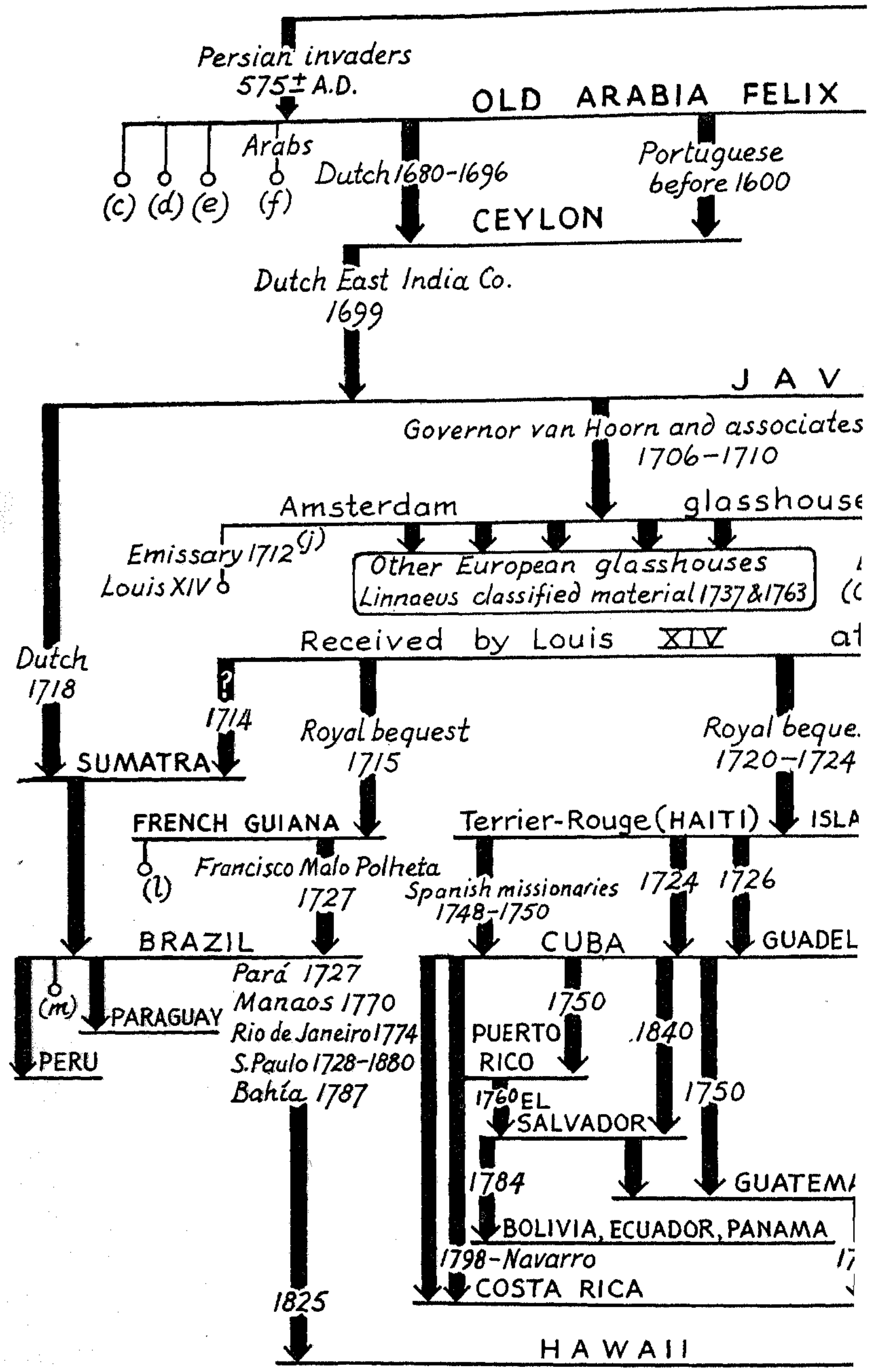
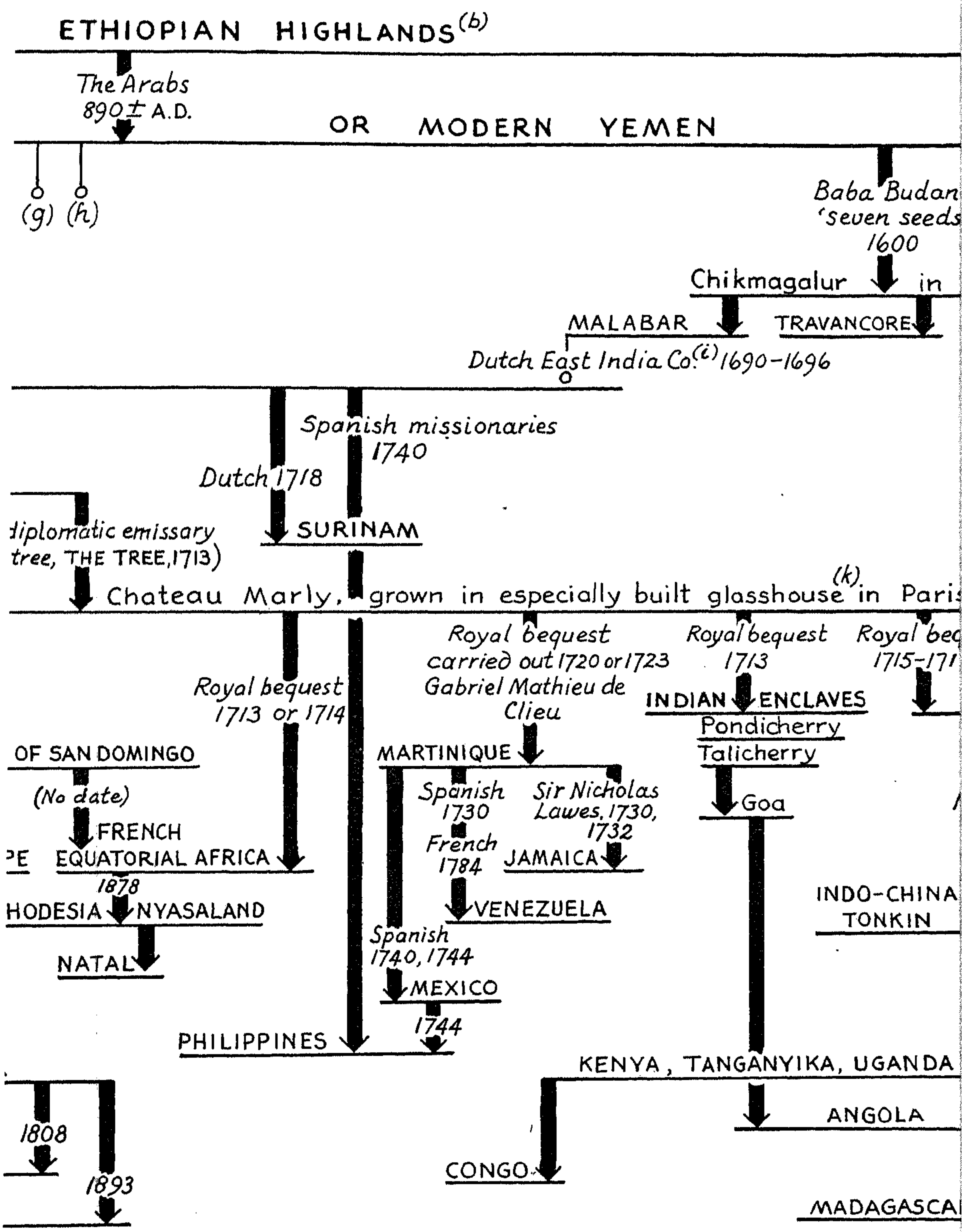
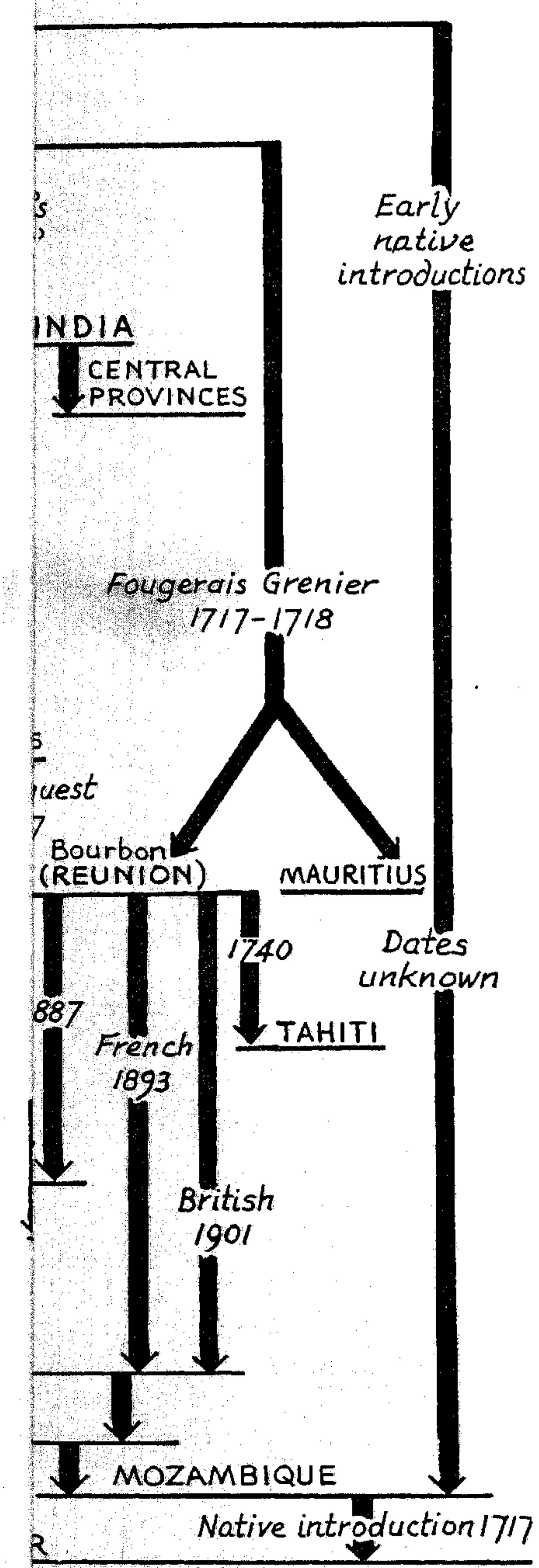


FIG. 2. Chart showing the distribution of the growing of *Coffea arabica*. [*a*] There are haz *arabica* extending for a short distance into the south-east corner of the Sudan. (*c*) Introduction (*f*) Introduction into fields in Ceylon by Arabs before 1505. Failed. (*g*) Introduction into fi earthquake and floods. (*j*) First attempted gift of tree for Louis XIV; it died in transit. distributed to all his tropical empire. This was carried out even after his death. (*l*) Attempts to



'erences in the Old Testament and in the Koran, which are interpreted by some as pertaining to coffee. (*b*) The Ethio
Persia, 1500 to 1510. Failed to grow permanently. (*d*) Introduction into Syria, 1500 to 1510. Failed to grow permanen
in Holland by Dutch in 1616. Failed. (*h*) Introduction into fields in France by French in 1620. Failed. (*i*) Introdu
On receipt by Louis XIV, the first glasshouse in France was constructed on royal order especially for The Tree.
ain the tree were made in Brazil before 1727. All failed. (*m*) Seeds taken to Chile. Failed.



pian, or Abyssinian, highlands that have wild C.
ally. (e) Introduction into Turkey, 1554. Failed.
(fiction into fields in Java by Dutch. Failed from
edIt was Louis's will that seeds from this Tree be
di

III

DETAILS OF ORIGIN AND DISPERSION OF ARABICA COFFEE

THE early history of coffee, its discovery and its distribution from one part of the tropical world to another, is possibly the most interesting and romantic that any crop can boast. Parts of it have been discussed for years and it has been written about in several languages in Europe and the Levant. Some of the stories are considered questionable and, in some cases, they have been embroidered to add sales appeal to a product of commerce. An attempt has been made here to sift out the matters of less certain foundation, probably without complete success. Out of nearly 150 writings, those of perhaps leading importances are cited. No attempt is made to give the chapter subject detailed treatment. This is rather an outline. To cover it completely, as in a memoir, would require a book in itself. Some of the world dispersion of Arabica is presented herewith in the form of a chart (Fig. 2).

EARLY KNOWLEDGE OF COFFEE

One of the first writers on coffee in a European language was Bradley (1716). His book is not well known but it is important and came before Linnaeus's. He was a traveller, he had seen and studied the growing, fruiting tree, and he believed himself more of an authority than some of the armchair botanists and medical men. He told of Casper Bauhin, who had described it as *Euonymo Similis Aegyptica fructu baecis Lauri Simili.* He quoted the 1622 description of Parkinson of the tree called 'Arbor Bon' that had fruits 'somewhat larger than a Hazel Nut, pointed at the Extremities, and of greyish Ash Colour; that each Berry contains two white Seeds, which the Turks make Drink of, and is in great esteem among them'. He said that, in 1691, the botanist Ray had mentioned it as *Coffee frutex, ex cujus fructu sit potus.* There was some argument as to its botanical placement, and Bradley had a personal communication from the savant, Comelin, who said it was to be classed among the 'Jessamines'. The jasmine Bradley knew must have been the typical fragrant flowered shrub of Europe, whereas the coffee was a tree. To one who had seen both plants, some wide differences would be notable. We are impressed that he might have been uncertain of Commelin's dictum, for he gave his own eye-witness description: Tn the Physick Garden of Amsterdam are two coffee trees, about 17 Foot high each, which have been for some time in bearing state, and have at most seasons fruit upon them.' Undoubtedly, these were growing in the glasshouse there. He described the other characters, too. The fruits, he said, were red, and noted that if poorly ripened they were yellowish. He noted further that other observers had reported they had seen trees in nature grow to 40 or 50 ft. in height.

At that time, some botanists believed the tree originated in Arabia but Bradley felt it well to point out that Poncett, in his voyage to Ethiopia, 'makes of it a Native of that country; it was transplanted from thence to Arabia Felix, and at this time the Aethiopians cultivate it only as a curiosity'. Along with that he quoted another author, Robert Balle, Esq.: 'Coffee, says he, is not known to grow naturally in any Part of the World, but only in Arabia faelix; some few Days Journey Inland from Moco, in the Valley of the Great Mountains, and near the City Saana, about 20 Degrees North Latitude.' It was from this region of Arabia that coffee came for world trade, and the masters of that land wished to have the market cornered there.

The Arabs would not allow living fruit or seeds to leave their shores, and had, in fact, inflicted severe punishments on luckless ones caught attempting such removal. Bradley commented: 'Notwithstanding this their Extraordinary Care and Caution to preserve this Plant peculiar to themselves, the Hollanders some years agone found means to furnish themselves with it, and have made a Plantation of it about Batavia in the Island of Java, which has already produced some Tons of Fruit. From this Plantation they have lately brought two Trees to Amsterdam, which by the Skill of their ingenius Gardener flourish and bear fruit in such perfection, that several hundred Plants have been rais'd there from seeds, ripen'd at that Place; and which from time to time they transmit to Surinam, and such places in the West-Indies as are in their Possession.'

DESCRIPTION BY LINNAEUS

Bradley, himself, obtained seeds from the glasshouse coffee in Amsterdam and took them back to England. About this time there were writings accumulating, repeating beliefs that The Tree actually came from Arabia, completely overlooking Bradley's suggestion that Poncett considered it Ethiopian in origin. The observation of botanists and teachers, such as those Bradley quotes, were the writings to which Linnaeus (1737) later had access. In them the numbers of essays were overwhelmingly in favour of Arabian origin. Later, after Bradley's time, in his *Species Plantarum,* Linnaeus (1753), understandably enough, named it *Coffea arabica,* and repeated its habitat as 'Arabica felici'.

I considered it reasonable to hope that study of the first botanical specimen of C. *arabica* L. might give further clues as to its source and the reason why Linnaeus gave it that specific name. In 1956, I visited the

Linnean Society of London and there was privileged to examine the original specimen that Linnaeus had mounted as his example of the species. It is on an interesting sheet. The 'exsiccate' is numbered in Linnaeus's own hand as '232', and is included in a package with three others, being marked '232 Coffea', '233 Chiocea', '234 Hameflia', and '235 Lonicera'. The coffee specimen is a terminal portion of a characteristic lateral fruiting branch, with all the relatively delicate appearance of being the bronze-tipped Typica variety, later described by Cramer. This branch part had been broken away, not cut, and had at one time eight nodes. The very tip node must have been small and young, and, after drying, easily rubbed off. The three oldest nodes at the base of the branch each still have one well-matured leaf attached. Others have dropped off, possibly in prepartion. Those present were glued by Linnaeus to the sheet, using their upper surfaces, so that domatia openings and venation can be seen as well as the shape and character of the leaves. It does not look like field-grown material. The mature leaves were months old when the specimen was collected. These older leaves exhibit a few small holes, apparently eaten by an insect perforating the lamina while it was growing in the glasshouse. The edges of the holes in the leaves had healed over long before the branch had been broken off. Those three oldest nodes have in their axils well matured, but unopened, typically arranged flower buds, just prior to swelling into the candle stage. The apical four nodes have two leaves each, which had started to expand in a manner characteristic of the new growth that follows a period of semi-dormancy. The word 'india', underlined, and uncapitalized, appears in small writing in ink, again in Linnaeus's own hand. The word is written on the sheet directly at the base of the stem. It seems to me that we might consider that he had obtained this branch off a tree, European glasshouse grown, from seed originating from what he spoke of (1763) as in either the so-called 'India Orientalis' of the *Praefectum* of Van Hoorn, or 'India Occidentals, Colombo'. He certainly believed, at that time, that the 'India' material had both originated and proceeded from Arabia. At the bottom of the page is written the species designation of 'arabica' This sheet is contained in a carefully folded cover, marked on its upper left with the number '232', and on its lower left with '230 Coffea'

As botanists well know, after Linnaeus published his description of the genus *Coffea* (1737) he recognized only one species in the genus and to that one he gave the name *arabica* because of his belief of its geographical source. Later, in writing (1763) of the places of its origins, he coupled 'Arabia' and 'Aethiopia' together. He cited seventeen workers publishing valued information about coffee. One was Meisenerium in 1621. Another of the most famous was Prosper Alpinus who wrote of it in 1591 in his *Plantis Aegypti*. Also of note was Verulanius, with his observations in 1624 in his *De Coffee Potu*. Linnaeus mentioned as of special importance the memoir of the royal botanist, Antoine Jussieu, published in the *Actis*

Parisinus of 1713. In this, the tree had been described and illustrated from the second living specimen grown in a glasshouse in Europe. The last report he cited was one by Kalmium in 1755. It apparently seemed to Linnaeus throughout that the best judgment was that the tree first came from Arabia, although he felt Ethiopia was associated in its story.

ORIGIN OF ARABICA

Since that time there has been re-analysis of the place of origin of Arabica coffee. Some scholars (cf. Ukers, 1922) held that certain of the present Ethiopian tribes came really originally out of Arabia, and that they went to Ethiopia in early ages, taking coffee with them. Lankester (1832) was of the opinion that evidence showed that coffee had come to Arabia from Persia. According to another (Porter, 1833), there was good reason to believe that *C. arabica* was probably taken from Ethiopia to Persia first, and, after this step, to Arabia. The critical old botanist De Condolle claimed to have evidence *(see* Fauchere, 1927) that this coffee was originally wild in Abyssinia, Sudan, Mozambique, and Guinea. In historical studies, Southard (1918) found indications that Arabs had secured seed from the Harar region of Ethiopia in the eleventh century and had grown plants in Arabia. It seems that it was this special strain of coffee, with the large bean for which it is still famous, that they grew in Arabia under their cultural conditions. Four centuries later they took it back to Ethiopia for cultivation and exploitation, for its beans were much larger than those from the ordinary wild-coffee forest collections.

It is of interest that there is a pride of region in the history of coffee. This is understandable and speaks highly for the regard in which it is held. To the present time one still hears, occasionally, the sincere statement that the crop is so much at home in the American Tropics that it must have been native to those regions. There even has been mention of supposed documentary evidence that, at least, it might have been in the Americas long before the French introductions. As an example, Tigerino (1954) quotes as evidence for this possibility the writings of an old Dominican in *Los Viajes de Tomds Gage en la Nueva Espana*, etc., which appeared in 1632. The book reported wide travels in Mexico, and among these were described Verapaz, capital city of Coban, with the principal plant products found about it, namely achiote, cacao, cotton, honey, coffee, sarsaparilla, and maize. On a visit to the regions of Mixco and Pinola there was a report that 'violence of rains ruined much wheat and brought ground to the coffee plantations of the Indians.[5] It is not possible to know just what crop 'coffee' referred to, but it seems undoubtedly something other than trees of *Cqffea*, of whatever species. All botanical evidence, carefully gathered from both hemispheres, shows that coffee did not come to American shores without the well-authenticated hand of man, and, at the earliest, in 1714.

DETAILS OF ORIGIN AND DISPERSION OF ARABICA COFFEE

Some of the most complete information on where C. *arabica* first evolved has been reviewed by Chevalier (1929). He discussed the observations of explorers and botanists, as well as published works on its evident natural occurrence. Poncett saw it growing wild in Ethiopia in 1698 to 1700. The first technical description, of C. *arabica* trees in Yemen, was by surgeon Barbier in 1712, and it appears the trees were not wild but under cultivation there. James Bruce saw Arabica growing in nature, without suggestion of cultivation, in Ethiopia in 1762. The tree, at all times, gave evidence of being an under-storey forest inhabitant, and not a desert plant that could have arisen in Arabia Felix, where it has always required careful attention and irrigation. In a geographical study on coffee, Fuchs (1886) gathered together good evidence of the origin of C. *arabica* in the so-called Abyssinian highland, in the provinces of Galla, Enarea, Kaffe, Raume, and other parts of Ethiopia. Chevalier (1929) related experiences, in the middle of the last century, of the explorers Grant and Speke who saw native coffee plantations in the Victoria-Nyanza region and the central part of Africa. Since then, it has become evident that these men may not, necessarily, have seen Arabica there but other species. Very recently, Sylvain (1956) has indicated that, judging from literature, horticulture, and physiological facts, *C. arabica* could not have originated, as the tree that it is, in the more or less desert country of Yemen or old Arabia Felix. It has been shown by A. S. Thomas (1942) that it is in a small part of the Ethiopian hills, extending into the Sudan, that C. *arabica* grows in natural conditions.

Judging from its definitely spontaneous occurrence in large numbers as part of the natural forests, its adaptability to conditions there, and the phenomenon of its unquestioned indigenous presence since time immemorial, the highlands of Ethiopia, and their southerly projection into the lower Sudan, may be unreservedly considered as the centre of nativity of the species C. *arabica*. However, it is probable that it may have long occurred naturally several hundred miles from this centre. It probably extended into the moist forests far south from the mountains and plateaus of Ethiopia and south-east Sudan. There are a few coffees occurring outside Ethiopia that are superficially C. *arabica*, yet vary enough to allow botanists to describe them as different varieties or species. One such is C. *arabica* var. *intermedia*, described in 1895 by A. Froehner from Uganda material out of the Ruwenzori mountain region, some 300 or 400 miles south of the acknowledged area of natural C. *arabica* occurrence, Cramer (1957), who was probably our greatest critical evaluater of the details of variations in coffees, thought that the variety might well be a very closely allied but different species. Not more than 150 miles south and west of the Ruwenzori area, other variant coffees were obtained which were closely allied to C. *arabica*. According to the account, by Lebrun (1941), of how he found these, they are of undoubted natural occurrence in high parts of the Lake Kivu region of the Congo. In them, certain characters were sufficiently unlike *arabica* for him to describe one as C. *kivuensis* and the other as C. *vanroechoudtii*. After much study, some botanists may still retain them as species, but others look on them as varieties differentiated on morphological bases, probably varying as the result of long geographical isolation. Nevertheless, for all main purposes, the mountainous part of Ethiopia is still considered the land of origin of C. *arabica*.

DISPERSION OF ARABICA

From the high hills of its nativity, this coffee was spread by the efforts of man m what, for convenience of discussion, amounts to eight waves over the tropical world. The accompanying chart (Fig. 2) shows something of how Arabica has been dispersed. Some of the waves were early and of slight duration or extent. Some were extensive and into areas far removed from any which the plant had hitherto reached. Probably the first wave was that started by aborigines taking the seed from Ethiopia to what is now Mozaxnbique'and then, in modern time, to Madagascar; the latter date is given as about 1717. The second movement was the longest lasting. It began by the carrying, by the Persian armies, of seed coming out of what was probably Harar in Ethiopia. They took the seed to Arabia Felix in about A.D. 575 and, again, in about 890. It grew there, and from that place was taken to many other lands of the Levant from (about) 1500 to 1550, Some trials also were made during later years in open fields of Holland and France where coffee seedlings died from frost, and in 1696 they were judged to be failures. At that time, this phase came to an end. The third movement of dispersal was short, and in progress during the last part of the second phase; it was the more successful carrying of the seed to the widespread and difficultly reached provinces, presidencies, states, and rajs of the Indian Empire.

Another small but long-lasting wave, the fourth, started again with Arabica seeds from Yemen. They were taken to Bourbon and Mauritius of the Mascarene islands, and from there, by long transport, through the Indian Ocean and the South China Sea to Indo-China. This wave started about 1715 and lasted until nearly the end of thenext century. The fifth of these waves of man-carried seed was possibly the most spectacular. It began with probably a single tree, about 1706, brought from Ethiopia by way of Java to Europe. Through combined Dutch, French, English, Spanish, and Portuguese effort, more than two-score moves were consummated. It lasted during the whole of the eighteenth century, and seed distribution and multiplication resulted in the astounding feat of covering the American Tropics with a few billion trees in twenty different countries and islands.

On the other side of the world, during the last part of the eighteenth century, a sixth penetration of this crop was taking place. Islands, archipelagos, and mainlands of the Tropical Pacific, were in the midst of an agricultural revolution from introduction of Arabica coffee. The seventh phase of its roaming history was the wave that took place during the last quarter of the last century and the first years of the present one. Planters of French, British, German, Boer, and Belgian blood took seed to increase the agricultural wealth of Central and East Africa and the Congo. The latest wave started during the Second World War, was begun by soldiers in Ethiopia who sent seed to other African countries, and is being further carried on in these current years by people of several nations, led by scientific agriculturists, in co-operation with other tropical workers all over the world.

Some of the best authenticated dates concerning the history of the movement of C. *arabica,* have been reviewed by several writers *(see* Porter, 1833; Chevalier, 1929; Ukers, 1922; Cheney, 1925; Hille Ris Lambers, 1930; Stanford, 1934; and Coste, 1955). Much came in the latter part of the sixteenth and the early seventeenth century. By the year 1554, coffee received from Arabia was being drunk in Constantinople. From the Grand Bazaar there, it was introduced to Venice in 1560. There was a growing interest in the beverage and the ever-enterprising Dutch had been examining the possibility of its further commercialization. According to Jacob (1935) they had brought coffee plants to Amsterdam from Arabia in 1690, but only as botanical curiosities. They were soon to obtain examples of the coffee plants and started testing them for growth in one tropical country after another. About 1690, they tried coffee in Java, but the first plantings were lost from storms, although some seedlings that had come directly from Arabia to Batavia were finally well established in 1699. From that day on, during the next two centuries, the steps taken by Arabica coffee became more and more rapid, and more numerous.

THE 'NOBLE' TREE

Those plantings of Arabian coffee seedlings in Batavia, Java, had been secured from Arabia Felix through the efforts of Governor van Hoorn of Batavia. It was of precisely this material that Linnaeus (1763) wrote. This work of van Hoorn was a most remarkable thing for the crop. It seems that one tree was sent by him in 1706 to Burgomaster Nicolas Witsen of Amsterdam, who was also High Governor of the Dutch East India Company. This was a botanical curiosity, obtained for the Physick Garden in Holland. The tree, fortunately, was from a species that is self compatible. As soon as it was sufficiently grown it bore self-fertilized seeds in the glasshouse, and many were sent away. It was from these, according to Porter (1833), that, by as early as 1718, colonists had begun plantations in Surinam and other Dutch West Indies countries, and in Sumatra. Meanwhile, a few of the seedlings were seen in other European botanical gardens. One of them is of especial interest because of the fabulous travels of its progenies. Its story is as follows.

From this one tree of Burgomaster Witsen in the 1706 shipment from Java, comes a long line of remarkable progeny. It seems that this one had come originally from Ethiopia, as a seedling probably out of the province of Harar. It was of the kind that produced fine, bold, large beans of excellent quality. When it had fruits in the glasshouse, their seeds were germinated and potted. The best of these was selected to be used as a royal export. The first trial for exportation was in 1712, when, through some mismanagement, the shipping failed. It was attempted a year later, under perhaps more skilled auspices, and in 1713 a tree that was 5 ft. high was sent successfully as a fitting gift to the celebrated Chateau du Marly in France, where lived the King-Emperor Louis XIV *(see* p. 19). This one tree was destined to become, through the will of Louis XIV, the progenitor of coffee in practically all of the American Tropics, as well as many other tropical regions. One of the very earliest records of this was in 1714 when the Dutch East Indies Company took plants from Louis XIV to one of their colonies in Sumatra.

The first French colony of the Americas to get a start from the noble tree was Martinique, and this was a romantic incident. A few potted seedlings from the Jardin des Plantes were given to a responsible Chevalier of the navy to take across the ocean, in one of the sailing craft of those days. These seedlings were to be given every care. This was in 1720 or 1723, and the guardian was Chevalier Gabriel Mathieu de Clieu. The story is well known. He lost all but one plant, for the ship entered the doldrums and lay by for weeks on glassy seas with sails slack and the heat almost unbearable. Drinking water ran low and all were put on scant rations. A crazed passenger saw de Clieu giving half his daily drink to the tree and attempted to destroy it. A branch was torn off but the owner fought him away, and the ship's crew helped to keep the tree from the demented man. The ship finally came to Martinique with the gaunt chevalier and his living coffee seedling. He had carried out his responsibility to the King, and brought a specimen of a living coffee tree to his home island.

It is believed that de Clieu planted this tree where he could tend it himself, and that it grew well. Some question the exact date of this introduction, but more authentic information is that it first bore fruits in 1726. It is supposed that all of the first seeds from it were planted. The doughty little chevalier soon had large fields growing coffee, and he began distribution to others. The Martinique coffee trees flourished, and in 50 years there were about 19 million of them growing on that island alone. In the meantime, the bequest of Louis XIV sent trees of coffee to the nearby French island of Hispanola or Saint Domingue, first in the part now known as Haiti.

The French now had possession of ample sources of coffee seed. They had studied the crop quickly and intently, and obtained information from Dutch and other sources. They rapidly increased the selfed progeny of the noble tree of Louis XIV, and by 1715 to 1717 they had sent it to the Orient, to the Island of Bourbon, now known as Reunion, from which it went farther eastward. For example, it was sent to Tahiti in 1740. Colonists in the Orient had been clamouring for a profitable crop. Coffee growth was becoming understood, and the drink was gaining in popularity. It grew under wise attention, and it answered their prayers. At the same time, the tree had been taken to Mexico. Over a century later, in 1887, it was taken from Bourbon to Indo-China.

THE FIRST COFFEE FOR BRAZIL

The long-established Dutch and French colonial planters were, perhaps, the most serious distributors of Arabica coffee. It seems now, looking back, that their only original source was that one Amsterdam greenhouse-grown tree received from van Hoorn of Batavia in 1706. It may well have been the very tree that Bradley (1716) described. Progenies of it were introduced into Dutch Guiana or Surinam, in 1718. A few years before that, it had been taken to the warm, low-lying port city of Cayenne, French Guiana, but there it grew poorly. Five years later an attempt was made to introduce coffee culture from Cayenne to the environs of the Brazilian city of Bel6m do Para. If coffee had grown indifferently in Cayenne, the poorer situation in Belem, with the much greater heat and its almost year-round rainfall, resulted in stark failure. Meanwhile, word of this went southward to anxious Portuguese farmers and many of them abandoned hope.

However, there were those Brazilians who had seen coffee grow in other countries and were certain it could be cultivated on their new farms. Sometime between the years 172=; and 1730, patriots say it was in 1727, a charming and suavely Jannered young B r f a n envoyf named Francisco de Melho Palheta, was sent to Cayenne. The story goes that he carried on his diplomatic duties to French Guiana with good effect, and in so doing made wide use of his attractive attainments. His Emperor had been most anxious to secure coffee seed, even from poorly growing trees in Cayenne, for a new test in the Empire of Brazil. No one has recorded all that transpired, but the romantic envoy worked carefully and cleverly towards that end. During this time, he had caught the lovely eyes of the young wife of the French Governor. Through enchanting qualities, de Melho Palheta gained her friendship, and she sent him, buried in a bouquet of fine blooms, gifts of both seeds and plants of coffee. These he dispatched with all rapidity to Brazil. He had sent them to drier, more southerly and cooler spots in Para, far from Belem. They were planted and were soon growing much better than their mother trees in Cayenne, and became an exciting success. The next move, in 1770, was further southward to an even cooler country, up the Amazon river on good land in the region of Manaos. There the plants grew reasonably well.

It was quickly evident that coffee was a crop with a golden future and seeds were gathered from the Manaos planting. They were taken by ship, in 1774, down the Amazon, out to sea, and around the bulge of Brazil to Rio de Janeiro. There the crop did even better than in Manaos. It was taken to Bahia in 1787. In 1782, and again in 1880, although Pestana (1927) has said the first reference to coffee in Sao Paulo was in 1797, it was moved to the land of its greatest development, the famous State of Sao Paulo. Here, in the much drier, cooler state, between 2 and 3 billion coffee trees have been and are being grown. Through the years, coffee seed had also come to Brazil from Sumatra and, possibly, also from Goa. Both sources reached back to Yemen, out of which emerged the noble strain of Arabica. Meanwhile, Brazil sent seed to Hawaii in 1825. These happenings in Brazil all took place while she was politically an important part of Portugal. She was the motherland's treasure of agriculture, in Lisbon was called *sua vaca de kite* by awed stay-at-homes, and was the grand and uncouth frontier. Coffee of the noble strain added the crowning touch of gold to make the people of Portugal depend more gratefully than ever upon their Empire in distant Brazil, for living and luxury in their European culture. Partly for the booming coffee wealth, the Empire of Brazil had been made one of the three Portuguese Kingdoms.

FURTHER SPREAD IN THE NEW WORLD

During the time that these events were occurring in Brazil, coffee seed had been secured from Martinique by the Englishman, Sir Nicholas Lawes. This was for Jamaica, where coffee was introduced in 1730 or 1732. From there it has gone since to other British West Indies islands. About 50 years later, progenies of this noble coffee were taken from Martinique by French priests to Venezuela, and right after that again to Mexico, in 1790, although the latter country had had an earlier successful introduction in 1740. The fact is that seeds from trees of the first introductions were also taken to the Philippines in 1744. In those islands, Arabica coffee planting and exportation was forced as rapidly as possible by the Spaniards. This was, all of it, the nobilized coffee of history. It was the self-fertilized tree, remaining pure in its inheritance and true in its growth characteristics no matter where it was taken.

Trees of this Arabica were, in the meantime, being grown in shaded gardens of the Terrier Rouge, now a part of modern Haiti but then the French island of Saint Domingue. The Royal thought had been to introduce coffee there to add to the production of wealth. This segment of the oldest European settlement in the New World was a rich fraction, indeed, of the French Empire. Coffee did not exactly thrive in the hot seasons of low-lying Terrier Rouge, so, in addition to being sent to other colonies, it was moved up to the Dondon area of Saint Domingue, where it flourished from that day to this. It was in Guadaloupe by 1726. Coffee was becoming a success in one place after another in the New World.

Great credit should be given in Latin America to the old French gardeners and scientists of their West Indies. They were skilled, and much interested in this new crop. Of course, they were stimulated and helped through Royal backing, through information out of the botanical garden in Paris, and through French horticultural professionalism. But they studied it themselves as well. They liked it. They learned to know it.

At this time, visitors from Spain were coming to Saint Domingue and they saw the small, beautiful, productive Arabica trees there. These were directly of the noble strain, and it was plain to see that they gave promise of filling the money chests of the anxious growers who were furnishing European trade with the product. Coffee was rapidly becoming a crop of primary importance in the world.

Probably the first step of coffee out of Terrier Rouge was to Cuba. This came about in 1724. Curiously enough, the introduced plants did not grow so well. History does not say why specifically. However, it seems now that it may have been because of planting in the dry red lowland soils where it was hot and coffee suffered. Moreover, in that .part, sugar cane was a bonanza, flourishing and pushing other types of agriculture out of the way. Soon those early Cuban coffee plantings failed; but not before a few seeds were saved and, in 1748, sent to Costa Rica. In that country coffee was first grown in the sun, without the best results, but on later study of its exhaustion it was shaded and the crop then saved and established. Results were also poor, at first, in Cuba, except that the coffee interest was so overcome by sugar cane that no one gave much thought to the help of shade. There were new reimportations in 1748 to 1750 into Cuba. They had come again from Terrier Rouge but went to some of the higher, more moist, parts of the Cuban island. There, that noble strain of Arabica settled, spread through the cooler and more shaded hills, and has remained ever since.

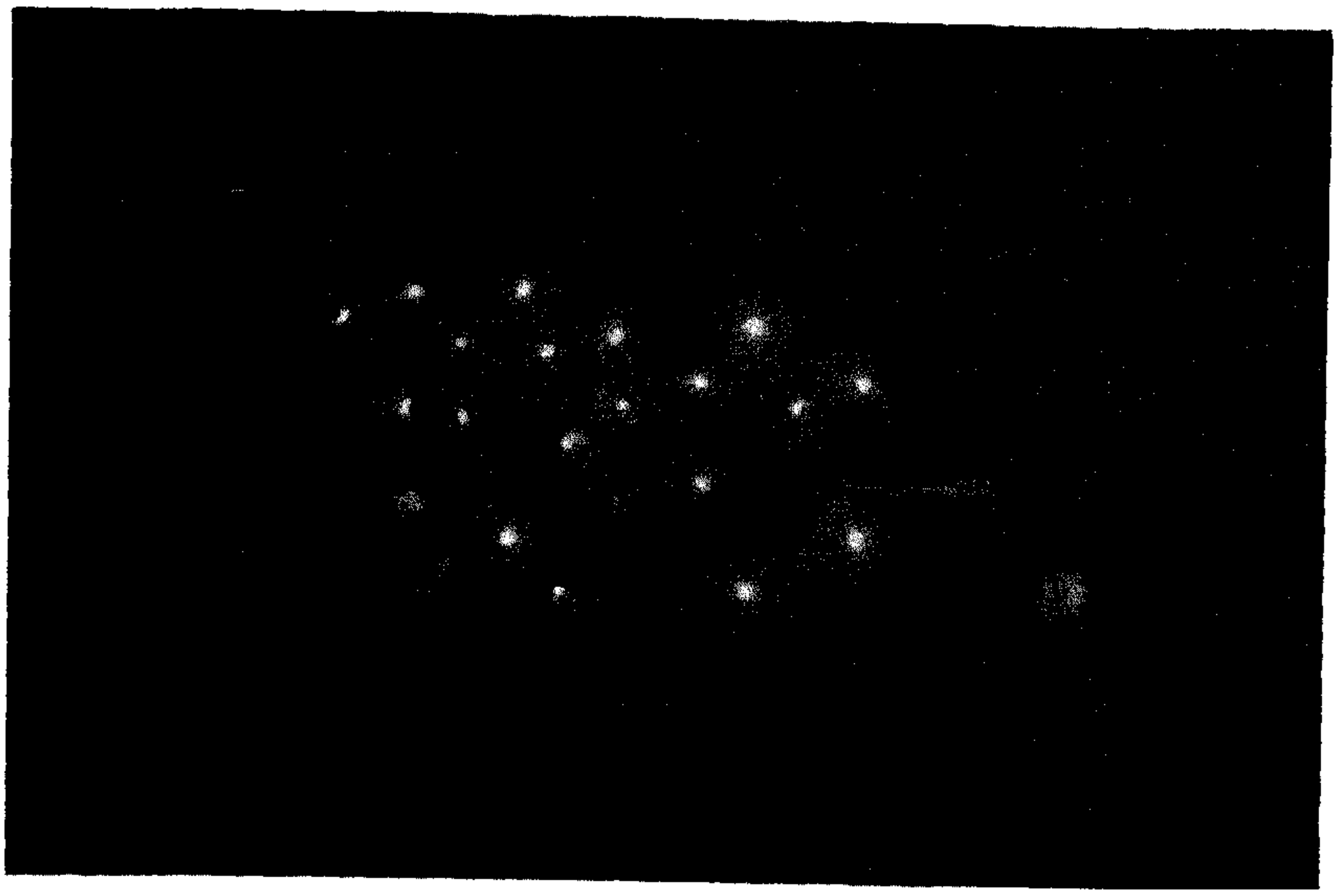
Spanish missionaries took some of the first seed to be produced in Cuba to new charges in Puerto Rico and Guatemala. These introductions were to help the agriculture of struggling colonists over the decade 1750 to 1760. From Puerto Rico it was but a step for the tree to see its progeny in El Salvador, where it arrived about 1760. It was grown with intelligence and skill, and by 1780 coffee from there was commercially famous. It is said that Guatemala first secured seed from El Salvador in those days, and Colombians who had connections in El Salvador also secured seed between 1780 to 1790. Guatemalan seed was obtained by Costa Rica in 1796, and another importation from there by Costa Rica was obtained in 1808. Some of the earliest Colombian farmers grew their first plantings without shade. Under those conditions, trees rushed into heavy production but soon weakened and many died. Seeding had to be done again. Learning from El Salvador experience, shaded plantings became more and more the vogue, and early failures were replenished from re-imported seed, again out of El Salvador. By this time, man was recognizing things about cultural limitation to certain surroundings in growing this strain of Arabica.

During all of this time it had been sent from place to place. Some of the movements were much farther than others. In 1893, Guatemalan seed was taken to Hawaii. Coffee was increasing in importance in world trade, and metropolitan parts of Europe and the United States were asking for it in ton lots, first by the hundred and soon by thousand. Labour was cheap, and under the limitations they knew, growers had learned a simple but surer growing system, that almost resembled forest culture, for this strain of Arabica.

DISTRIBUTION TO AFRICA AND THE EAST

This same wonderful coffee was being successfully tested and enviously looked upon by other countries. It became the turn for Colombia to furnish coffee seed for starting the crop in even further places. In the year 1784, it was taken from there to the countries of Panama, Ecuador, and Bolivia. Very soon after that, Brazilian seed had been obtained for trying the crop in Chile, Peru, and Paraguay. This Arabica could soon truthfully boast some other billions of trees in its fields. It has been said that Brazil had secured, in about 1760, some of its coffee start from Goa. This is the small, low-lying, Portuguese enclave, situated over half-way down on India's west coast, looking out to the Arabian Sea. India had received her first coffee from the holy man Baba Budan, who brought from Mecca his 'seven seeds[5] to be planted near his philosopher's cave near to Chikmagalur in the hills of India, in 1600. Some have believed it is possible that from there it had spread in succeeding steps first to Travancore and Malabar, then to Pondicherry and Talicherry, and later to the Central Provinces and Goa, If this is true, the coffee of those areas may be a different strain of Arabica from that in other parts of the world. It would have had its origin as seed from Mecca, probably long before that secured from Harar in Ethiopia. This latter came via old Arabia Felix that is now called Yemen. However, even this taken from Harar, fundamentally, is from the same basic region from which came the nobilized tree of the Americas and other places in the world. These steps, as suggested here, in India are somewhat clouded as to their certainty. There is clearer evidence that Louis XIV sent a start of coffee to Pondicherry about 1714.

. It is amazing how progeny of the original tree spread into the French Provinces of Africa, first by Royal design from the old glasshouse of the Jardin des Plantes in Paris. About the time the seedlings from King Louis's special tree had gone to Martinique, similar progeny were sent directly to French Central Africa. There, they were grown and harvested for over a century and were taken, in 1878, into what was then known as British Central Africa and from there far south to Natal. In 1895, the

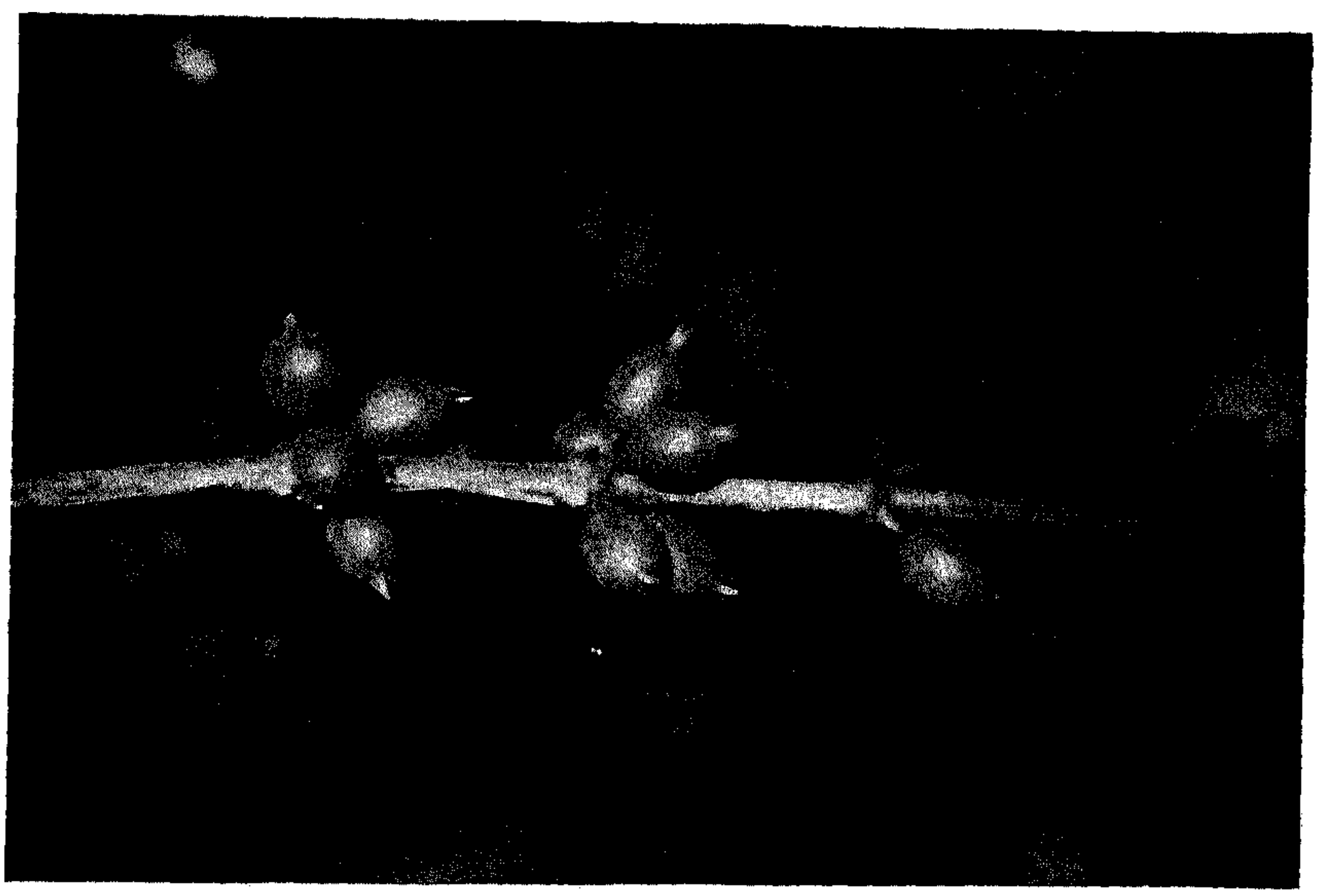


(a)

PLATE 6.~-(*) A promising new Arabica strain from a forest in Ethiopia. It produced heavily for three years Fruit-colour, shape, and disk-form are distinctly different from commercial Arabica. (Reduced to about J.) LA.I.A.S., Costa Rica.

(b) An attractive curiosity among the mutants from Arabica: the variety Goiaba with persistent calyces. (Reduced to about J.) LA.I.A.S., Costa Rica.

(b)



French seed was carried by missionaries to Kenya in British East Africa. From there it went to the Congo and had also been taken to Angola and thence back again across the African continent to Mozambique. The regions of British East Africa and the Congo had received importations of seed from the island of R6union, or Bourbon, in 1901. In this way there was returned to them, in a very roundabout manner, seed of the identical inheritance that existed in their first exportation to nearby French Central Africa.

These seeds could all be traced directly to the tree put into the hands of that young Professor de Jussieu by King-Emperor Louis XIV in 1713. This is all the more astonishing when it is realized that only some hundreds of miles away, albeit rough miles through jungle and high land, there still grew, and grow to this day, in the Ethiopian hills, wild stands of *Coffea arabica,* untouched by agriculturists and harvested by natives. Present-day scientists, working on problems of plantation culture, are beginning to wonder more and more how the original wild growth of this tree appeared. They have begun to wonder if it might not be a good plan to reinvigorate the highly refined inheritance with more variable types of the Arabica strain.

As may be seen from this review, it can be logically concluded that, practically speaking, all the Arabica coffee of commerce has come originally from one tree. It was a tree that could set its seed under conditions of self-pollination; it grew easily from seed, it was readily distributed from one country to another, and it produced standard, high quality, aromatic coffee. There are billions of these trees now descended from that first one, and each bears from less than one to several pounds of coffee every year. Because these all came from one, wherever found, they all belong to the same strain, although there are sub-strains or mutations. This is that strain that has been presented as nobilized and cherished, perhaps beyond the experience of any other crop that has become of world renown.

Because C. *arabica* is habitually self-pollinated, trees of Typica or Bourbon types, from any part of the more than fifty countries where it is grown, have remarkable stability in genetic composition. The eccentric dwarfs, giants, growth and colour variants, that have mutated from plantation growths, are still basically the same strain, from the seedling that, in 1713, was presented to the august presence of Louis XIV of France. It is of interest that coffee horticulturists are now starting to work with more than this. They are going back to Ethiopia and the region of its nativity, to secure better, stronger, more resistant strains from among the countless thousands of wild trees of the coffee forests. There is reawakened interest, likewise, in the possible differences in C. *arabica* strains that can be found in the countries of Mozambique and the Mysore State of India, and on the islands of Reunion, Tahiti, and Madagascar. These all obtained their original Arabica source from Ethiopia, but probably from different plants from that supplying the noble strain, so well known in the coffee world.

NEW COLLECTIONS OF ARABICAS FROM THE WILD

With the advent of World War II, seasoned veterans of coffee work in Africa were joined to armed forces in that continent that came within visiting distances of original Arabica growths. In several places in Ethiopia and the Sudan they pocketed seeds from wild trees, and brought or sent them to Kenya and to the Kivu region in the Congo. Since that time, there have been other strains of C. *arabica* brought from Ethiopia. These are the source of Arabicas different from the noble strain. But they were secured only very recently and are mostly still in the observation stage. So far as the world market is concerned, the Arabica of commerce comes from some billions of trees that had their beginning in the Harar of Ethiopia. At the risk of repetition, let it be stated that this very beginning, the exact story of which has long been lost, was probably from one or, at the most, from a few trees and, if so, these were from a handful of seeds out of, probably, only one tree.

The remarkable Arabica of commerce is a somewhat delicate, highly uniform, self-fertile tree, that, in plantation, goes through many generations with a very small amount of natural crossing and then only with close, selfed kin. Fortunately, it responds to a considerable range of conditions. However, it has its weaknesses. It is highly susceptible to certain diseases and insects, and is readily unbalanced physiologically. For some conditions, it is remarkably successful. With all its adaptability, to all intents its selfing habit makes it almost like a clone in its phenomenal sameness. Through what has appeared, in the many billions of the seedlings from selfed progenies that coffee-growing man has observed, have arisen some mutations deserving varietal perpetuation. As Arabica plantations have developed into more intensive, more modern agricultural enterprises, it has become evident that changes in husbandry and in kinds of diseases and insects have resulted in steady losses. This has meant the bringing in of other coffee species. The original Arabica tree, for all its nobilized forbears, is being replaced through the centuries by the more hearty, more variable species and strains. This will continue more rapidly unless even more attention is given to the greatly divergent Arabica materials in some few museum plantings and in those still existent in coffee forests of Ethiopia. The true wild range of this species has still to be fully investigated botanically, and understood horticulturally. It needs serious study in comparison with other species.

Plates 6 and 7 illustrate salient features of some interesting strains or mutants of Arabica, including a promising new one from Ethiopia,

IV

ON SOME BOTANY AND PHYSIOLOGY OF *COFFEA*

THE trees that produce the coffee of commerce belong to the genus *Coffea*, and because of their great economic importance they have had considerable attention. Details of their botany have been a source of uncertainty and of a great deal of controversy. However, this has not deterred developments in the crop, and has added to its interest.

The genus is made up of tropical members, as is the case with the majority of the genera composing the family Rubiaceae to which it belongs. Several close relatives of coffee are well known in ornamental and crop-plant horticulture. For example, there are the dye-bearing Madder, so long used by man, the brilliantly flowering Ixoras, and the handsome and spectacularly blossoming, fragrant Gardenias. In the family Rubiaceae there are altogether over 4,000 species, and some 350 genera. Of these, by far the most important genus is *Coffea*.

THE GENUS *Coffea*

This is a variable genus of plants. The botanical placement of coffee had been studied for over two centuries before Linnaeus (1737) described it in modern terms. Since his work the genus has had considerable attention, and through botanical explorations was proved to be a large group of species. Something of its diversity may be gauged by reference to publications of selected authorities: Cramer (1913), Cheney (1925), Chevalier (1929,1931,1937,1938,1939,1942,1946,1947), Houk (1939), Krug *et al* (1939), Carvalho (1945-6), and Coste (1955). In addition to these should be included reference to the fact that some of the great figures of botany have dealt with *Coffea*, among them H. Baillon, A. P. De Condolle, J. D. Hooker, A. de Jussieu, and K. Schumann. The genus has become of immense economic importance, especially during recent centuries.

Houk listed 190 specific names of coffees that had appeared in literature, and he reduced them in synonymy to 86. About sixty years ago, W. P. Hiern listed 15 *Coffea* species in his monograph, and a total of 35 species had been given by De Condolle in his *Prodrome* published in 1880. Eight years later, Froehner gave 29 species, but some ten years after that A. Engler indicated that he believed the genus contained some 50 species. In the year 1901, de Wildeman (1901) listed 36 species but by 1910 he chimin! there were 80, and a number of new species have been found sines

Chevalier *(q.v.)* gave altogether 87 species, and Coste (1955) has considered that there are 60 good species.

It is of special note that Chevalier (1931) counselled that a great amount of botanical study be done on the genus *Coffea,* and pleaded attention from the International Association of Plant Selectors. He very strongly suggested protection of wild coffees growing under primitive conditions, for further botanical work.

The exact number of species of true coffees depends upon which botanist is accepted as the authority. Some say there are about 50, while others believe there are more species than do either Coste or Chevalier. are still being studied and probably are not all known. Very recently Germain & Kesler (1955) described a completely new species that had first been collected in 1935 and was studied for several years before being given its botanical disposition. The species problem in *Coffea* is being studied in several places. It is far from being settled.

THE SPECIES PROBLEM IN COFFEE

In his posthumous book, Cramer (1957) contended, and with sincere reasoning, that the tendency of the lumpers[5] to reduce many of the accepted *Coffea* species to synonymy was not correct. He held, to the day he died, that these species needed to be considered on the basis of something more than intensified dry herbarium morphology. Inferences from both Cramer and Chevalier have been that to pass judgement on coffee species from herbarium botany alone, or from pure literature review, was as untenable as to have a new species appear out of every plant that looked different or that came from a new geographical location. In his first definite study, Cramer (1913) held that there were a limited number of species. Cramer's later decision (1957) that there were possibly close to a hundred 'good' coffee species was not lightly reached. Reading his reviews of the species problem, especially as it relates to coffee (1913,1957), shows that his opinion was tempered by his close association with Professor Hugo De Vries in the University of Amsterdam, This classic master had had young Cramer with him for years as an assistant while developing methods of experimental study of evolution of species, and especially of the theory of mutation to explain the sudden appearance of a new type among a large population of ordinary forms. Cramer felt that there are more coffee species still to be found, and the same belief was expressed by Chevalier.

Superficial plant characteristics in coffees cover a very wide range. There are small-leafed shrubs, sometimes almost spiny in appearance, many of them hairy and with branches varying from stiff to trailing in habit. There are those with leaves that are dropped annually with the onset of the dry season; others that are evergreen may hold onto their leaves for three or more years. In colour these vary from yellow and dark greens to bronzed and purple-green (PL i). Textures differ from delicate to stiff and leathery. In some species leaves may be pubescent, and in others they are scaly. In some, the leaves are quite small, no bigger than a man's thumb-nail, or they may be found as large as a wide-brimmed hat, with all gradations between. While some species are small, woody shrubs, sometimes trailing in habit, most of them are bushes or small to medium-sized trees, and there are a few that are characteristically rather large forest trees. The bark varies in colour from almost white, through tans and browns, to very dark, and from fine-grained to a quite coarse texture.

Ripened fruits differ considerably. Some have a good, sweet flavour, and others are distinctly inedible. Normally there are two seeds embedded in flesh. Fruits may range in size from that of a small flattened pea to that of a good-sized plum. Colours of ripe fruits vary widely in the genus. They can be green or greenish-purple. Some are almost brilliant black, some purple and streaked purple on red, or streaked red on pink. The pinks and reds vary a great deal; some are blood-red, some verge on purple. Some are mauve, some have an orange shade; others are a clear yellow, and there are types reported that are almost white. Flower differences may also be seen. There are those that are small and unattractive, with no scent, while others have large dense clusters like pompoms, with abundant fragrance. Some species have white flowers, some pink or almost purplish, and some creamy to yellowish. Some have short corolla tubes, while in others these are long, like those of honeysuckles.

It is true that wide diversities in the coffees are mostly given in quantitative descriptions. Some of the differences, of course, are measurable, as shown by Krug *et al* (1939). Certain of these problems of variability were given special study by Cramer (1913). He used methods of study developed under and in collaboration with Professor Hugo De Vries of the University of Amsterdam. The results which Cramer gathered have long deserved amplification and re-analysis in the light of what has been learned since in genetics, statistics, and botany. He found greater ranges in irregularities of vegetative characters than in the more stable features such as seeds. His studies were largely on the problem of species, of mutants, and of varieties and hybrids that were available in Java. Some of Cramer's data on his seed studies are presented in Table I. There are remarkable variations between mutants within the species C. *arabica*. Of striking note is the very small seed of the Mokka coffee, and its evident inheritable character when crossed with C. *arabica* var. *typica*. The Mokka coffee was considered in these seed studies as part of the Arabica complex, but was described by Cramer in the same book (1913) as a separate species. Such variations among beans were much less marked than the measured differences found among trees or bushes, leaves, branches, or other vegetative features.

TABLE I

COFFEE BEAN MEASUREMENTS IN CERTAIN SPECIES AND VARIETIES* OF THE GENUS

Coffees	Measurements in millimetres † Short	Middle	Long	Width	Proportion ‡ or out-turn	Bean weight in gm.
C. arabica var.:						
angustifolia	10·0	12·0 (10·2) ‖	14·5	8·5 (7·0)	5·2	0·15
bullata	7·0	9·5	12·0	9·5	16·2	0·088
bourbon	—	— (8·1)	—	— (6·1)	—	—
columnaris	11·5	14·0	15·0	8·5	5·4	0·20
erecta	9·0	11·5	14·0	8·0	6·0	0·14
laurina §	10·0	12·0 (8·2)	14·0	7·5 (5·2)	7·0	0·13
maragogipe	12·0	16·0 (11·7)	20·0	9·5 (7·3)	9·5	—
mokka ¶	4·0	6·5 (5·3)	9·0	— (4·7)	4·9	0·05
murta	—	— (8·5)	—	— (6·7)	—	—
pendula	10·5	13·5	16·0	7·0	6·8	0·13
purpurascens	10·0	12·5 (7·7)	14·5	7·5 (5·4)	5·7	0·14
typica	9·5	11·5 (8·7)	14·0	9·0 (6·5)	6·6	0·19
mokka × *typica*	7·5	10·0	11·5	8·0	3·6	0·16
C. liberica × *C. arabica* **	10·5	12·0	14·5	—	—	—
C. liberica	12·0	15·5	19·0	10·5	—	—
,, F	—	17·0	—	—	9·8	0·29
,, G	—	15·5	—	—	12·5	0·28
,, K	—	18·0	—	—	11·0	0·36
C. abeokutae 1	—	12·0	—	—	7·0	0·14
,, 4	—	11·5	—	—	8·4	0·13
,, F	—	12·0	—	—	8·8	0·14
C. excelsa	—	13·0	—	—	6·8	0·34
C. mauritiana	12·0	17·0	22·0	—	6·9	0·285

* From condensed data from text and tables in Cramer's (1913) work on coffee variability. The figures in parentheses are from Krug *et al.* (1939).

† Cramer's measurements, all seeds in parchment shells.

‡ Calculated by weight, the lb. of fresh cherries needed for 1 lb. of clean market coffee. Expressed by some as a proportion, e.g. 1:5.2, meaning that it required 5·2 lb. of *angustifolia* cherries to produce 1 lb of clean market coffee.

‖ Figures in parenthesis are from Krug *et al.* (1939) and are measurements without parchment shell.

§ Said to be a cross between *C. arabica* (*typica?*) and *C. mauritiana.*

¶ *Mokka*, included by Cramer among the 'arabians', but given the specific designation of *C. mokka* by him.

** This was the famous Kalimas hybrid.

SOME BOTANICAL FEATURES

Although some coffees are bushes or trailing plants, probably most of them may be classed as trees. They are perennial, woody, and with a resistant stem or trunk covered with bark. In some, the roots are characteristically rather superficial, and, in others, they are habitually deep in their penetration of the soil. Some of these trees are large and impressive forest inhabitants, others are small. The trees of the genus *Coffea* all have opposite leaves and opposite branches, although occasional abnormal individuals are found in which there are whorls of three.

A well known botanical feature of coffee is its two types of stem growth (Arndt, 1929,19290; Cook, 1911). One is that part of the tree which grows vertically. This is the orthotopic, vegetative part of the tree structure that forms the trunk and central axis. It has nodes on it, with opposite leaves, and in the axils of these leaves are found the series of buds from which growth proceeds.

The first bud that commonly comes out appears at a little distance above the leaf axil. From this comes the plagiotropic or horizontally growing, fruiting branch. This is an organ especially for fruit production. There are at least four, and sometimes five, buds below this first or top bud, one or two of which may be stimulated to grow out and develop into orthotropic stems.

In the case of *C. arabica,* as well as in some other coffees, we have a rather unusual plant comportment or configuration. Its bud arrangements and developments have been described by such as Wakefield (1933), van der Meulen (1939), and Rayner (1942,19460). The flower-buds have been found to be initiated at almost any time during the year, if observations are considered from several workers. Where a distinct dry season is experienced, evidence has pointed towards flower-bud development especially during the dry season. However, in regions where there is usually no distinct dry season, it is evident that bud initials are laid down with the development of any new node, and may be demonstrated microscopically one or two weeks after the node is observable.

The vegetative buds are those occurring below the plagiotropic, or fruiting, branch buds. These latter are the buds that become activated when the horizontal branches have stopped vigorous functioning and an upright has been fixed in a bent-over position. If an upright is cut away, a pair of orthotropic shoots will grow up from buds below the cut, and these will strive to replace the original lead growth. It is not long before orthotropic stem tissue becomes sufficiently mature that the primary, plagiotropic, fruiting-branch buds start growth. In certain species, the fruiting wood flowers and bears fruit for only one year, and cherries must come from new wood each season. In other species, the side branches may produce at the same nodes a number of years in succession; and, in some, fruits are occasionally borne even on the central axis.

The flower buds that typically come out on the side branches appear in clusters at the nodes. The number of these flower buds that will mature, ready to be forced into bloom, will depend on the coffee species and the nutritional condition of the tree. The buds are packed more or less closely together at the nodes, here again depending upon the species. The numbers at nodes may vary from one or a very few, to fifty or sixty.

The flowers of the genus *Coffea* are quite irregular in many respects. Petals vary in number from four to more than nine, depending on the species and variety. Calyces are often four- to five-parted and the corolla tube is cylindrical and, in many instances, quite elongated. The pistil consists of a two-parted receptive surface, attached to the receptacle and coming up through the centre of the corolla. The stamens have filaments attached towards the middle of the anthers, and are inserted in or below the throat of the corolla. The pollen grains in such types as Canephora and Liberica are easily carried on light breezes, whereas pollen from Arabica is relatively heavy and sticky and not so readily distributed.

The leaves of certain coffee species may be elliptical, with sharply acuminate tips, but, in some, they are rounded, blunt, and almost fiddle-shaped. Textures range from smooth and silky types, through leathery and coriaceous, to scaly and pubescent. The main veins of the leaves vary in numbers, and are usually quite prominent. In most of the species small pores or domatia occur at the point where the main veins join the mid-rib. These domatia cause a swelling on the upper surface of the leaf, but are open on the underside. In some species, they are a quite prominent characteristic and may be elongate and, in some cases, surrounded by tufts of leaf hairs. So far as is known, all species have leaf stomata only on their undersurfaces.

The fruit of coffee is a drupe. Typically, it has two seeds in it that are pyrenes. The embryo in them is somewhat curved, wrapped in foliaceous cotyledons, and the albumen is horny when mature and dry. A seed, the 'bean' of commerce, usually has a crease down the middle of its flattened side. This face or inner surface is at the place where the two seeds come together. A seed commonly tapers a little to one end and the embryo is located there.

The skin of the fruit may or may not be of resistant tissue. The pulp, or exocarp, is often juicy, although this is not always the case in all species, and it envelops the endocarp or parchment shell. This shell is somewhat resistant. Directly inside the parchment is the seed-coat. In Arabica this is the 'silver skin', but it is not silvery in colour in some other coffees. This 'skin' is a tissue made up of several layers of parenchymatous cells, always including sclerenchyma. The epidermis of the endosperm is made of thickened cells, the walls of the cells being characteristically pitted inside. There are variations in all ofthese characteristics, depending upon the species.

ARRANGEMENT OF THE COFFEE SPECIES

It can be seen that appearances among species of coffee must differ greatly within the genus. As is the case with a number of other complex genera, *Coffea* has been partitioned into sections and sub-sections by botanists. While under these are listed groups of species that fall together on logical Linnean bases of morphology, it is of interest that, in general, the groupings also represent human usage differences and ecological and geographical connotations, as well as the morphological variations. It is, at present, reasonable to agree with the consensus of the workers in the Ivory Coast (Bouriquet, 1954) that the botany of coffee is somewhat confusing and difficult to use in practice. Probably there are species still to be found, and those we know are rather recently out of the wild.

What we have recourse to, at present, are mostly the numerous and extensive systematic studies of Cramer, Sibert Lebrun, Schumann, Hiern, and Wildeman, but particularly the work of Chevalier in which he partly summarized his conclusions in two books (1942,1947). He took into account as far as possible the studies and findings of others. Through a long life *(see* Jacques-Felix, 1956) he was the one botanist who saw and worked with the largest number of different coffees in nature, in herbaria, and in cultivated fields. Until an equally able botanist can spend the years living with the genus as did Chevalier, or as did Cramer, and remodels the present *Coffea* genus concept, it seems acceptable to follow mainly Chevalier's systematics. These are recognised now by several workers, and perhaps most effectively by Coste (1955). The same system will be used here, with the exception of a few liberties in making one or two minor changes in acceptance of species.

No attempt is made directly below to present technical diagnoses of the species of *Coffea*. The specializing botanist is referred to the systematic works of Chevalier, Linnaeus, Wildeman, Lebrun, Cheney, Hooker, Hiern, and Baillon. The present book does not seek to give for coffee species, differences in relation to the structural variations in flower parts and fruits, e.g. along classical Linnean lines. All that is offered here is an indication of certain salient variations. It is hoped that from this it will be evident to the general reader that the species are of unusual interest. Herewith is presented, then, the organization of the genus. After each species are given countries of origin in brackets. Short remarks are added on certain characteristics of the plants named.

THE GENUS *Coffea* L.

A. The section *Paracoffea* Miquel. These are woody bushes, dropping annually the usually small, short leaves when dry seasons are severe or prolonged cool weather comes. Flowers are borne both laterally and at the tips of fruiting branches. Seeds inside the fruit have a membranous covering, and seeds within the covering are marked with a light crease. Some bushes may be almost spiny in appearance, but are not so well known as a group. Their uses are largely local, as substitutes for Arabica coffee.

C. *bengalensis* Heyne ex Roem. & Schult. (Bengal, Burma, Sumatra.) Small leaves, scaly stems. Long corolla that marks a prominent, beautiful flower. Has been cultivated widely in Bengal; much used by natives.

C. *cochinchinensis* Pierre ex Pitard. (Indo-China.) Rather large bush, with many branches, the fruiting branches short. Leaves small, pointed, oblong to oblong-lanceolate. Large domatial openings surrounded with nairs.

C. *dongnaiensisYizTxz* ex Pitard. (Cochin-China, Indo-China.) Bush with slightly pubescent stems. Very small leaves. Small fruits with tendency toward squat or flattened appearance.

C. *floreifoliosa* Chev. (Central Madagascar.) White flowers with prominent foliaceous bracts, isolated or in pairs on fruiting branches. Small leaves.

C. *floresiana* Boerl. (Moluccas.) Not well known, but acceptable to Chevalier^ Coste, and others.

C. *fragrans* Wall. (East India, Burma, Siam.) Possibly a variety of C. *travancorensis*. Comparatively large leaves for this group. Leaves lance-shaped. Flowers borne singly, white.

C. *grevei* Drake ex Chev. (West Madagascar.) Somewhat pubescent leaves and stems.

C. horsfieldiana Miquel. (Java, Madura.) Handsome bush, used as ornamental in Indonesia. Leaves drop during the dry season.

G. mahyana Ridl. (Malay Peninsula.) Medium-tall bush. Large elliptical but acuminate, leathery leaves.

C. *merguensis* RidL (Malaya.) Small shrub, somewhat pubescent. Close relative of the next species.

C. *travancorensis* Wight & Am. (West Central India, Travancore, Ceylon.) Small shrub with many branches. Young branches tend to be finely pubescent. Fruits rather small, black, pubescent.

C. mightiana Wall. (South-west India, Travancore, Coorg, Coimbatore.) Small bush strongly branched, almost spiny in appearance. Withstands semi-aridity. Pubescent and almost woolly on some leaves. Very small leaves, and very small fruits. Flowers often at branch tips.

B. The section *Agrocoffea* Pierre ex de Wild. These are woody bushes and some are vine-like and creeping. Leaves deciduous in some, more persistent in others. Special fruiting branches short, with one or more flowers at their tips. Fruits globular with thin flesh. Seeds in this section without median crease. Branches may be downy or fuzzy; leaves brilliantly green. Used as substitutes for other coffees. Natives said to prefer certain species of this section for their own purposes. Fruits and dry seeds are apparently chewed.

C. *afzelii* Hiern. (Liberia, Sierra Leone, Cameroons, Ghana.) A trailing woody plant, the branches rigidly at right-angles. Domatia small. Flowers solitary or in pairs.

C. *jasminoides* Welw. ex Hiern. (Guinea, Ivory Coast, Liberia, Cameroons, Congo.) Noted for short fruiting branches with terminal flowers. Fruits with prominent calyx tips.

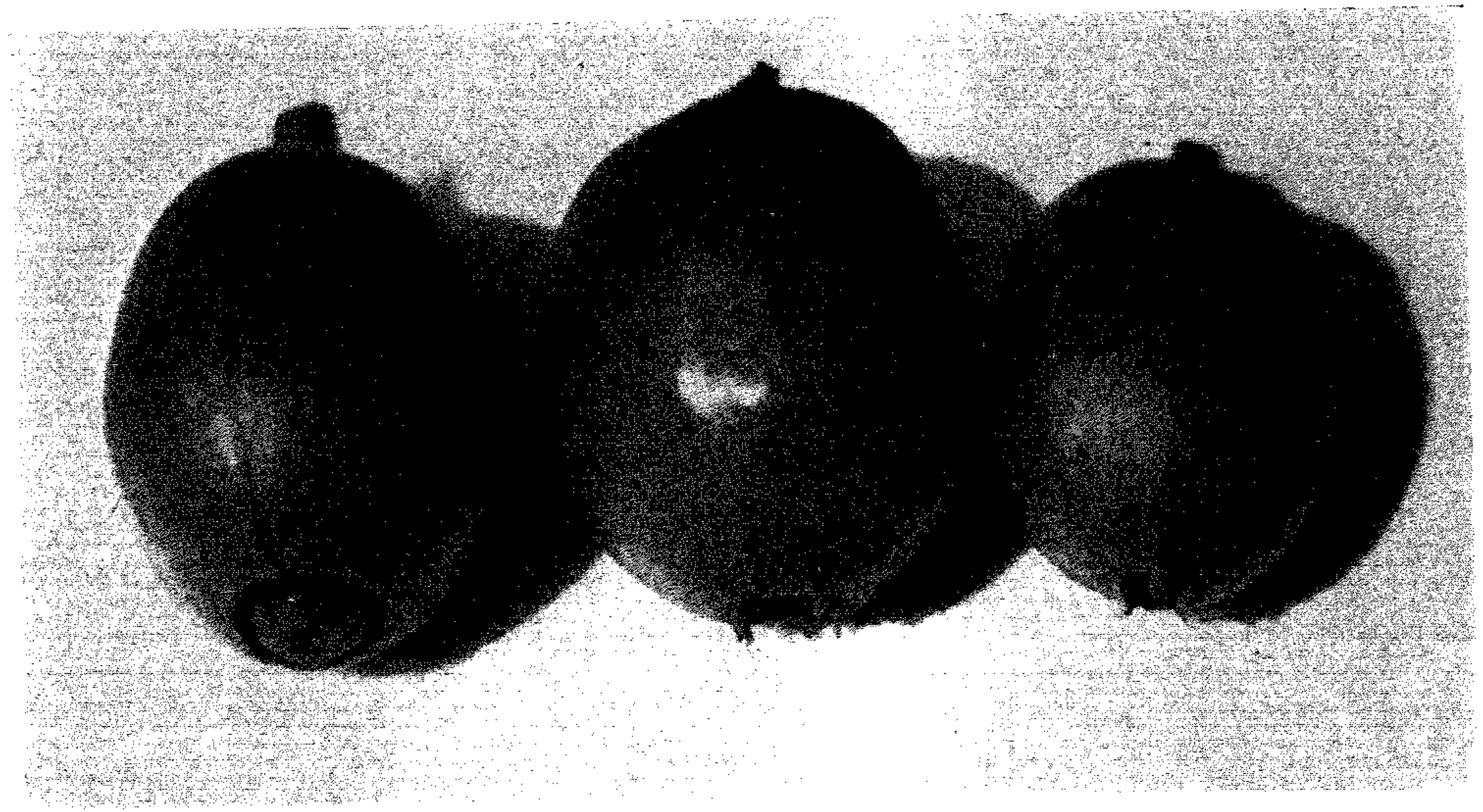


PLATE 7.—Cherries of wild Arabica coffees. (Enlarged × 3·1.) On the left is seen the smooth disk characteristic of the long-cultivated Arabica of commerce. The others show irregular shapes and the persistent calyx-tips typical of some recent collections from the forests of Ethiopia. I.A.I.A.S., Costa Rica.

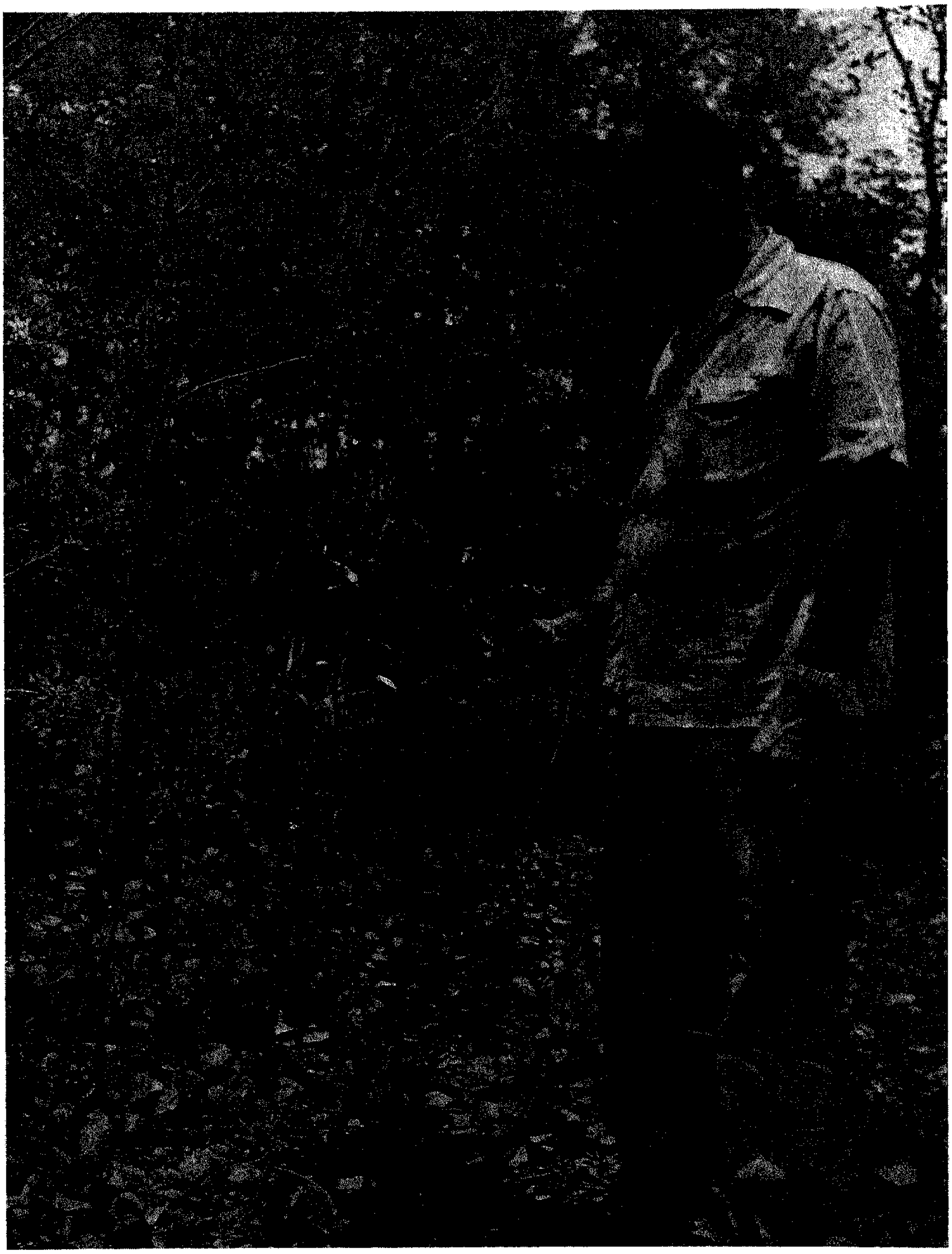


PLATE 8.—Examination of a species of *Coffea* from Madagascar. It is reputed to have elongated fruits, horny beans, and no caffeine. Bogor, Indonesia.

C. mehnocarpa Welw. ex Hiern. (Angola.) Low bushes. Young foliage finely pubescent. Leaves more or less persistent.

C. *nigerina* Chev. (French Guinea.) Bushes rather densely branched, somewhat trailing in character. Branches angular, the slender flowers borne on tips. Leaves small, broad.

C.nudiflora Stapf. (French Guinea, Liberia, Ivory Coast.) Fruits inedible, but seeds used by natives.

C. pulchella K. Schum. (Gabon.) Completely trailing, woody bush, notable for its small fruits and small leaves.

C. *rupestris* Hiern. (Nigeria, Congo, Ghana, Dahomey, Ivory Coast.) Bush with finely pubescent young branches. Flowers borne more or less singly, with long corollas. Inedible fruit with five persistent calyx points.

C. *scandens* K. Schum. (Congo, Cameroons.) This is a distinctly trailing species. Branches numerous and slender. Leaves small. Fruits unknown.

C. *subcordata* Hiern. (South Nigeria, Congo, Cameroons, Gabon.) Slender branches, trailing habit. Somewhat pubescent. Mostly in dry forests. Small leaves that are deciduous annually. Prominent bracts in inflorescences. Fruit quite small, squat.

C. The section *Mascarocoffea* Chev. These are bushes or trees with leathery leaves that may or may not be persistent. Fruits mostly elongate, ovoid to pear-shaped. Seed is horny, with central crease. Many species devoid of caffeine or nearly so. Used by local natives in medicine and in their diet as well.

C. *alleizetti* Dub. (Madagascar.) Bush. Leaves slightly leathery, medium-sized, elongate, attenuate at base and tip with long tip portion. Domatia very large, with tuft of hairs about them. Flowers borne in groups of two or three. Fruit pear-shaped.

C. *bertrandi* Chev. (Madagascar.) Bushy type of growth. Seeds claimed to make a good-quality drink. Has no caffeine.

C. *boiviana* Drake. (Madagascar.) Much-branched bush, whitish bark. Small, stiff leaves, almost round to somewhat oblanceolate, or with blunt tips. Plant adapted to moderately elevated, forested, calcareous regions.

C. *bonnieri* Dub. (Madagascar.) A bush. Fruit or seed contains no caffeine.

C. *commersoniana* Chev. (Madagascar.) Bush with side branches almost erect. Leaves tend to be obtuse. Fruit unknown, apparently a shy bearer. Grows in lowland forests along coast.

C. *dubardi* Jum. (Madagascar.) Bush to small tree, evergreen. Leaves oval to elliptical, undulating, the domatia surrounded with hairs. Fruits oblong, somewhat fuzzy, medium-sized.

Q. gallienii Dub. (Madagascar.) Small tree, distinct and well developed trunk. Fruits elongated, pear-shaped with small end at base, medium-sized, the pulp white and sweet. No caffeine. Moist forest inhabitant, in shaded ravines.

C. humblotiana Bail. (Reunion, Grande Comores.) Tall tree of mountain forests. Good-sized obovoid fruits. Contains caffeine.

C. *lancifolia* Chev. (Madagascar.) May be an uncertain species. Large lanceolate leaves. From dried material the flowers appear large and handsome.

C. *macrocarpa* Rick. (Mauritius, Reunion.) Small tree. Leaves broad. Fruits rather large, elongated. Calyx end provided with sharp point.

C. *mauritiana* Lamarck. (Reunion, Mauritius, Madagascar.) Short tree with leathery leaves. Small, white, elongated fruits, borne almost sessile. Seed with deep ventral crease. Low caffeine content. Very common forest inhabitant.

C. *mogenetiDuh.* (Madagascar.) Mountain forest tree. Leaves undulant, almost crenate. Fruits medium-sized, subspherical and somewhat compressed in appearance. No caffeine.

C. *pervilkana* Drake. (Madagascar.) Withstands dry weather. A small tree.

C. *resinosa* Ridl. (Madagascar.) Tree of good size. Dry-land forests of the littoral.

C. *tetragona* Jum. & Perr. (Madagascar.) Small tree, the evergreen leaves looking much like those of C *arabica.* Fruits of rather good size, ovoid, rounded, at base slightly truncated, somewhat four-sided. Seeds appear very similar to those of Arabica. Moist forest inhabitant.

D. The section *Eucoffea* K. Schum. This is the most economically important section of the genus. Range is from small bushes to large trees. Botanical characters close to the previous section. Seeds notable for containing a good supply of caffeine. Fruits mostly edible. There are five subsections.

I. Subsection *Erythrocoffea* Chev. Small to medium-tall trees. Fruits red and purplish-red to yellow at maturity. Pulp sweet, thick, readily removed from seed-coat. Seeds marked with deep ventral crease. The greatest coffees of world commerce included in this group. These are all evergreen species.

C. *arabica* L. (Largely Ethiopia, but with some in the Sudan, possibly some in Uganda and Congo.) Described in detail elsewhere in this book. By all odds the greatest coffee of the world markets, of aromatic cup quality, lending itself well to man's husbandry. Over twenty known mutants, about eight of which are fixed commercial varieties. Many other genetically more complex varieties in use. Fruits sweet, mostly red, some yellow. Has hybridized with C. *mokka, C. liberica,* and other species.

C. *canephora* Pierre. (Central and West Africa, Congo.) Described elsewhere in this book. As a commercial species, increasing in world market importance, and next to *arabica*. Numerous varieties are known in this species. The famous Robusta variety belongs here. Contains more caffeine in its beans than the previous species, but more neutral in cup quality although known for body. Has been hybridized with other species.

C. *congensis* Froehn. (Basins of Nile and Congo rivers.) Tree very much resembles *arabica*. Wet forest inhabitant growing well in low locations that may be commonly flooded each year, and withstands periods with roots covered by running water. Red fruits, sweet-fleshed. Good quality coffee from seeds. Has hybridized readily with *canephora*.

C. *lebruniana* Germ. & Kesl. (Congo.) Virgin forest inhabitant, in plateau country. Leaf apex elongated, becoming spatulate in form. Fruits whitish when young, turning to mauve, later becoming violet to purplish at maturity.

C. *mokka* Cramer. (Eastern part of Ethiopia.) Dwarf tree or bush, several stems; small leaves and fruits. Adapted to withstand drought conditions. Is variable in its forms and hybridizes readily with C. *arabica*. Exquisite flavour as coffee from beans, this quality inherited when crossed with C. *arabica*. Discussed elsewhere in this book. It has been suggested that it may be a fixed mutant of C. *arabica*.

II. Subsection *Nanocoffea* Chev. Bushes to dwarf and small trees. Leaves small to large, persistent. Fruits medium-sized, red at maturity.

C. *brevipes* Hiern. (Cameroons, Congo, Ivory Coast.) Common dwarf tree. Slender, leathery leaves, become red during dry season. Fruits good-sized, with prominent calyx points. Seeds oblong, slightly pointed at base. Much used as a source of native coffee in West Africa.

C. *humilis* Chev. (Liberia, Ivory Coast.) Long, rather coarse leaves. Fruits small with prominent calyx tips,

C. mayombensis Chev. (Mayoumba, Gabon.) Small tree. Poor fruiting habit. Fruits ovoid to oblong, medium-sized. This species is not well studied.

C. *montana* K. Schum. (Cameroon Mountains.) Another species not well understood, but accepted on grounds of herbarium studies.

C. *togoensis* Chev. (Togoland.) Small tree. Species not well studied and of uncertain position, but apparently distinct. Fruits a good size, ovoid to elongate, used locally in West Africa.

III. Subsection *Pachycoffea* Chev. Trees coarse, medium-sized to quite tall. Evergreen, with mostly large handsome leaves, leathery in character. Fruits medium-sized to quite large, often with prominent blossom-end, red to reddish-brown and streaked when ripe, the skin thick and pulp sweet and fleshy at maturity. Seeds good size, some having commercial use, the caffeine content more than in the first subsection.

C. abeokutae Cramer. (Cameroons, Ivory Coast, Ghana.) Fairly large tree up to 30 ft. high, conical shape. Leaves lanceolate, shiny and somewhat leathery, pigmented with bronze. Fruits mostly round, with small blossom-end scar. Medium to good-sized seeds, the taste quality fair. Cultivated in fairly extensive plantations. Close relative of *C. liberica* of which some consider it a fixed variety.

C. excelsa Chev. (Ubangui-Chari* and Central Africa, Sudan). Dry-land species, somewhat variable, grows to be a large tree, deeply rooted, with large leaves ; the commercial varieties have small fruits that are short, blood-red, juicy, somewhat oblong, easily de-pulped. It is possibly the most frost-resistant (Chevalier, 1929*a*) of any of the more commonly planted coffees. Beans also small, with mild flavour, of fair quality in some strains. Grown in small amounts for commerce in Philippines and Java. Used for blending in the Orient.

C. klainii Pierre. (Gabon.) Small tree, sometimes cultivated. Large oblong leaves; fruits and seeds somewhat oblong to wedge-shaped. Used in commerce in small quantities.

C. liberica Bull ex Hiern. (Liberia, Cameroons, Ivory Coast, Ubangui-Chari in the Congo, Gabon, Sierra Leone.) An immensely variable species that has been partly described elsewhere in this book. Its varieties are numerous, but often unstable. Such names as Zenkeri, Dewevrei, Arnoldiana, Dybowskii, and Sylvatica apparently belong in this species. Large trees, able to withstand serious neglect and still produce a crop. Leaves very large, roundish, leathery, persistent. Tree shape elongated to globular. Flowers large, white to pinkish and lavender, strongly fragrant. Fruits edible, hard and thick-skinned, some as large as plums, others much smaller, yellowish densely striped with red. Difficult to de-pulp. Large beans. According to some, coffee from its beans is bitter and not of best flavour quality. Liked by many Asiatics and Africans for this bitterness.

C. oyemensis Chev. (Gabon.) Small tree. Leaves very large, oval, acuminate.

IV. Subsection *Melanocoffea* Chev. Medium-sized trees, of elongate, almost columnar shape. Dark green stems and persistent leaves with distinct petioles. Leaves thick and harsh, narrow to oblong. Flowers white to rosy. Fruits black at maturity. Seeds small, said to be of fine flavour, used commercially in a small way.

*In literature, the first of these names is variously spelled as 'ubangui', 'ubangi', and 'Oubangui'. In some cases no hyphen is used between these names, but usually they are hyphenated. Sometimes the 'Chari' is not capitalized, and is commonly given as 'Oubangui-chari'.

C affinis de Wild. (Ivory Coast, Guinea.) Small tree of pyramidal shape. Suggested as a fixed mutation of C. *stenophylh.*

C. carrissoi Chev. (Angola.) Irregularly branched tree. Good-sized fruits. Dry-land type.

C stenophylh a Don. (French Guinea, Ivory Coast, Sierra Leone.) A small tree, cultivated on a limited scale. Withstands dry conditions. Leaves leathery, narrow, with wedge-shaped base and sharp point. Fruits black, borne on notable peduncle; seeds slightly smaller than m C. *arabica*, said to be of fine flavour.

V. Subsection *Mozambicoffea* Chev. These are small trees and bushes. Adapted to dry conditions, some habitually drop leaves during dry season. Stems often slender. Leaves small, may even be scale-like. Fruits oval to subglobular. Seeds very small, contain caffeine. Used by natives; said to be of good cup quality.

C. *eugenioides* Moore. (High Kivu of the Congo, Ruanda-Urundi.) A good bush to small tree, pyramidal in shape. Leaves leathery, small, lanceolate to oval. Leaves may be persistent but readily dropped under bad conditions. Fruits more or less oval, red. Good quality. Some are plantation grown.

C. *ligustroides* Moore. (Northern Rhodesia, Gazaland.) Bush. Small leaves shaped like those of privet. The yellow fruits are oblong in shape and usually one-seeded.

C. *racemosa* Lour. (Mozambique, Tanganyika.) Low tree or bush. Leaves small, leathery, undulating. Fruits relatively small, pointed at blossom end. Used for coffee among African tribes.

C. *salvatrix* Swynn. & Phil. (Mozambique.) Variable tree, both large and small. Strongly branched. Leaves oval, acuminate, wedge-shaped, of leathery texture. Fruits green with red streaks.

C. *schumanniana* W. Busse. (Tanganyika.) Small tree with small leaves. Fruits small and oval shaped.

C. *zanguebariae* Lour. (Zanzibar, Tanganyika, Mozambique.) A good-sized tree. Leaves somewhat leathery, undulating, reasonably large, oval to wedge-shaped, superficially similar to those of C. *arabica.* Fruit size and appearance of seed like C. *arabica.* Somewhat cultivated, furnishes coffee for Zanzibar.

From even a superficial reading of the above, wide variations within the genus cannot help but be evident. It is obvious, also, that coffees occur that are adapted to grow under a wide range of ecological conditions. One factor seems common to all the species, namely that they are tropical; they are warm- or hot- as well as cool-country plants, but they do not grow where a season of freezing weather is an annual occurrence. In nature some species grow well in forest shade, others grow well in the sun. There are species that reproduce themselves in deep forest, even with long periods when their roots are inundated with flood waters. Some require open sunny woodlands. PL 8 shows a species from Madagascar, growing in Bogor, Indonesia.

There are those which inhabit soils black with humus, and others that do well in sands. In some, acid soils seem more favourable and, in others, alkalinity seems to be no disadvantage. Some seem well used to extremes of heavy rainfall, and others are adapted to almost desert conditions. Knowing these facts, among others, has made the coffee specialist the more interested to learn the physiological reactions of his plants, as they lead to an understanding of growth, fertilizer, and adaptation problems. These are physiological problems. Much of the physiological research has been accomplished on Arabica coffee, although there has been a great deal done with Robusta. Some of the significant physiological findings are reviewed here, in the hope that they may provide for fuller understanding of the growing crop.

PHYSIOLOGY OF PHOTOSYNTHESIS

There has long been controversy about the limiting conditions for photosynthesis in coffee. The necessity for shade growing is of popular belief, due to the knowledge that much coffee grows in shade. However, there is the equal realization that much more than half of the producing coffee trees in the world are grown in full sunlight. There is argument on the side of shade growers, who believe that taste quality from shade coffee is the best, that shaded trees are healthier, and that shade plantations last longer than those in the sun. The growers who have their trees in the sun consider that their trees are sufficiently healthy to be satisfactory, they are learning that quality is not lower, and that the economics are better because of the larger quantities more easily produced. They also contend that, properly handled, their fields should be about as long-lasting as could be expected anywhere, or that not too much is lost after 10 or so years.

Some of the greatest planters of their time were coffee men of Ceylon, which was, in one epoch, the largest producer of coffee in the world. Typical planting in that island was in the sun. In old Mexico, as in many countries, coffee growing started in the sun; but there are problems connected with it. It has been shown by Franco (1947,1952) and Franco & Inforzato (1950,1951), that Arabica coflFee in Brazil is grown in the sun, not because it grows better there than under the shade, but because the margin of moisture in the soil is too narrow for growing both coffee and shade trees intermixed in the same field. The 'choice' of sun growing in Brazil is no choice at all. It is simply what has to be done, and is apparently a moisture relationship and not a light problem. The situation, on analysis, would quite likely prove to be the same for sun-grown coffee in dry parts of India, Madagascar, Kenya, Ruanda-Urundi, French Cameroons, Sudan, and Angola. Coffee planters in these and many other sun coffee areas are also much concerned with the reason why coffee grows successfully in the sun when, by some, it is traditionally considered a shade plant. It is likewise of interest that in Angola the Arabica is grown entirely in the sun, while Canephora is shade grown—although in Central America it is held that Arabica is a shade-adapted tree and that Canephora is better grown in the sun.

In some instances, data have been secured showing that shade is a good thing. For example, some years ago Guiscafre-Arrillaga & Gomez (1942) and Machado (1946) presented data showing that Arabica grew better and produced more in partial shade than in full sun. More recently Vallaeys (1954) has reported that Robusta coffee exhibits a strong preference for shading where possible. There are others who have come to similar conclusions, working in many countries. In addition, it has long been known that Arabica and Robusta were both originally lower-story, shade tolerating trees of spontaneous occurrence in African woodlands. All such information has led to the conclusion that coflfee is adaptable to partial shade conditions. Some of this conclusion follows analogy, that a small tree which is an inhabitant of dense forests must need shade. It was shown by Jacob (1938) that Robusta coffee was what he called a weakly evaporating plant, and naturally adapted to shade. Leaves wilted and the stomata closed quickly in direct insolation, the sun increasing the leaf temperature at noon by V5°C. over the air. When a coflfee tree that had always grown in the sun was compared with one that had always grown in the shade, the shade tree evaporated less water than the sun plant. This, in itself, could have a marked effect on photosynthesis.

A series of intensive studies on the problem of photosynthesis have been carried out on coffee. As is well known, when leaf stomata, the 'breathing pores', are opened, the coffee tree both loses moisture and takes in carbon dioxide and oxygen. There has to be a balanced interchange of elements, or carbohydrates are not developed and thus growth is halted. This important gaseous movement is found to be dependent on the opening and closing of the stomata. A number of researchers, such as Nutman (19370, 1937^), Franco (1938), J. Small & Maxwell (1939), and Alvim & Havis (1954) have found that, in Arabica coffee, the stomata ordinarily start opening early in the morning, just before sun-up, and close again late in the morning, towards noon, when light is most intense. By sundown the 'breathing pores', or stomata, are closed for the night. In strong sunlight it was found that stomata are open for a comparatively short time in the early part of the day, and that they soon close and stay closed for a much longer period than when in shade. The tightly closed stomata in sun-exposed leaves open quickly when shaded.

In studying rates of photosynthesis, Nutman found that they appeared to vary directly with light, and increased with increasing light, so long as light intensity was low. However, as soon as light intensity became high, the rate of photosynthesis was reduced to practically nothing. During a cloudless day he made studies of leaves on Arabica trees that were shaded and that were sun-exposed. He was able to secure data from both at the same time, to be compared under parallel conditions as can be seen from the accompanying table. It was found, for one thing, that assimilation rates were three times higher in moderately shaded coffee leaves than in those that had no shade.

TABLE II

RATE OF PHOTOSYNTHESIS AS INDICATED BY APPARENT ASSIMILATION OF CO2 BY ATTACHED LEAVES OF COFFEE (C. *arabicd)* UNDER VARIOUS CONDITIONS OF NATURAL ILLUMINATION

Condition of leaf	Time	Weather	Rate†
Unshaded	8 a.m. to 7 p.m.	Dull	1·9
Unshaded	All day	Very dull	0·9
Shaded	All day	Bright	1·4
Moderate shade	All day	Cloudless	2·1
Unshaded	All day	Cloudless	0·7
Unshaded	Second Minute	Dull sky	2·4
Unshaded	Fourth Minute	Dull sky	1·8
Unshaded	Sixth Minute	Sun	1·2
Unshaded	Eighth Minute	Sun	0·6
Unshaded	Tenth Minute	Sun	0·6
Unshaded	Twelfth Minute	Dull sky	1·2
Unshaded	Fourteenth Minute	Dull sky	2·4
Unshaded	Sixteenth Minute	Sun	1·2
Unshaded	Eighteenth Minute	Sun	0·6
Unshaded	Twentieth Minute	Variable sky	0·6
Shade	Twenty-second Minute	Sun	2·4
Shade	Twenty-fourth Minute	Sun	2·4
Shade	Twenty-sixth Minute	Sun	2·4

* Adapted from Tables I and III, Nutman (1937*a*). Work done in Africa.
† Rate—mg. CO_2/dm.^{2}/hour.

It was the opinion of Nutman, after further work (1937^), that maximum photosynthesis in coffee would be obtained in light of an intensity less than one-third of that of the midday sun. He found that, in an unshaded tree, photosynthesis started at dawn, but that leaves in full sun ceased photosynthesizing at near 9.00 in the morning as direct light intensity increased. These leaves did not begin photosynthesizing again until about 4.00 in the afternoon. It was also notable that the period of photosynthesis was clearly dependent upon the time the stomata were open. Moderate shading resulted in opened stomata and allowed the leaves to proceed with good rates of photosynthesis during the whole of the period of daylight. From one of his most interesting series of studies, using both whole trees and single leaves, Nutman found that photosynthesis was stopped by full sun. However, it could be started again at any time if the tree, or a single leaf under test, were shaded either artificially or by a passing cloud. Moreover, in sun-exposed leaves in which photosynthesis had been stopped, it could be started again in a very few minutes by shading.

It was likewise found that very dense shading resulted in great reduction in photosynthesis- Nutman concluded that Arabica leaves are sensitive to sunlight, and this would logically add to the reasoning that holds shade to be beneficial in coffee. In thinking of shade as an adjunct to coffee husbandry, Nutman regarded methods of shading as largely dependent upon local conditions. For example, there would certainly have to be enough moisture to grow both coffee and shade plants. Where there was sufficient cloudiness, extraneous shade would be unnecessary. In some regions, use of shade trees would lend the required advantage; where shade trees or reasonable cloudiness were absent, the grower would need to space, prune, and train the trees in his plantation to furnish self-shade. It can also be added that, in cases of necessity, where shade was important but natural shade could not grow along with coffee, artificial shades of mounted wood slats, split bamboo, or even metal screening might be employed, should economics permit. J. Small & Maxwell (1939) considered that their findings on the role of *pH.* in stomatal behaviour, gave added weight to Nutman's findings.

SHADE AND PHYSIOLOGY

When a plot of shaded Arabica coffee trees is observed growing beside a plot of unshaded trees, it is possible to see the much more intense green of leaves on shaded trees. Angelo (1937) described the chlorophyll complex in coffee beans. He extracted the various components from dry 'grain' in alcohol and found beta-chlorophyll at the concentration of 075 parts per 1,000. Grains before maturity contained 0-33 per 1,000 of xanthophyll and 0-16 per 1,000 of carotin. Unroasted beans contained leucophyll, chlorophyll, carotinoids, and anthocyanin. The importance of chlorophyll as the basis of photosynthesis is, of course, recognized. One of the problems in connection with photosynthesis deals with proofs of measurable differences in the relative amounts of chlorophyll produced in certain leaves growing in different light intensities. This has been studied with some care in Brazil by Franco (1941). He found that coffee leaves in full sun had a mean percentage of chlorophyll of only 0-176, those in the shade of a Gliricidia tree had 0*248 per cent, and the leaves from well inside coffee trees, that is to say shaded, had 0*338 per cent—nearly twice that in the sun. Results of such determinations are most interesting and add much to understanding of the shade problem. It is to be hoped that such studies as these will be carried further in other localities, under different conditions and with other techniques, and with other coffee species.

There is an altogether different method of study that estimates light effect on plants, and is known as determination of net assimilation rate, Plants are grown at different light intensities, and data are secured with respect to the increase in weight per unit of leaf area per unit of time. Such information was secured by Alvim (1953) on Arabica coffee of the Bourbon variety. This grows in Central America and produces well in the shade ; it also does well in the sun in Brazil. In one experimental series it was shown clearly that the highest rate of assimilation occurred at full light exposure, and the poorest at lowest light intensity. Intermediate exposures of light gave intermediate assimilation rates. The relationships were abundantly clear in this series. For unexplained reasons, a second series did not give such clear results. From plants under different shade treatments, counts were made of the number of leaf stomata, and it was determined that the numbers of those pores increased as light intensity increased. This seemed further indication that coffee leaf photosynthesis was more effective in well-illuminated than in shaded plants. All of these problems deserve re-study under varying conditions, and on several different coffee species and types.

Results of such studies as those discussed, indicate that Arabica trees growing in unshaded fields are certainly photosynthesizing more than those in shade. Personal observations are that about four or more times as many leaves develop on Arabica trees in the sun as in the shade. Unquestionably, much more carbohydrate must be produced in the sun than in the shade. Sun trees would be able to use more fertilizer and, if supplied, would grow more than trees in the shade. Judging from experimental results, leaves growing on the outside of coffee trees may be so fully sunned that, in some exposures, they may be forced to close their stomata early. It is true that such leaves may be practically valueless as photosynthetic organs. However, those more to the inside, with sufficient self-shade, would be the ones acting more vigorously. Coffee leaves will orientate themselves towards the light, as any observer knows, and as has been well described by Arndt (1929). This may be a means of increasing efficiency in the use of available light, if leaves are inside the tree. In sun, as leaves develop exposed on branch tips, they will have more stomata than if they had developed in shade. Leaves keep the stomata that formed in the beginning, and the sun-grown leaves with their larger number of stomata, become shaded later on. Once they have the benefit of self-shading, the stomata are functional and these leaves may be even more efficient photosynthetic organs, with their larger number of stomata, than if they had grown from the first in a more protected environment. This point needs proof or clear refutation.

SUN AND PHYSIOLOGY

Theoretically, the general good effect of sunlight on Arabica coffee, under desirable environments, would seem to be to insure greater absorption of nutrients. It would appear that coffee-tree metabolism is increased in the sun. Working in Hawaii, with trees under partially controlled conditions, Tanada (1945*a*, 1946) found that heavy shading increased the size of leaves but that they were fewer per plant and, in reality, tree growth was decreased. In parallel series, trees in full sunlight had larger trunks and larger root systems. At the same time, intermediate leaf shading increased the total content of nitrogen, but decreased dry matter and carbohydrates, with a tendency toward an increase in potassium, calcium, and phosphorus. The effects of increase in potash, and its importance, will be discussed below.

When Tanada withheld nitrogen from his trees, there was a decreased nitrogen content in leaves and stems, and when studied under heavy, medium, and no shade, these nitrogen-starved trees showed less differences under the different light-intensities. He also found that a good proportion of the nitrogen demonstrated as present in coffee leaves is apparently storage nitrogen. This could be readily increased by adding nitrogen fertilizer. The storage nitrogen could be called upon by the rest of the tree, taking it from the leaves when it was not available at the roots.

With good, but not excessive, shade the soluble nitrogen increased in the foliage, and it decreased in unshaded leaves. With no nitrate present at the roots, it was quickly used up by the plant, but when it was supplied again it was just as readily put back into the leaves. With the presence of an excess of nitrogen, the degree of accumulation was more or less dependent upon the amount of solar energy available to the plant. A long time previous to this, it had been shown by Jacob (1939), in his studies in Java on nitrogen absorption in Robusta coffee, that, under too much shade, there was seriously reduced carbohydrate formation and, in consequence, poorer use of the ammonium compounds. This resulted in actual tissue injury that caused leaf symptoms, apparently from release of the excess ammonium-ion.

CHEMICAL METABOLISM

A common symptom of unbalanced physiology *(see* Schweizer, 1940) in many coffee countries is yellowing, often accompanied by blackened beans. This is said, in some cases, to be a nitrogen situation. It has been found that if there is a relatively small amount of soluble nitrogen in the leaves, in comparison with the insoluble protein nitrogen, they will yellow. At the season of yellowing, if the trees are in bearing, green, and normal, the phosphorus, nitrogen, and potash should be at their maximum concentration in the trees. As the leaves yellow, the phosphorus and nitrogen decrease until the rime when the leaves are ready to fall. Meanwhile, potash has greatly increased in the leaves; in fact potash has been drawn from the fruits and stem back into the leaves.

The leaves are storage organs, while fruiting branches are structures of reproduction, which have tissues that are specially susceptible to potash exhaustion. Schweizer *(q.v.)* showed that potash was stored in the coffee leaf, but that it moved from fruits to leaves, and later from leaves to fruit-branch tissues, after which the leaves fell. Potash metabolism apparently is not carried on as rapidly as is that of nitrogen. Edwards *et al* (1936) had found, during six years of fertilizing, that potash was markedly absorbed into both the pulp and bean of coffee. Following this, Dean *et al* (1941) demonstrated that even with heavy chemical applications the good effect of adequate potash was not felt until the second year. Potash is so absorbed, that it shows a positive correlation with calcium. In all the studies of these problems, it was repeatedly shown that the occurrence of a poor supply of potash invariably resulted in tissue collapse of coffee branches, and consequent so-called 'die-back'. Tanada's demonstration that moderate shade tended to decrease potash loss in leaves, may indicate one reason why shade culture is effective in a more balanced fruiting rhythm, and that die-back is reduced under these conditions.

Along these same lines, studies had been going on in Java on Robusta coffee, that added confirmation to results on Arabica that have just been discussed. Roelofsen & Coolhaas (1940) also proved that potash was of the utmost importance in the plant. As a young leaf became full grown it was taking up all the main elements, and especially absorbed nitrogen and potash until the tissues were hard and mature. These leaves of Robusta, as with Arabica, acted as storage organs. Afterwards, as the fruit crop progressed, the leaves gave up the elements more or less as they were required. Phosphoric acid was continually being released for translocation, while calcium, magnesium, iron, and manganese were accumulated up to the very last. The quantity of the major elements left in the leaves varied in proportion to the increased development of fruits.

Relatively speaking, the leaf had a minimum amount of nitrogen, phosphorus, and potash at the time coffee cherries were ripening. These chemicals had all been transferred to the fruits. Results indicating what was found in a fruit-bearing branch are of utmost interest. These researchers determined that the fruits on the branch took up 75 per cent of the total potash in the whole branch, and 65 per cent of the total phosphoric acid and nitrogen. Fruits also were 60 per cent of the total dry-weight; they contained 60 per cent of the carbon, 40 of the magnesium, 40 of the manganese, 30 of the iron, and 15 of the calcium.

Studies on the course of changes in the nutrition of Robusta coffee are now in serious progress in French Equatorial Africa. From a recent publication, using methods of foliar analysis *(see* Busch, 1956) of mature Robusta coffee in the Central Ubangui, seasonal effects were given considerable attention along with tree growth. With respect to leaf nitrogen, it was found to be directly related to rainfall, and, in general, soil applications were not followed by rapid perceptible absorption into the leaf. Effects from phosphorus were much the same as noted with nitrogen, but soil applications, during the season when leaf phosphorus was being increased, added phosphorus to leaf storage. As found by several others, leaf potash was found to be low during fruit-set and subsequent growth of the cherries; leaf potash was stored most during the time when no fruit was on the tree. It was further demonstrated that the best time to apply potash was when leaf potash was highest, that is, some time following the end of harvest. But applied in considerable quantities, potash depressed magnesium absorption, and thus caused severe leaf-fall and other physiological disturbances. This could be avoided by not applying excessive amounts of potash at one time. The most efficient absorption of nitrogen and potash could be obtained by nutrient application at the beginning of the rainy season and again when the dry season had become well established. Phosphorus was best absorbed during the early part of the rains, and was of less value if added during the dry season.

A short but significant report by Cooil *et al.* (1948) is of special interest at this point. These researchers, again in Hawaii and working on Arabica, had corroborated the findings of many others that die-back of trees was the result of excessively heavy fruit production. They had also found that to produce good crops of coffee there had to be a fully adequate potash content in the soil, but that one 'good' crop could still be produced at a certain median level of potash. However, if the potassium present were not a little more than this, there could not be a continued optimum in both growth and yield, going on as they should, then and later.

Using monthly leaf analyses, they found that there were marked seasonal trends in the amounts of chemical constituents in the leaves. Nitrogen and potash were at a maximum after the middle of the year and then these components declined. The trees had flowered and set fruit, and it was during this period of decrease in leaf nitrogen and potash that cherries were being formed and maturing and, therefore, using these nutrients It was likewise of great interest that, after harvest and growth had again taken place, the potash content of the soil was positively correlated with growth in the length of fruiting branches. These branches, as they were growing, apparently stored potassium, did the leaves, in preparation for fruiting the following year. The better fruit branches combined storage of chemicals that came from the soil, with building of a carbohydrate reserve. This developed best though their increased photosynthetic surfaces resulting from the more vigorous foliage.

The efficiency of photosynthesis in coffee, as in any other crop, has a direct effect on increased production. There are only a few isolated studies on record, some of which are reviewed here, involving observations on production as related to leaves. Sturdy (1935) saw that shading leaves of Arabica increased the crop produced by 83.3 per cent. Shade also increased total leaf area per branch by 20.5 per cent. From a study of overbearing and consequent die-back in coffee, a trouble said to be due to an unbalanced condition of too low carbohydrate production, it was learned by Perkins (1948*a*) that Bordeaux-mixture-sprayed trees were Better producers. Of course, this was in some measure due to disease control, but it is known that this fungicide also acts as a partial shade. Whatever happened, even if there was disease control as well, the addition of carbohydrate materials in the shaded foliage would have given improved results. This might well have been from partial shade due to applying Bordeaux. Schweizer (1940) found in Canephora coffee, of the variety Robusta, that a low quotient between number of leaves and the crop followed when there was early leaf-fall, before fruit ripening, and, therefore, poor carbohydrate production. A high quotient of leaf to crop was the result of leaves hanging on for a longer period, remaining green and in physiologically good condition. Consumption of carbohydrates was very great during the period when the cherry was turning red, but if there was sufficient leaf surface retained, a branch could hold its fruit and, furthermore, mature wood for the next crop.

PHOTOPERIODISM IN COFFEE

It was but a step from a study of photosynthesis to that of the photoperiodism of coffee. To be sure, the only coffee used in this, so far, has been Arabica, and, at that, varieties of the noble strain. This strain is grown commercially under wide differences in day length, in a wide range of the tropics. It is grown outdoors, with some difficulty, in the southern part of Florida, U.S.A., and commercially as far north as Formosa and the West Indies at the Tropic of Cancer; from such northern parallels it extends southwards over the Equator, past and below the Tropic of Capricorn, to more than 26 degrees south in Brazil (Fig. 3). Over this geographical band, where coffee is grown commercially, the length of day varies from about 13 1/2 to 10 1/2 hours, with 12 always on the Equator.

The species C. *arabica* is believed to have originated in a region about 10 degrees north of the Equator. At certain times there, the length of day is just a little less than 11 hours. From the works of Franco (1940), and of Piringer & Borthwick (1955), the early indications were that the common Arabica coffee required less than 12 hours daily to flower. In the more detailed studies of the latter workers, trees were kept at 21°C. under day lengths of 8,12,14, and 18 hours. It was learned that flower buds developed in 2 1/2 months in 8-hour plants, the 12-hour plants required 3 months, while none developed at 14 and 18 hours. Further special tests disclosed that the critical day length was between 13 and 14 hours, since longer than this resulted in nothing but vegetative growth, while at this and somewhat shorter day-lengths flowers were induced. The effect of continual vegetative growth and no flowering was to increase the numbers of nodes and the lengths between nodes on the lateral branches.

In the work of Went (1955), performed in greenhouses in California, the results might be considered as a little different. He found that an Arabica variety, Semperflorens, had an intermediate day length covering long- as well as short-days, as it initiated flower buds at the 8-, 12-, and 16-hour day lengths. However, the three varieties selected in Brazil for their conditions, Bourbon Vermelho, Caturra, and Mundo Novo, all flowered at a photoperiod of 8 hours, and not at 12 or 16. In the greenhouse they flowered in November, which was about the 12-hour day in California. It is certain, from what I have seen, that in Turrialba, Costa Rica, all the three Brazilian varieties mentioned flower well in days of over 11 hours. Curiously enough, in Went's work all of the three special Brazilian varieties produced a few buds when subjected to the extreme condition of continuous illumination. These studies suggest Arabica coffee as an intermediate- to short-day plant, although not clearly a short-day type. It can be seen that there is still much work to be done on this problem in coffee, using various species and varieties, obtained from widely separate day¬lengtn areas.

FLOWER RESPONSES

It appears, as well, that successful flowering is not altogether a photoperiodic response. There are other important related factors. Hacquart (1941) worked with data secured from plantings on both sides of the Equator, under various times of rainfall and other climatic changes. He, as well as van der Meulen (1939), Boiteau (1941), and many others, had concluded that flowering was dependent on the coming of rains. The popular recognition of this is implicit in the planter's phrase 'blossom showers', that is heard in various languages in various countries. In more and more studies, the flowering factor seems of greater complexity than simple water-relations in the tissues. There appears to be a shock effect that may be induced by several environmental changes. The most common of these still appears to be the 'showers'.

In some regions blossoming appears that is abnormal. At times these unwanted flowers are so numerous as to give planters a great deal of concern about the season's crop, because such flowers seldom set fruit. It was found by several (e.g. Perkins, 1947; Cramer, 1957; K. M. Thomas, 1950; Mes, 1955; Went, 1955; Gilbert, 1946; Wilson Mayne, 1935; and others) that there are many factors involved, both before and at the time of flowering. Among them are internal water content of the tree, nature of the plantation cultivation, variations in shade intensity, severe strains the previous year from excessive fruit production, occurrence of distinct and extended dry periods, and temperature fluctuations. These last, along with an effective length of day, were studied by Went in greenhouses under carefully controlled conditions. At a warm 26°C. day and a cool night of 23^0 to 20°, or a cool day of 23^0 and a cooler night of 20^0 to 17^0, there were many flower buds formed, many producing normal flowers, and many fruits set. Arabica grown at a hot, 30°C. day temperature and a warm 26^0 night produced a few flower buds but all had abnormal flowers.

These abnormal flowers are what are often called 'star', 'sterretje, 'estrella', 'virescent', or 'atrophied' blooms. Under controlled temperature conditions, Went (1955) found that if days were kept warm at 26º or 23ºC, with nights also warm at 26^0, buds formed but flowers were mostly abnormal, with little to no fruit-set. Such temperature effects seemed especially applicable to flower development, since leaf and shoot growth was satisfactory. But temperature is not all that counts. It has been found in Turrialba, Costa Rica, that there is considerable variation between varieties in star flower formation. This is an observation in which both Sylvain and I came to identical conclusions without knowing of the other's observations. Certain Arabicas recently imported from Ethiopia seemed specially resistant to this abnormality.

In some early work on this problem of abnormal flowers, Cramer (1910) concluded, after several years of observation, that it was due to one or all of six causes: a previous season's unusually large amount of fruiting, flower opening during an unusually wet period, drought at the wrong time, excessively rapid thinning of shade, poor soil fertility, or excess of soil moisture. There were numerous observations following the appearance of the publication by Cramer. The later observers indicated that star flowers were possibly due to water stress, poor light relations, heavy rains, excess cloudiness, and low temperatures. Porteres (1946) and Bouriquet *et al* (1954) analysed these observations, concluding that floral atrophy resulted from trees being put into environments unsuited to the species. They believed that probably selective adaptation would ameliorate this 'physio-ecologic' trouble.

TEMPERATURE EFFECTS ON COFFEE

As would be expected, temperature affects more things than flowering. One obvious effect is that Arabica coffee, at least, cannot stand freezing. But there are other growing temperature relations. An example of what has been noted by numerous workers can be cited in the excellent observations of McDonald (1930). He concluded that in a cold climate growth was slow, accompanied by development of more secondary and tertiary branches, while 'normal growth' developed in a mild climate, and in a hot climate there was little secondary or tertiary growth. It was stated by Alvarez-Garcia (1945) that coffee seedlings he had under greenhouse-controlled temperatures between 20° and 32°C, developed best in the warmer houses. Years later, Mes (1955) worked with 3-year-old trees under controlled temperatures, measuring amounts of growth. In a cool day and cool night, 20° and I7°C., respectively, or slightly warmer day and night (26° and 23^0), growth was practically the same. A warmer day of 30^0 was vegetatively unfavourable, as was a continuous cool day of 14^0 or below. A continuously warm condition, 30^0 day and 24° night, produced sickly-looking trees with excessive upright or orthotopic shoot development.

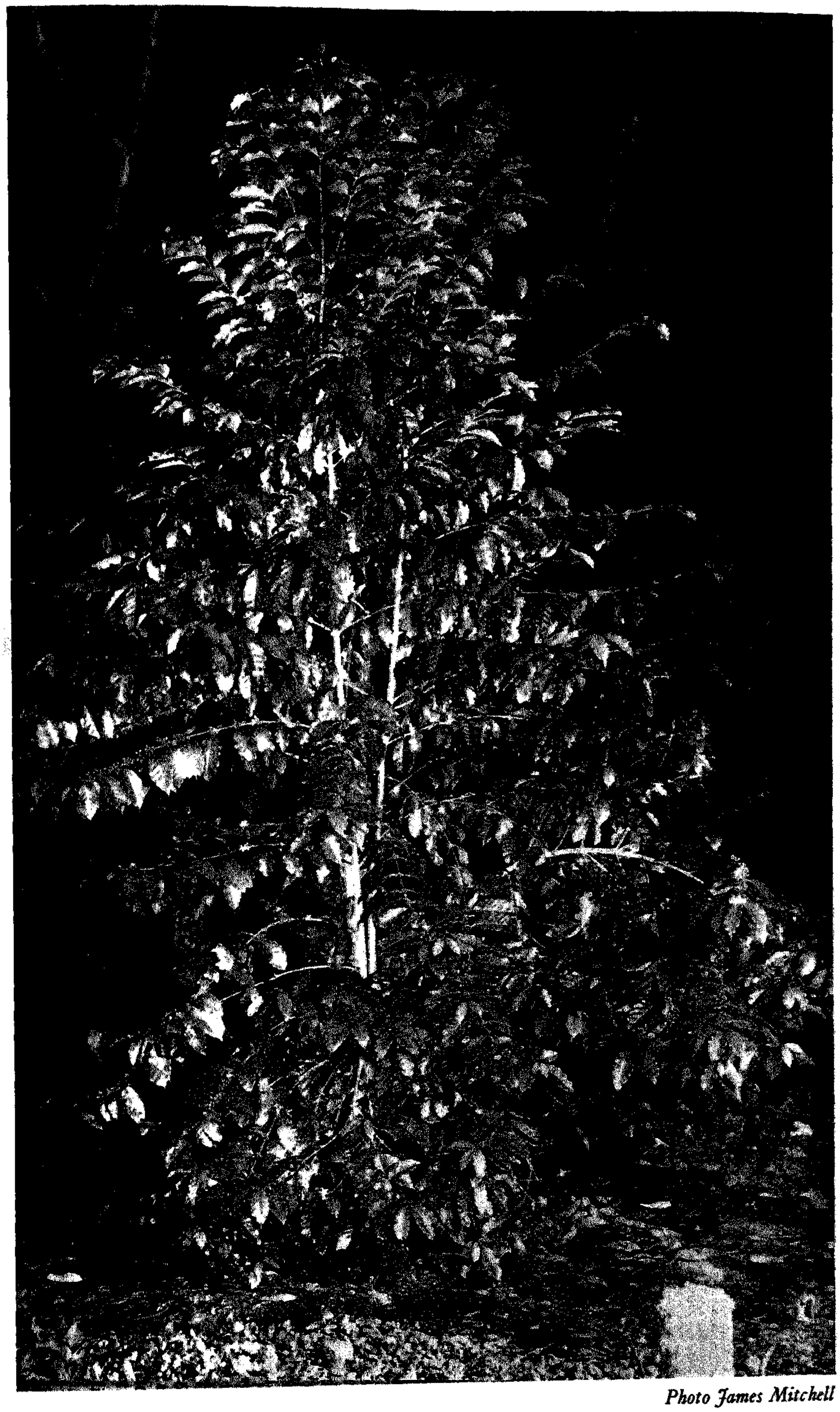


Photo James Mitchell

PLATE 9. - Tree of Arabica, of the variety Bourbon (over 2 m. high), showing the study growth. The laterals are thicker and held more upright than in Typica, and the tip oi tue tree tends to be flattened. Guatemala.

Since Arabica does not respond well in flowering or vegetative growth to heat, it seems of special interest that high temperatures are good for seed germination. Some years ago, Toole & Toole*, working with constant temperature incubators, found that Axabica seeds germinated best at 28^0 and 30°C. It was reported by Mes (1955), that, at temperatures of 14º to 32°C, there were most rapid first germinations of 6 or 7 days, and half the seeds germinated in another 2 days, at 28º to 32º. At 17º it took 22 days for the first germinations, and half the seeds had germinated in 26 days. This worker considered the optimum temperature to be probably 26°C, where first germinations took 8 days and in 2 more days over half had germinated. Mes also studied root growth of young seedlings and reported the optimum to extend over the fairly wide range of 26º to 32°C. Even at 23°C, the roots grew only half as fast, and at the cooler 20º and 17º temperatures, extension was very much slower. Within reason, warmth was good for roots.

On the other hand, Mes (1955) found that excessive orthotopic shoots developed on trees exposed to long periods of heat. This would indicate deranging effects on the action of regulatory growth hormones in Arabica. Field differences are also seen in various climatic zones. However, it may be that temperature is not the only factor involved. For example, 1 found in Turrialba, Costa Rica, where mean temperatures do not vary excessively during the year, that I could induce excess orthotopic shoots by complete defoliation of mature trees during the months of November through February. Strictly comparable trees defoliated in April, May, and June had few orthotopic shoots. This may be related to length of day.

AUXINS AND GROWTH

My observations since have shown me that vigorous Arabica trees develop larger, more vigorous buds on the stronger growth of lateral branches that are initiated around the turn of the year under Turrialba conditions. Study of literature (e.g. Rayner, 1946*a*) has shown that such differences occur elsewhere, and advantage has been taken of this in grafting operations in Indonesia. There the horticulturists differentiate carefully between the more vigorous 'fan' scions and the apparently weaker 'whip' scions, for multiplication from their clonal coffee varieties. It was pointed out by Coolhaas *et al* (1939) that, when graftings were made with Tan' scions, the old trees upon which they were inserted were forthwith strengthened and stimulated both vegetatively and in fruiting. The 'whip' scions resulted in much inferior growth. A branch part that would be a 'whip' scion, could be turned into a 'fan' by treatments that increased the tree's vigour. The phenomena respecting orthotopic shoot development and the difference between 'fan' and 'whip' branches deserve some careful

* Personal communication. Dr. and Mrs Eben H TooleILSBant Industry Station, United States Department of Agriculture, Beltsville, Maryland, U.S.A.

study of the growth-regulating substances involved. The so-called 'growth-promoting' substances or 'auxins' have effects in the rooting of coffee. Roelofsen & Coolhaas (1939) found that roots from upright or orthotropic cuttings of Robusta coffee penetrated downwards into the soil, while the side branch or plagiotropic cuttings pushed out roots more horizontally. D. R. Fiester made similar cuttings of Arabica in Turrialba, Costa Rica, and I have observed the same rooting phenomena, of side-roots from fruit branches and tap-roots from orthotropic stems, in cuttings from Arabica. Dutch workers have also produced improved rooting of cuttings by auxin applications.

Certain auxins are, supposedly, quite common in mammalian urine. Extracts of it were proved in India to increase coffee rooting. K. M. Thomas (1949[a]) reported that it gave 87.6 per cent rooting, while phenylacetic acid gave 75.2, indolebutyric acid 62.9, and untreated 61. It was proved by Gillett & Jackson (1937) that indoleacetic acid stimulated root development. Such findings have been made by others, too. Light, which affects growth substances or auxins, also effects rooting. Franco (1940) found that Arabica plants under a long-day produced some five times the amount of roots as compared with plants in short-day illumination. In shade studies, Machado (1946) has shown that seedlings in either sun or shade produce about the same feeding roots, but the deeper, more mechanical or anchoring roots are about doubled in number in full-sun plants as compared with those shaded. Sylvain[#] has also found distinct differences both in root and branch habits in sun and *in* shade, and this adds to the conclusion that the differences are, at least partly, of hormonal effect.

[#] Personal communication from P. G. Sylvain, detailing findings on coffee seedlings under about two-thirds shade in comparison with those in full sun. This was from work done by him in 1951 on nursery seedlings of C. *arabica*.

V

IMPORTANT SPECIES OF COFFEE IN COMMERCE

THERE are many species of coffee, but in Malaya, places in the Philippines, and in parts of Africa, the planter may think of coffee as only from the beans out of the coarse, large cherries from his trees with the large, dark green, leathery leaves. This is the sturdy and tall, strong-growing Liberica or 'Liberian' coffee and its relative Excelsa. It is also true that when one talks to plantation owners from Java, Angola, French Equatorial Africa, or the middle Congo, one may gain from them an impression that, in the main, coffee is from the Canephora or 'Robusta' trees. These are medium-sized trees, with light green leaves, that bear small, red cherries. On the other hand, there are places in Africa, India, Central America and, above all, in Brazil, where the planter never thinks of anything but his Arabica species, or varieties of it. These are the smaller, beautiful trees, with handsome green leaves and juicy red fruits.

NUMBER OF SPECIES USED BY MAN

It has already been pointed out that the genus *Coffea* is made up of possibly a hundred species, although only about sixty may be recognized by some botanists. The genus has not received as much attention as botanists should give it. In fact, considering the pre-eminent importance of the crop to the tropical world, it is surprising to learn of the relatively modest amount of detailed botanical study expended on it. Partly this is because, whereas a few highly competent botanists have made intensive studies of herbarium and growing materials, it appears that, even before the ending of their work, the urgency of matters of practice excluded the much further morphological study, physiological investigation, and botanical exploration that the genus so richly deserves. Again it is always to be remembered that wild coffees, which are our botanical subjects, are commonly inhabitants of almost inpenetrable growths, and great physical difficulties must be endured to secure them for study. Most trees of the tropics do not grow in great numbers in pure stands but are mixed with multitudes of other tree species. This means that great areas have to be traversed by the botanist, over difficult and often dangerous terrain, through thick and unpleasant growth. Jungles are far away from growing collections, exhaustive libraries, and herbaria for comparative, studies. What has been done botanically for *Coffea* in the field is due to herculean efforts.

As has already been stated above, the botanical organization of the genus is still somewhat unsettled. A review of discussions and descriptions of species in the genus shows that many of the species are not important commercially. The majority are unused by man. From analyses of several published monographic treatments of coffee, there are evidently a number of species that are of some commercial use restricted either locally or in the world market. In the studies of Chevalier (1942, 1947) there seem to be about 16 species thus listed. Haarer (1956) lists 17. In the book by Cheney (1925) the number in use is 19, while Zimmermann (1928) believed this number to be about 16 distinct species. This does not take into account as separate entities the very many different varieties, hybrids, and clones that are used. Also, no one has ever attempted an exhaustive study of the full list of all coffees used by aborigines and indigenous peoples in Africa and the Orient. It will probably never be possible to know all the wild, otherwise commonly considered useless, species that are or have been harvested and used as acceptable adulterations. This has occurred and may still be going on at the less supervised shipping points.

THE COFFEES OF COMMERCE

It is easy to realize that much poor coffee has been put into commerce during the centuries, as well as much good. In times past, coffee buying for shipping has been an unscrupulous game. Nevertheless, there has grown up a dependability on markets for the major requirements of good commercial coffees. This was inevitable, else the coffee growing business would have disappeared. A food product, to be popular, if it does not fill hungry stomachs, must be stable and good. One of the Special requirements of a good coffee has been its carrying of a reasonably satisfying quantity of the stimulating caffeine. When, on roasting, a change in the coffee bean results, that is delightful and distinctive in flavour, this character becomes associated through experience with the useful, pleasing, and harmless stimulus. When all this is from a tree that can be adapted to a not too greatly expensive culture, and can be produced in large quantity, it makes a highly valuable combination. In horticultural adaptability of any world crop, there must be included, in addition to ease of growing and harvesting, dependable yearly productivity, disease and pest resistance, and, as the crop's history lengthens, relative malleability of the plant through environment and genetics. Probably the most obvious key characteristic in such a crop as coffee is its flavour. It may be the one character that overshadows all others.

However all that may be, coffee was apparently first used for human consumption as a product taken from the jungle. I have seen, both in Uganda and in the Congo, how coffee is gathered for special reasons directly from the jungle. In Ethiopia, the natural 'coffee forests' are,

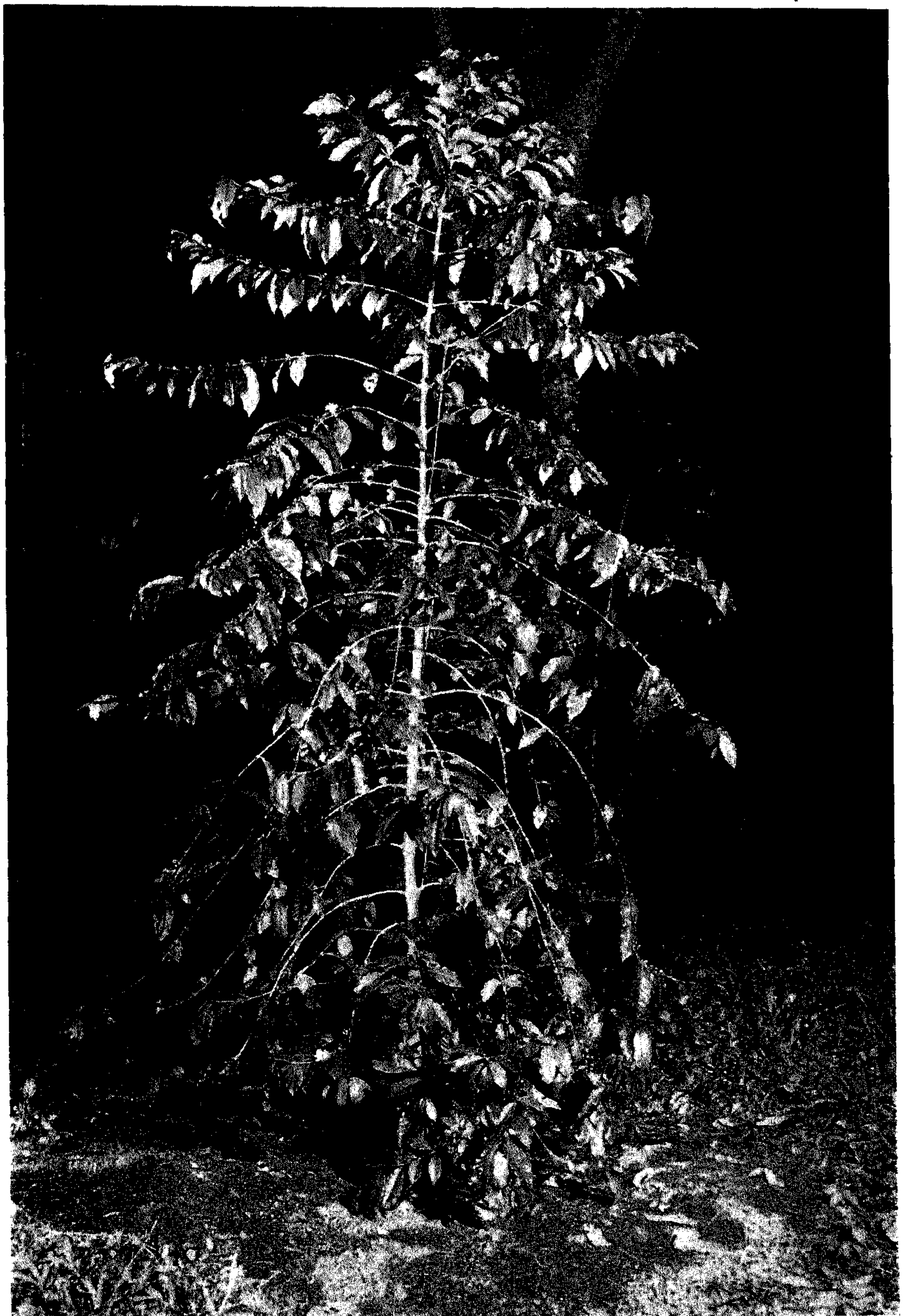


Photo James Mitchell

PLATE 10.—Tree of Arabica, of the variety Typica (about 2 m. high), showing the rather slender growth. The laterals droop readily, and the tip of the tree has a tendency to form a conical point. Guatemala.

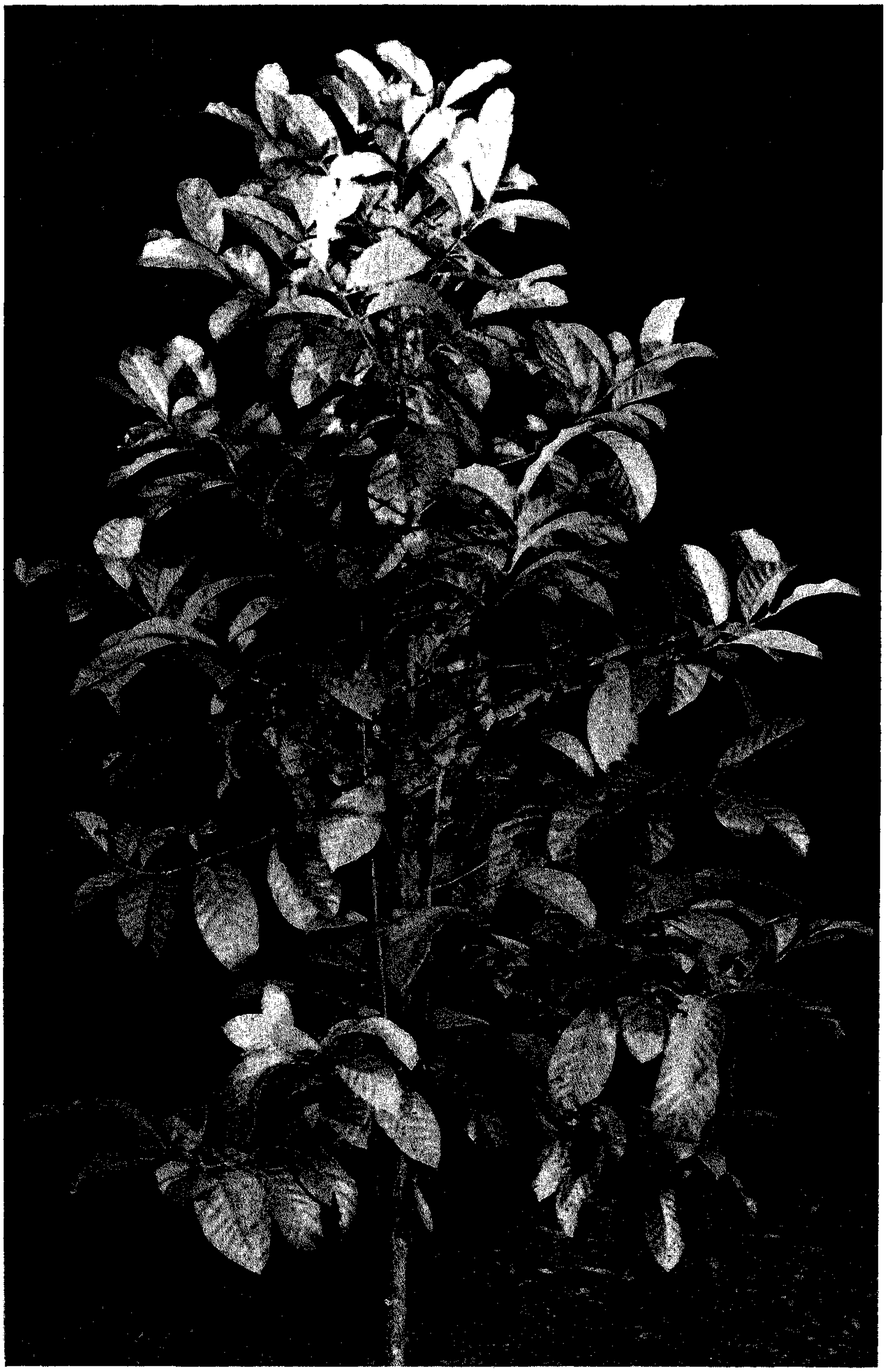


Photo James Mitchell

PLATE 11.—A young tree of Liberica coffee. It grows to be a large tree in the wild. The leaves (mature examples 25-35 cm. long) are large and leathery. Guatemala.

even today, a large source of coffee collected from uncultivated trees and exported from that country. I have been given descriptions by eyewitnesses of the way the native peoples in Madagascar and Mozambique gather coffee berries from wild species of bushes that are very different from any grown commercially. I was told in Angola that coffee used by the natives there mostly came from forest trees, and some from those that had escaped or were naturalized. However, on the whole, the coffee of commerce is a cultivated crop.

By far the most important species of cultivated coffees are, first C. *arabica*, next C. *canephora*, with C. *liberica* and C. *excelsa* combined as a poor third in popularity. There are numerous fundamental differences between these species. One of the most notable is size of seed. A pound of Arabica contains approximately 1,200 dry seeds, a pound of Canephora approximately 1,600, and one of Liberica about 800. The immense success of these three species, together with a few related ones that are used but are only of minor importance, and the numbers of wholly wild species that are little known outside of botanical descriptions, is somewhat reminiscent of certain other great horticultural bush and tree crops. There is, for example, the genus *Pyrus* that contains the apple and the pear, with their numerous less used relatives and those that are only wild members. There are the sweet and sour cherries, crops of immense antiquity and of once common ancestry, and their numerous, nearly related but almost never grown, close congeneric allies. Only in rare instances has an extremely popular tree crop come out of a single species that has thus become widely known, as in the avocado. Coffee is one of the newest comers under the horticultural hand of domesticated man and, for a long time, the species C. *arabica* was the only one known in cultivation.

Along with early commercial use of Arabica, was the collection and sale of the very small but exquisitely flavoured grains of the dwarf-growing Mokka coffee bushes that probably originated in Ethiopia but were grown in fields in Arabia, the shipping point being the old port of Mocha. Fuchs (1886) claimed that the first coffee to come from Arabia was this same exquisite Mokka. There is some botanical argument as to whether *Coffea mokka* Cramer, in the sense described by Cramer (1913), deserves to be set aside as a species separate from C. *arabica*. There has, likewise, been the same kind of argument among fruit specialists respecting the true separability of *Prunus avium* L., the sweet cherry, and its close relative P. *cerasus* L., the sour cherry. There are such arguments over *Vaccinium angustifolium* Ait., the low-bush blueberry, and *V. vaccilans* Soland., the huckleberry. Similar professional debate has arisen in connection with species or variety nomenclature among several other horticultural crops. C. *mokka* shows as good differentiation from C. *arabica* as do closely related species in many crops. Its capacity to cross with C. *arabica* is no valid reason, in itself, for considering it the same species, as numerous interspecific crosses are known. When results of crosses between *C. mokka* and *C. arabica* are studied, they behave in a manner characteristic of other interspecific crosses (Cramer, 1957).

The important point is that Mokka is markedly different from Arabica, and is a rare but unusually line coffee that looks, grows, and tastes unlike any of the Arabicas. Mokka was, and is, gathered from low bushes developing under very dry conditions. The well established word "moka" or 'mocha', as a synonym of this superlative beverage in literature and commerce, reaches back to the thirteenth century and doubtless earlier. In those days, bags of the small grains were exported from Arabia Felix for the delight of the great in late medieval Europe and the countries of the Middle East. There is also another coffee of somewhat similar nature. This species, *C. stenophylla* G. Don, was first used, however, in more recent times. Its commercial development has not progressed far. It is grown largely in Sierre Leone and near-by West Africa, The tree has a rather slender habit and is highly resistant to rust. The fruits are relatively small, black in colour, the grains are not large, but the liquor quality from them is said to be excellent. It grows well in semi-desert at low elevations and in reasonably moist areas in fairly high locations. Neither the Mokka nor the Stenophylla coffees are heavy bearers, yet both have characteristics that should attract more horticultural eyes as the years progress.

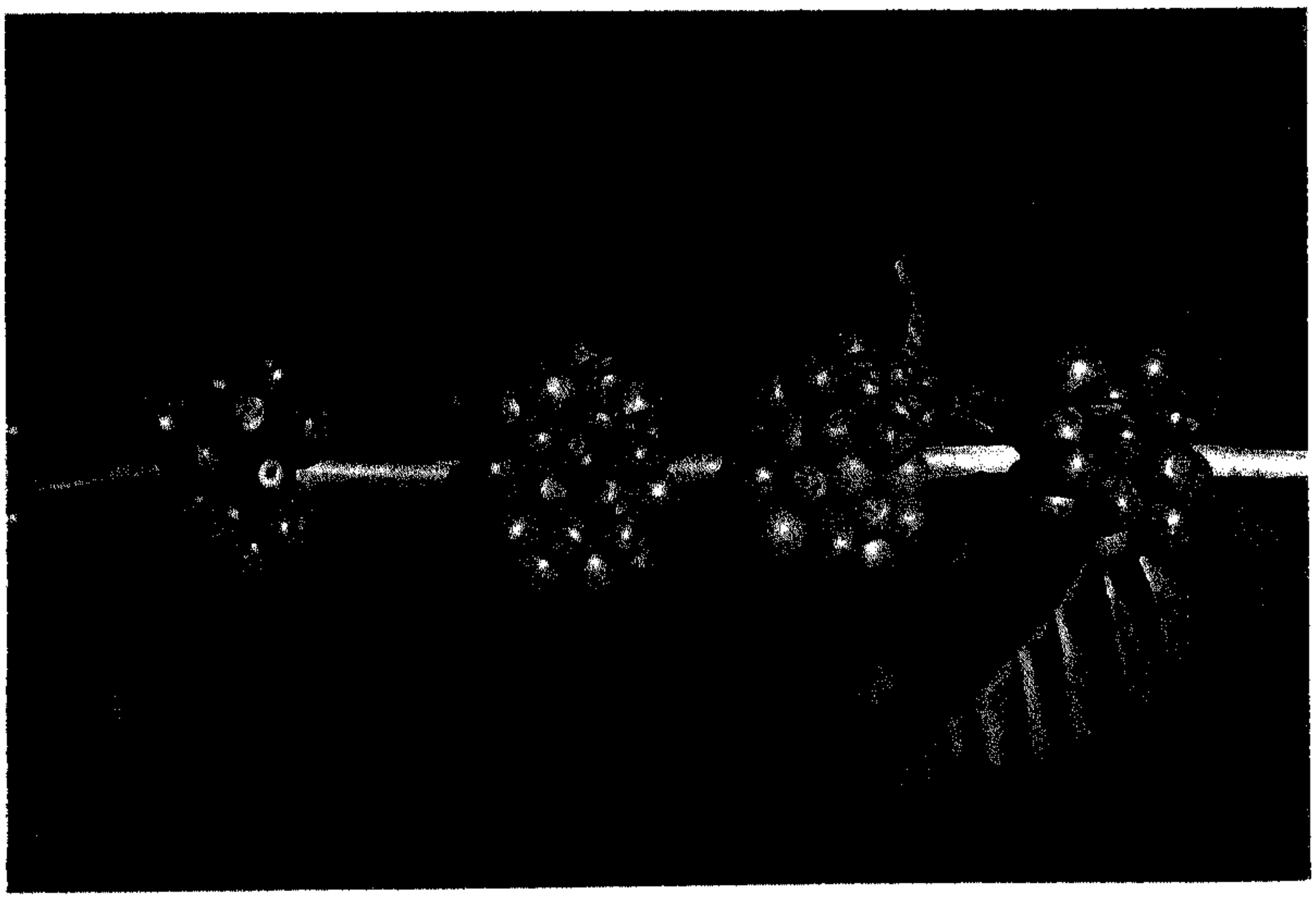
There are two other species of little commercial value but somewhat close to Arahica for quality, that have minor usages. One is *C. mauritiana* Lam., a relatively tall tree, and once said to grow in numbers on the island of Reunion. Its special characters are tolerance of rust and vigorous growth under rather crude conditions of cultivation, Another interesting species, close to Arabica in appearance and quality, but more resistant to hemileia, is *C. congensis* Froehn.—quite separate and distinct from the rugged, large-leafed variety 'Congensis', a hybrid of this species with *C. canephora.* Trees of the true species *C. congensis* are relatively delicate, may be from 3 to 12 ft. in height, and good producers without necessarily being prone to over-bearing. The tree has foliage quite similar to Arabica, and is likely to be conical in habit; the fruits tend to be pointed and are large, as are the grains in them; the bark seems fine-grained, and the plant; differs in other characteristics. As mentioned previously, it came originally from along the banks and in nearby open glades of the Congo and tributary rivers, and is adapted to standing with its roots in water for long periods of time. In fact, it often flowers and sets fruit while its roots are inundated during the flood seasons. According to Hille Ris Lambers (1930), it was brought to Java early in the present century and, under moist conditions, has produced well, both as a species and as a hybrid tree. The coffee given the name *C. kivuensis* Lebrun is also of good quality, and has been considered possibly only a variety of *C. arabica*. It is said to be less adapted to wet growing conditions, but lives well at higher altitudes in the Kivu, even up to the frost line. These coffees, less well-known than Arabica, are of comparatively little commercial importance at present. However, they have

(a)

PLATE 12.—(*a*) Large, thick-skinned cherries (in this case averaging over 30 mm. in diameter) of Liberica coffee, which may reach the size of plums. Excelsa is a near relative but its cherries are small, pure red, and thin-skinned. I.A.I.A.S., Costa Rica.

(*b*) Cherries on a fruiting branch of Canephora. (Reduced to ½.) The closely-held clumps are characteristic of Canephoras, including the Robusta variety, and they do not drop readily on maturation. I.A.I.A.S., Costa Rica.

(b)



produced and still bear crops that are harvested at times by small planters and natives and have been, and may still be, marketed as Arabica after generous mixing with other plantation products. The relative adaptabilities and manner in which they have survived, their horticultural properties, their qualities and use by natives, and their resistances to diseases and insects, deserve much careful study and exploratory attention.

ARABICA OR ARABIAN COFFEES

Arabica has withstood the long years of being the greatest member of a great world crop. Some of its characters can be briefly reviewed. It was used in the commerce that we know for the longest time of any species. The small tree that bears the bean is a beautiful plant, with a more or less conical shape and handsome, brilliant green leaves. The ripe fruits are commonly red to dark purplish, but in certain varieties may be yellow or of shades between. The tree is a heavy bearer, sometimes to its own disadvantage. Fruits are in clusters, burying the petioles of paired leaves along the side branches. Plantation after plantation will look remarkably similar. While the little plants are young and of the same age, a field gives the impression of being set with trees stamped from one standard pattern. Above all else, it is known in commerce that the beans from these trees have a flavour, spoken of as 'aromatic', of extreme popular appeal.

As the popularity of Arabica increased and became settled down the centuries, it was inevitable that large concentrations of the crop had to be grown to produce enough for wide commercial use. The place of its origin is well recognized (Chevalier, 1929; Cheney, 1925; Ukers, 1922; Fauchere, 1927; Krug & Carvalho, 1951; Sylvain, 1955; A. S. Thomas, 1942) as the highland of Ethiopia and its extension into the southeastern corner of the Anglo-Egyptian Sudan, not far from Kenya. From Ethiopia it was first moved to Arabia, exact details of its transport being lost in the haze of tradition and fable, but this was over 500 years ago. Some 350 years ago it was found in small patches in gardens of the islands of southeast Asia. About a century later it was started on its remarkable progress throughout the tropical world—*see* Chapter III.

The mountainous lands in the Caribbean Islands, Central America, and South America produce large amounts of coffee. Brazil is first in production of Arabica in the world, while Mexico comes third. There are South American countries that grow less, among which Venezuela is an old and still significant producer. In Africa, much Arabica comes down from the Congo highlands, and Ethiopia is an ancient perennial source with great unrealized potentialities. India has been producing Arabica for several generations, and one of the very oldest prdoucers is Indonesia. In these countries, Arabica is of minor importance, being superseded by Robusta, due to the latter's resistance to rust disease. Kenya is known for a consistently good, dependable production of Arabica that is well thought of in England and Europe. The same is true of that from Tanganyika, where Arabica production is increasing among the indigenes, and at no expense to quality. Growing of Arabica in Uganda is not extremely extensive, but the bean from there is highly regarded in commerce. There are certain Arabica-growing islands in the Indian Ocean and South Seas, such as Mauritius, Reunion, New Caledonia, and Hawaii. From the last comes the famed Kona coffee with its distinct appeal for a particular trade. Lastly should be mentioned Yemen, with its old port of Mocha, from which Arabica grain has come for over a thousand years—grown and shipped, even now, in its ancient manner.

Exact information is lacking, but, from crude calculations, it seems that there are probably some 9 billion coffee trees growing in the world at the present time (Wellman, 1957). That is a sizeable horticultural interest. According to a recent report (1957) of the Foreign Agricultural Service of the United States Department of Agriculture, it is estimated that world commercial production amounts to over 5 billion pounds of dry coffee a year. According to Chevalier (1929, 1931) over 90 per cent of this is Arabica coffee. There were several good reasons for its acceptability. It was proved adaptable to a variety of methods of husbandry; the prepared dry beans made a valued, concentrated shipment that could be transported over long distances, and seldom was there loss from spoilage; drinking of it was agreeable, and its stimulus was highly regarded—and perhaps as well, because much of the time its cultivation was in parts of the tropics where life was salubrious and worth the effort. Billions of these small trees are now growing in fifty or more tropical countries, usurping what used to be primeval woodlands. They like continuous supplies of humus, and, in many cases, the crop is grown among other trees in order to take advantage of debris from them.

It is true that the greatest coffee-growing country of the world is Brazil, and the coffee there is all Arabica. In the states of Sao Paulo and Minas Gerais alone, there are almost 5 million acres in coffee. It is estimated by Van Royen (1954) that, when he wrote, Brazil had a total of 2,168,000,000 trees. Years before that, there were even more. At one time that country shipped over 70 per cent of the coffee of commerce; by 1935 it had dropped in percentage to 60, and at the present time is somewhat nearer 40. Meanwhile coffee has been coming, of course, from many other countries, A total of 87 to 88 per cent of the coffee produced for market comes from countries and islands of the American Tropics, 7 to 10 per cent comes from Africa, only a trace comes from Arabia (but it is still produced there), and south-east Asia and the Pacific Islands grow the remaining 6 per cent. From all these, the over-all percentage of Arabica produced still remains overwhelming. Let it be remembered that almost all of this immense crop is from the descendants of that one 'noble' tree sent to Louis XIV of France nearly 250 years ago.

Arabica produces well under certain conditions, as many records show. Whole countries may average 6 to 10 and more hundredweight per acre. Some average much less. Sometimes there are well authenticated very high productions. Now and then, planters see individual trees that have, through circumstances, produced a phenomenal crop in comparison with field mates. The trouble is that the next year's crops on the same trees may be practically failures. However, there are certain selections that are high producers. For example, A. S. Thomas (1947) found that Kent's Arabica regularly doubled the expected yield from common Arabica in Uganda tests. The variety Mundo Novo has shown high yielding capacity in Brazil and Central America, greater than the other comparable Arabicas. Such a varietal characteristic can be dangerous in trees growing under anything other than the best nutritive conditions, as 'fatal exhaustion' may occur unless the tree can draw on good soil fertility at all times. It was recorded by Barrett (1928) that he knew of individual trees that yielded 'at the rate of 15 pounds a tree for years on end'. He insisted that this depended not only on inheritance but also very much on cultural conditions. The Arabica, in proper environment and care, and in fertile soil, is a good productive crop species, but it has to be managed with judge-

Arabica coffee is planted at various distances in the field, and a fairly successful, not uncommon but rather narrow, spacing is about 8 by 8 ft., which makes some 680 trees to the acre. In Brazil, coffee is put in, keeping four to six or more trees close together in a low basin or 'cova', and these are counted officially as one tree. The trees, thus placed, are said to be mutually helpful in self-shading, produce a better 'skirt' to protect the soil, and grow to bend outward more easily for harvesting. In such countries as Colombia, Kenya, India, Hawaii, and many others, where coffee horticulture is specialized in a different manner, single trees are used with skilful pruning, and other husbandry treatments include fertilization, sprays, and treating with minor elements. McClelland (1912) reported that, in Brazil in 1896, a field of 2,000 Arabica trees near Sao Paulo produced about 200 lb. of dry coffee per acre; but in one area were reported 17 lb. of cherries to a tree—equivalent to about 3,600 lb. of dry coffee per acre. The proportion of fresh cherries to prepared 'beans' is about 5.5 to 1 by weight. In Costa Rica, the average harvest is about 650 lb. of dry beans per acre, but special experimental plantings have given over three times that much for short periods. Equal records, and more, have been made many times in other countries, but, it should be emphasized, for only short periods and under special conditions. In El Salvador the average production is 700 lb., or more, per acre, and in South India it may be near 300 lb. The world-over average per acre is considerably less than 200 lb. of clean coffee 'out-turn'.

VARIATIONS IN ARABICA

Attempts to improve Arabica in production, in horticultural adaptability, and in long-time field performance, first began with folk selection. There are some well-known varieties from this general selection that are undoubted improvements over the usual types likely to be planted. In some cases, they have been further enhanced through scientific work. They come from several countries, and a few that are listed here are examples. They are known for special reasons, seem fairly well fixed as to type, and are probably somewhat complex as to genetic content. A few such are: the Arab 'Zeghie'; the Ethiopian Tchertcher', 'Sidamo', and 'Gimma'; the Jamaica 'Blue Mountain'; the Kivu 'Local Bronze' and 'Mbirizi'; the India 'Kents' and 'S.288'; the Java 'Blawan-Pasoemah'; the Costa Rican 'Nacional'; the Kenya 'Bronze Tip'; the Brazilian 'National' or 'Cafe Commun' and 'Mundo Novo'; and the EI Salvador 'Hibrido de Bourbon'. There are other such Arabica varieties aside from mutations.

The numbers of mutations from Arabica are also many, as can be seen from reference to the definitive studies of Krug *et al.* (1939), Krug & Carvalho (1951), Cramer (1913, 1957), and Chevalier (1947). These special variants are given botanical recognition and come from hundreds of generations *of* selfed progeny. It is of interest that all have mutated from that original parent tree of nobilized history, that tree that came by steps out of Ethiopia to Arabia Felix, to Batavia, to Amsterdam, and finally to Paris, whence it was spread throughout the Tropics. These many mutants have been described and published, and others are still being discovered. A number of more common and notable mutants occur that give some idea of the content of Arabica inheritance, and details of genetic composition of the mutants have been published by Krug & Carvalho (1951).

The first mutant to be mentioned here is of a recessive character named *angustifolia,* that results in a plant commonly occurring in nurseries ' usually discarded, it is distinguished by narrow strap leaves and poor productivity. Another is one very important type of a main division of the Arabica species, apparently recessive in inheritance, a tree with sturdy growth,broad leaves, stiff branches held at a steep angle, and green tip leaves, called *bourbon* (Pl. 9). Another sturdy tree is the mutant *caturra,* a medium dwarf, with a flattened top; it is a precocious bearer, with closely set leaf-nodes, and its inheritance is controlled by one pair of genes There is an unusually tall, cylindrical type with short side branches, rather light-bearing in the sun in Brazil and heavy-bearing in the shade in Puerto Rico, called *columnaris.* There is a vigorously growing, dominantly inherited mutant tree character, called *erecta,* that is marked by having all normally horizontal fruiting branches grow vertically. The *goiaba* mutation produces fruits characterized by long, persistent calyces (Pl. 6,*b*).

One of the oldest known mutants is the dominant *maragogipe*, a vigorous tree that is a giant as Arabicas go, with large, bulging or convex leaves, and abnormally big fruits and beans. In contrast is the weak-growing, delicate tree that, in spite of profuse flowering, sets only a few fruits, typically one-seeded, and is known as *monosperma*.

One of the complex mutants is a small tree, said to be somewhat frost-tolerant, with small leaves and poor productivity, and called *murta*. When selfed it gives half Murta type, a quarter Bourbon, and a quarter extreme dwarfs. A weak-growing, weeping type of mutant tree, called *pendula*, has specially drooping side-branches that, in extreme cases, lie on the ground. There are trees of the *purpurascens* mutation, marked by purplish-red leaves, with a fruit colour of red streaked with purplish-bronze—all characters recessive in inheritance. Another mutation is a dwarf tree, smaller than Caturra, known as *san ramon*, that comes out of the mutation Typica. It has large leaves, the tree has a conical form, fruits are thickly set on the branch, and it is drought- and wind-resistant. A tree mutation of recessive nature, but noted for its vigour, is *semperflorens* that apparently has no limit to its time of flowering, and sets fruit almost the year around. There is a second, main type of division of the Arabica species, different from Bourbon, noted for its more delicate, narrow leaves, slender branches, and bronze tip-leaves. It is known as *typica* (PI. 10), and is of apparent dominance. The last mutant to be given here is *xanthocarpa*, that is of recessive inheritance, characterized by the yellow colour of its fruit. The range of types from mutants has widened adaptability and has helped to keep the Arabica species popular among planters. However, one country after another has had to give up Arabica, for various reasons.

It has been believed by many that the Typica component of *C. arabica* is the primitive type. This was the one that Linnaeus and de Jussieu saw and studied. This is of dominant inheritance according to Krug & Carvalho (1951), but Sylvain (1956) reported C. *arabica* in original coffee forests of Ethiopia as characteristically both Typica' and 'Bourbon' in nature, the primitive type being probably a combination of the two. The bronze of the more delicate Typica is of dominant nature in inheritance. On the other hand, the Bourbon is a more rugged grower, and is a higher producer than Typica. Sylvain also noted much in the way of persistent calyces in wild *C. arabica* coffees in the original forests. This is quite a common character in coffees of the species that are being introduced from the wild into collections. Common observations are that it does not occur in either of the old standard Typicas or Bourbons. The standard types, used in commerce, apparently are of comparatively narrow genetic composition. Their uniformly high susceptibility to the Hemileia rust further indicates this.

Thus far, there is no major breeding programme being carried out with Arabica. Selection, however, is making good progress. As can be seen from reference to do Oliveira's publication (1954-55) there are several strains from several species being lifted for reaction to Hemileia rust. The work in India (Narasitnhaswamy, 1050) is outstanding and from it have come Arabieas S.333, S.645, and S.795 alt good producers and not requiring anti-Hemileia spray. Thus resistant lines are being selected, but we are still uncertain about the inheritance of resistance and susceptibility, This knowledge is possibly unnecessary at present Reliance is placed on either the finding of resistant clones or the isolation of an apparently fixed resistant character carried in the seeds of the selfed strain. The Arabica of commerce is a species with *its* varieties all of basically the same components, but with differing forms that are the result of mutations, What is being used now most commonly, the remarkably even mixture of selfed progenies from one tree, results in a species that is extremely hard to improve by routine selection* Arabica genetics that have been studied are mostly of the mutant characters (e.g. Krug & Carvalho, 1951) and the start of work in India on resistance to the rust (e,g, Wilson Mayne, 1936). What is badly needed is an evaluation of the newly secured Arabicas from the Ethiopian forests; these should be subjected to controlled pollinations, and be understood and crossed under a master geneticist, Such work would probably lead to a new era, in the horticultural development of the species*

THE LIBERICA COFFEES

The rust disease has been a potent: reason for changing coffee varieties, According to Chevalier (1929), *Coffea liberica B*ull *(see* P1.11) first: became popular in Java from 1880 to 1905, after the invasion of I femileia and the subsequent abandonment of Arabica growing, Liberia is a relatively old coffee from the standpoint of discovery. Its native occurrence, at least before European man started carrying it about, was quite widespread in Africa. From his own readings and observations, Chevalier (1947) gave the pattern of its original distribution. In the first explorations, after its discovery in extreme West Africa, it: was found front the Middle Congo to Bena Lucula in the Ituri forested region, and along the high tributaries of the Chart on the Ubangui It was also observed wild from the foothills of the Ruwenzori uplift to the Albert-Nyanza lake region It occurred, likewise, in French Guinea, the Ivory Coast, Liberia, the region of Lake Chad and Nigeria, and in part of the Nile Basin and the dry territories of the Anglo-Egyptian Sudan, Its wide distribution, and the somewhat discontinuous pattern of its spontaneous occurrence, have resulted in wide varietal differences within the species.

The species name, C *liberica* Bull ex Hiern, is sometimes questioned as to its priority. In a careful literature review, Chevalier (1929, 1947) showed that specimens of it were collected in Sierre Leone in 1792 by the old botanist Afzelius. Material was studied by Hull from the

Photo P.J.S. Cramer, courtesy of Mrs, Cramer

PLATE 13.—Tree of Excelsa coffee five years old, with cherries about the size of those of Arabica. This coffee hits been grown as a tall, multiple-stem bush, but otherwise forms a large tree. Java.

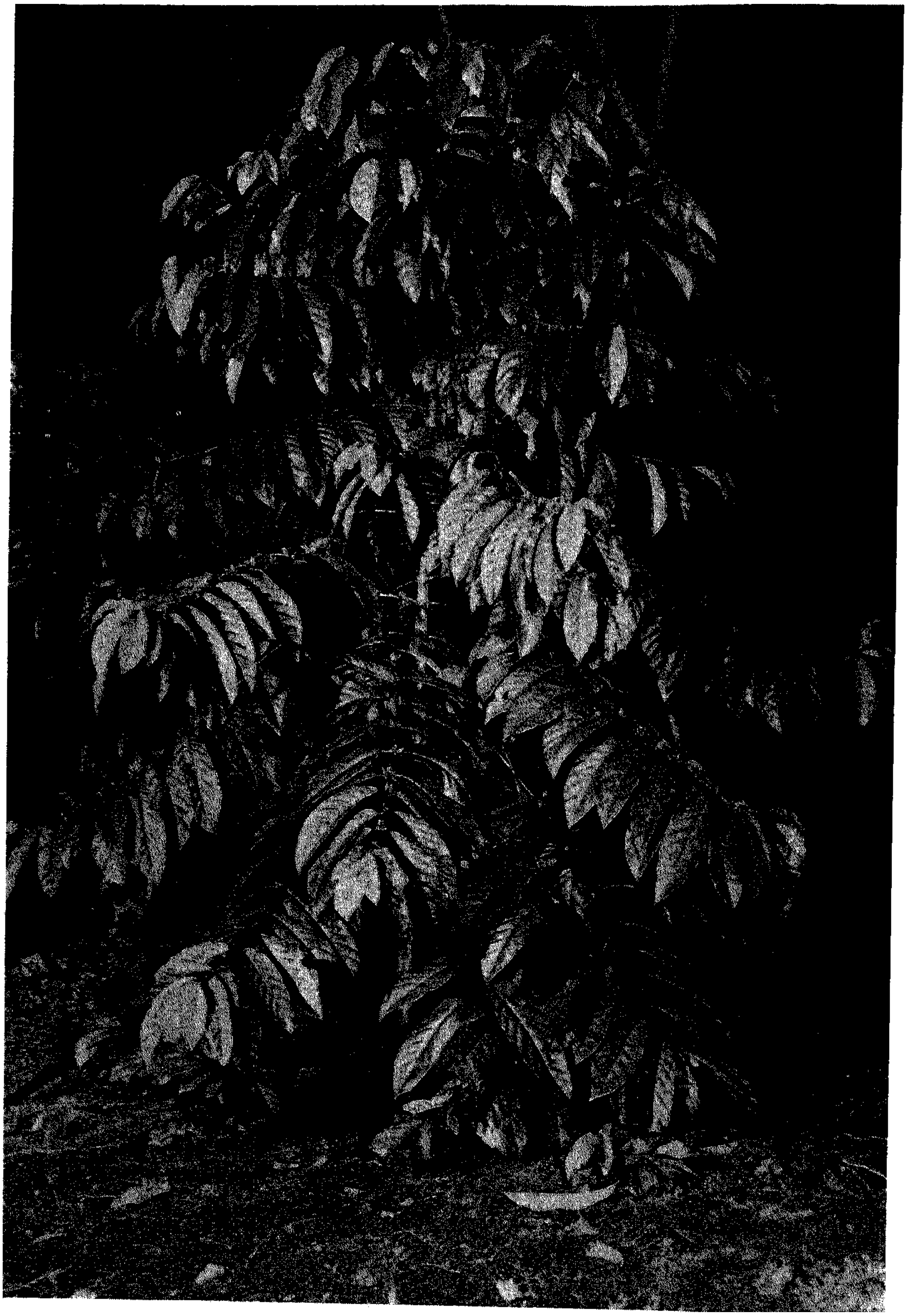


Photo James Mitchell

PLATE 14.—Tree of Canephora coffee, over 3 m. high. This is a variable species and the example here has smoother leaves than many. Guatemala.

West African country of Liberia and he described it in a catalogue and named it in 1874. It then became of considerable interest and Hiern gave it more careful descriptive attention in 1880. The next year a commercial planting of it was established in the Ivory Coast. Other of the more commonly applied names, reduced to synonymy, have been C. *macrochlamys,* bestowed in 1892 by K. Schumann, and C. *dewevrei,* given in 1900 by de Wildeman. These names now are used for varietal designations. It is generally recognized by careful students that, undoubtedly, the correct specific epithet is C. *liberica* (Zimmermann, 1928; McClelland, 1924; David, 1935; Fauchere, 1927; Chevalier, 1947), although there are still those, e.g. Wellman (1955), who, through some unenlightened reading have, at times, used one of the synonyms for the true specific denomination.* The species is self-sterile, therefore open-pollinated, and exhibits wide variability.

Milsum (1931) has noted that, among Asiatic peoples, cupping qualities of Libericas, including Excelsa, are preferred over Arabica and Robusta. In the Ivory Coast, Porteres (1939) tells of a variety selected and known there as 'Liberia Ameliore', that is, as its name suggests, much improved over common Liberica. Studies with it have been carried on in grafting, and out of it has grown the easier use of clones in some places, one of the most famous being Bangelan 122-01. There are also numerous tenable varieties other than those mentioned, with names such as Lulla, Kisantu, Chari Originaire, Chari Tonkin, Libonza, Sumatra, and Lang-Khoi.

However, there is a species, C. *excelsa* (Chevalier, 19290), that is commonly called 'Coffee of Chari' or 'Excelsa', closely related to Liberica and easily included with it commercially. It has some distinct horticultural advantages over Liberica: it is a heavier bearer, the fruits are small, almost like Arabica, and readily pulped; also it withstands pruning and is much more resistant to cold than Liberica. The flavour of Excelsa is mild, and far from the extreme bitterness of Liberica. The Liberica variety Dewevrei is somewhat resistant to the Stephanoderes berry borer, but Excelsa is even better in this respect. PL 12 shows a young tree of Excelsa bearing heavily.

There are some botanists who have suggested that *C. excelsa* is the same as C. *liberica.* However, there are those others who, living with the trees, have studied the two with critical attention and continue to treat them as good separate species. C. *excelsa* was described by Chevalier in 1903, and shortly afterwards Cramer (1913) started years of study of it. What he saw of Excelsa growing beside Liberica did not make him combine the species, although he grouped them together as 'Liberoids'. I saw the two growing close together in such places as Dschang, French Cameroons, in Cramer's own collection in the old Buitenzorg Garden in Bogor, Indonesia, in plantations in the Philippines, and in the collection in

* Wellman, in a Spanish translation (1956), corrected his original error (1955).

Lyamungu, Tanganyika. Throughout, I felt certain of the specific differences. I have seen *C. liberica* growing in Latin America in Puerto Rico, El Salvador, Costa Rica, Guatemala, and Colombia, but have only encountered what appeared to be good *C. excelsa* in Puerto Rico, and a few trees in Campinas, Brazil. The two species cross, and there are trees in the Americas that show some Excelsa relationships, but to me few are true Excelsa.

The coarse Liberica tree, and its relatively different cup-quality bean with the somewhat bitter taste, was brought under cultivation in French Equatorial Africa on land that had been growing Arabica coffee, but had been abandoned on account of rust. Soon it was taken to islands such as Mauritius, Réunion, and Madagascar. Later, it was introduced to replace dying Arabica in Java, where the rust was rampant. Besides its resistance, some of the characters that made it of interest were its tolerance of drought, its ability to grow in poor soils, and its vigour and capacity for withstanding horticultural treatment and neglect that would ordinarily destroy Arabica or Canephora. The tree, if left untouched, is a good-sized forest inhabitant, with large and broad, smooth, leathery leaves that remind one of a magnolia, large white or lavender to pink flowers, and fruits several times the size of those of Arabica. In its best plantation handling, the tree is pruned to a multiple-stem and kept at about 6 ft. in height. However, many growers leave it unpruned. In a few years it can grow to be 60 or more feet high, and harvesting is very often done with ladders, by climbing into the tree, or by use of bamboo poles for beating down the ripened fruits, which are then picked from the ground. These fruits are fleshy, and the proportion of fresh fruit to prepared beans is about 10 to 1 by weight—about twice that of Arabica. Pl. 13,*a*, shows the large, thick-skinned cherries of Liberica coffee.

Extensive plantations are grown in several countries. Of these there are numerous examples. It is found in French Equatorial Africa, in the (Cameroons, and is cultivated in several parta of the country of Liberia and in Nigeria. It has grown for a long time in Java, and was much used before Robusta was introduced, It was found to grow well in Malaya, and there it has replaced coffcee that could not produce because of disease or hard treatment. It was early taken to the Philippines, after the rust had stopped Arabica production in those islands and its introduction into the Guianas was brought about through Dutch agriculturists working between Surinam and the Indonesian Islands. It was suggested for growing in Panama (Madrid & Casorla, 1878) but was never started there, although it was said to develop well in warm countries.

Where Hemileia, worn-out soils, and other bad growing conditions have driven out, first, Arabica and, later, Canephora, it has remained for Liberoids to continue coffee production on a commercial wale. While this group furnishes only about 1 per cent of the coffee used in the world, this is still not an inconsiderable quantity.

The trees of these species are planted at considerable distances from each other. A common spacing is 12 ft. by 12 ft, resulting in approximately 302 trees per acre. They can exist and bear some fruit on poor soil, but, like any other tree, need a good supply of nutrients to give the most. It requires about five years for one of these trees to produce its first good crop. They are somewhat cold-resistant and grow best in well-drained soils and apparently prefer conditions verging upon the dry. Liberica is often grown under shade. In the Philippines it is thus protected, being planted under coconut palms. In fact, it is believed to require shade in some countries and is said to 'run out' if planted in the sun. In Ceylon, it was grown mostly in the sun, and some of its failure in Indonesia is blamed on that. It can develop good crops under shade in what might be classed as hot conditions, which would be out of the question for Arabica.

Years ago it was planted in great profusion out in full sunlight, and in rather dry sandy soils. It is of note that many of those plantations flourished for a while, but disappeared in less than twenty years. However, this species had made its mark on world coffee growing. Its wonderful vigour was very impressive, and a search was started for hybrids of it with other species, looking for a combination of toughness, good productivity, and better quality.

In rare instances, horticulturists have found *(see* Chevalier, 1929, 19290, 1947; Ferwerda, 1948; C. A. Krug *et al,* 1950; Cramer, 1957) successful crosses between Liberica and Arabica. Some hybrids have been of great interest and have even been planted on fairly large scales. At the time when this work was at its height, the war came along and it was stopped. In Java, Cramer reported natural Liberica and Arabica hybrids that were called Kalimas in one instance and Kawisarie in another, after the coffee estates from which they had come. In addition should be mentioned the highly successful Jackson's Hybrid, said to be Arabica crossed with Liberica, and back-crossed to Arabica. These hybrids were all rust resistant and had somewhat of a vogue for several years in places where rust had destroyed both Arabica and Canephora crops. The new Kawisarie and Kalimas hybrids had to be grafted, but they grew vigorously and had a fair capacity to bear, although not all fruits contained perfect grains. It has been of interest that such highly resistant hybrids come from parents of which one was extremely susceptible to the disease and the other was of medium to slight susceptibility. Highly resistant and vigorous hybrids have also been found to result from crosses between Stenophylla and Liberica. Krug and his co-workers described a natural tetraploid hybrid of Arabica and the 'species Dewevrei, which is actually *C. liberica*. This is now being used in studies for a possible type for growth in Brazilian coffee soils of depleted character. When coffee, as a whole, is compared with many other horticultural crops, it is disconcerting to see how much still remains to be done towards a fuller understanding of the limitations for varying local growing demands.

CANEPHORA OR ROBUSTA COFFEES

There is much literature that tells of the change from the Arabica species in rust countries to other coffees that were more resistant. A good illustration is the discussion of Ferwerda (1948), who told of how Arabicas were all but completely driven out of Java and other Indonesian islands. There had to be some replacement; so, about 1900, the growers brought in the hardy species *Coffea caneohora* Pierre, It was introduced first for its rust-tolerant qualities and, according to Steyaert (1946), was called 'Robusta' in recognition of its resistance to Hemileia rust'. A character of Robusta was its greater vigour than Arabica. In commerce the name 'Robusta' is much better known than Canephora, although, by some, it is simply called an 'African coffee', It could grow in old abandoned Arabica plantations that had become grass-infested following Arabica destruction by rust. If given moderate attention, Robusta could be managed so that it: would dominate the grasses, According to A. S. Thomas (1947), along with this unusual vigour was its high resistance to riemileia, This was indeed fortunate. It was reported by Porteres (1939) that a Canephora variety, Kouillou, had been planted in the Ivory Coast since 1910. There it was specially valued because its vigour was greater than that of Arabica, because of its greater productivity, ami because of its resistance to stem borers. Studies, then since show that it: has a much wider range of adaptability then Arabica, P1.14 shows

The region of origin of the species C. canephora is widely spread, covering much more variation in ecology than that from which C. arabica originally came. The indigenous region of Canephora extends from one side of the great: African continent to the other. It reaches througout the central portion, from the west to the east coast, in its widest part. It is found in the north, from the edges of the Great Desert, and south to where the tropical forests extend into more temperate zone conditions. It seems to favour jungle edges, but the forests from which it comes may vary from open to quite dense, and elevations range from moderate to fairly high hillsides. It is an irregular tree and it has come from irregular conditions. Its natural habitat extends from Senegal, Guinea, and Liberia in west: Africa to the Ivory Coast and Dahomey, It may be found growing spontaneously in the extreme southern part of the Sudan, in woodlands north of Lake Victoria, and in other parts of Uganda ranging to the foot of the Ruwenzori Mountains. It also exists naturally in southern Nigeria, the Cameroons, Gabon, the Middle Congo, the basin of the Kouiliou, and Portuguese Mayombe near Loanda. PI. 13,b, shows the closely held clumps of small cherries on a fruiting branch of Ganephors,

VARIETIES OF CANEPHORA

In some quarters, the specific name C. *canephora* is used in a confusing manner with C. quillou, C. *ugandae, C. robusta,* and others. It should be pointed out clearly that historical study shows that *C. canephora* is the original name, given by L. Pierre in 1895, which antedates the other names, later found to be synonymous. It is well known as a variable and very plastic species. It is said to be more cold-resistant than Arabica, and may grow well in both sun and shade, but may prefer shade at times. It withstands considerable dry weather, and grows in plantations at fairly low as well as medium-high altitudes. From this species have been selected varieties adapted to numerous different tropical climates, and to many of these have been given names such as Typica, Ugandae, Canephora, Robusta, Quillou, Maclaudii, Stuhlmannii, Bukobensis, Naiouli, and Laurentii. The most common variety is named Robusta, and this type has large, dark-green leaves, often with deep corrugations. Trees of the Robusta variety tend to have a flattened top, and the internodes are shorter in this variety than in some others. It has considerable tolerance of the Hemileia rust, and of some other diseases. Another special variety is Uganda, known for a very long time. Years ago, A. S. Thomas (1944a) described the variety 'nganda' as a spreading form like C. *quillou,* but rounder in tree shape. This is also called variety Ugandae. It is a medium-sized tree, somewhat dome-shaped and more adaptable to some conditions than Robusta. It may have smaller leaves of lighter colour, stems with a more drooping character making a more compact tree; and it comes fairly true from seed and responds well to pruning and cultural treatments. (Matheson & Bovill, 1950.)

The Robustas and Ugandaes come from a hardy species. They are easier to grow than Arabicas, especially in some places. In the wild, A. S. Thomas (1944) found Canephora, in his observation, to grow in very moist forest, therefore possibly in poorly-drained soils. It can grow on heavier and more alkaline soils than Arabica (Haarer, 1950), and apparently thrives at a little higher temperature. While it is recognized as tolerant to rust, it is likewise known to withstand root infections by *Fusarium* (Wellman, 1955). Some labourers and peasant growers may produce coffee from Canephoras where they may fail with the more exacting Arabicas. Along with increased productivity, these so-called 'Robustas' are more neutral in flavour and are readily adapted to horticultural practices. They are the source of most of the coffee from Africa.

A characteristic of many of the Canephora varieties, that requires more study, is the apparent ease with which they drop their lateral branches after fruiting, especially following heavy over-bearing. This is another difference, and advantage, over Arabica, which tends to cling to its useless, old, dead fruit branches. Branch-drop helps in the pruning problem, and may reduce the time required to recover from die-back. The fruits, somewhat smaller than in Arabica, are borne in tight heavy clumps, and are of a comparatively light red. Flowers are large, lush, very fragrant, and borne in pompoms along the fruiting branches. During the past few decades, commercial acceptability has increased, so that now at least 7 per cent of all commercial coffee is from Canephoras (Robusta, Kouillou, Uganda, etc.), and the quantity seems 10 be increasing In the United States it has recently come to be over 15 per cent of consumption. Cancphora is a much heavier bearer than Arabia, and easier to grow.

Canephora trees are planted fewer to the acre than Arabica, being commonly about 10 by 10 ft. apart: or approximately 435 to an acre. These distances are not fixed and vary with conditions. The trees are widely spreading, and some varieties require pruning to keep them under control In Angola, the species is grown in reasonably dry highlands and the trees are trained to multiple-stem growth. This is carefully regulated, and rotation of resulting uprights is carried on with great precision. In some parts of the country of Uganda, the tree is handled by the indigenous inhabitants in a remarkable fashion. If is pruned for several years to a number of main trunks. These are gradually bent down, but slowly, without allowing them to lose growth-response at the tip, As they grow older the multiple trunks increase in girth and continue to be fixed outwards. They are trained in several directions, and only a few well-scattered trees are allowed to the acre. A single tree, fifty or more years old, may thus cover a larhe area. The multiple trunks get buried in mulch, and successions of upright branches carry the fruit.

On first glance such an old and special, single tree may appear to be a clump of several trees. Foreign pollen comes from neighbouring old trees of the same species, or from young trees brought: in every few years from neighbouring places. These special old trees are never allowed to become tall; they are sometimes, at least partially, in the sun, but are often kept shaded with banana plants, and have annual vegetables and legumes planted in their shade, not only for human food but also for the trash mulch they form. In Indonesia, the Canephora trees have had long series of decades of serious research lavished on them. Selection, breeding, and re-selection has been carried on. Trees are mostly grafted onto certain basic rootstocks. Planters employ something like ten clonal tops to furnish the coffee crop. Clones are grown in carefully mixed plantations, as they are self-sterile and need cross-pollination to yield seed. Production, on the average, is much higher than with Arabica, though the cherries are smaller. The proportion of ripe fruit to dry prepared beans is about 5 to 1 by weight.

GENET1CAL IMPROVEMENT OF CANEPHORA

The size of the bean is considerably less than in Arabica. This, along with other characteristics, has made the search for a better strain, through hybrids between varieties of Canephora, of much interest. One outstanding clone from India, S.274, is known for its large-sized bean of excellent, 'bold' appearance. There have been a number of hybrids secured, with different varieties of Canephora as parents, and they have given various results. The Dutch first planted the Canephora variety Robusta in 1900. It was soon recognized (cf. Jacob, 1938) that this variety was extremely variable when grown from seed, which made difficult the standardization of plantation practices. In attempts to rectify this, searches and selecting were carried on for better types and possible hybrids. A hybrid series that has given much success is the variety Robusta crossed with a distinct species, C. *congensis*. Different types came from these hydridizations, the best being fixed as strains of a variety called 'Congusta' by Cramer (1948, 1957), and also known as 'Conuga'. It is sometimes even given the specific name C. *crameri* Chev. The varieties of Canephora used in these crosses were excellent bearers.

Congensis was a shy bearer, but highly rust-resistant. Its hybrids, the Congustas, are of better quality than Canephora, being said to approach Arabica, but they are self-sterile. They are resistant to rust, bear more freely than the pure C. *congensis*, and are not so prone to die-back as the usual lines of C. *canephora*. Chevalier (1929) and Schweizer (1930) have both pointed out that there have been successful hybrids of Canephoras with Arabicas, but these have been of little commercial use. They were investigated by Ferwerda (1937, 1948), and it was determined that, at least in the first groups of such hybrids, the flowers bore imperfect pollen. It was wrinkled, and largely non-viable, with but a few grains showing the mere start of germination. Solid plantings of progenies of hybrids such as these were worthless. Later, more work along these lines by the Dutch led to better results. Cytological analyses, breeding, special fertilization, studies on physiology, and chemical treatments to help induce hybridization, were being tried and gave promise.

Whether grown in the tropics of Asia, Africa, or America, the Robusta or Canephora coffees have a different type of liquor quality from Arabica. They are known as 'neutral' or 'sweet' coffees in some places, although they have a characteristic tang, that differs with the variety. When they come from certain African countries, the commercial world bands them all together as 'Africas'. One such important African country is Angola, and another is the French Cameroons, including French Equatorial Africa, In the former, the crop has tripled since the last war, and in the French Africas it is being industriously multiplied, until it is now of major importance. This is also the case in the Congo where, as in French Africa, a very great deal of research is being prosecuted, on a wide scale, on the species. The crop came to its earliest perfection in Java, where it has been grown since 1900, but it has also been in development for a long time in French Equatorial Africa.

Robusta is grown more and more extensively in the lowlands in India. It is of great importance, as well, in Madagascar and in Nigeria, and is of much economic value to Tanganyika and Uganda. At the present time, it is probably expanding more rapidly in French Africa and in Uganda than in any other countries. In the Western Hemisphere, it is being grown in a small way, at first experimentally, but it is eliciting a firm interest. Some is produced in good-sized commercial plantings in Santo Domingo, while it can be found in restricted field corners in Costa Rica and Nicaragua, and it has been planted in rather large fields in Guatemala. Ecuador has some extensive growth of it and the farmers are starting work with it in their littoral; it has also been produced for a long time in Surinam. These coffees in commerce are used in blending and are known to add both more caffeine and more 'body' Such coffees from many countries have recently become a common and welcome ingredient in the manu¬facture of soluble coffees of high quality.

These Robusta, or *C. canephora,* coffees are being studied and, in some areas, are all that is grown. They differ greatly as to productivity, which gives some added reason for attention. Should the yield of beans be as low as in Arabica and the cost of production just as high, they could not compete wttn the more aromatic¬flavoured beans. The matter of differenees in yields among Canephora varieties is quite an interesting characteristic. For example, A. S. Thomas (1947) gave averages for erect types, such as the variety Robusta, of 1,760 to 1,780 lb. of clean coffee per acre, while spreading types such as Ugandae averaged 925 to 1,590 lb. In a report of Kerkhorn (1947), the Robusta variety averaged over twice that produced by Ugandae under the same conditions. Such gross differences between natural varieties would indicate that spectacular gains might be forthcoming out of selection and breeding.

The development of Robusta as a cheaper, but satisfactory, competitor to Arabica, was a challenge for those who could not grow the latter. This was soon realized by the Dutch in their classic work in the Netherlands East Indies. It was introduced in 1900, but in 1907 they began their programme of selection in the species C. *canephora*. By 1916 *(see* Cramer, 1957), work had been carried on covering three separate improved generations of Robusta in the station at Bangelan, Java. There was such great promise from these results that efforts were redoubled on a long-term basis. To cite one result, among these studies were eleven clones compared for 11 years with their eleven mother trees. Averages for the first 8 years of harvest were compared with averages for the last 3 years, and then expressed as comparisons with 'the average yield of the mother trees'. To begin with there seemed to be no clear-cut result. However, using data from the more mature trees, and thus more comparable years, the average yields of clones considerably surpassed those of the mother trees. For example, the clone S.A.7 gave 65 per cent more than the mother, S.A.13 gave 51 per cent more, S.A.24 gave 88 more, S.A.56 gave 50 more, while S.A.74 gave 166 more. At the end of 19 more years of this sustained type of work the effects had been highly satisfactory, paying very well for the large staff involved and for the expenses of the stations. As an example may be cited the clone R.124, one of the best obtained and so far superior in both vigour and production habits as to be of prime historical note. It was tested under a wide range of conditions, did well everywhere, and was close to a type of'universal' capacity. At the end of 19 sustained years, selected improved material regularly yielded 65 per cent more than average Robusta.

ROBUSTA SELECTIONS

Selections had been based on well-conceived comparisons with Robusta and other *C. canephora* progenies. A 'production index' (PI) was developed, in the Indonesian work, based on the proportion of yield between the selected tree or tree family and the yield of average Robusta. Many controlled research plantations were set up under different conditions, and soon outstanding Robusta 'numbers' were known. 1 here was a selection from the variety Quillou, called Q^.Bgn.121, that gave an average PI of from 48 to 67 during 19 years of tests. This and other Quillous made vigorous hybrids with Robusta and were popularly grown. The variety Ugandae hybridized easily with variety Robusta, and from a long list of these hybrids four were finally accepted. There were differences in the way some clones could be used. For instance, S.A. 109 was originally a good yielder, and grafts from it produced well, but the seedlings from it gave poor crops; on the other hand, the original tree of Bgn. 105 was also a good yielder, and grafts from it yielded poorly, though its seedlings were good producers. Both were used to produce clonal seed. Clonal seedlings from B.P.56 and S.A.56 were similarly highly regarded. In comparing the results from clonal seed during 20 years of work, a good many numbers were outstanding. To a certain extent, the B.P.4 gave good results, but exceptional results came from B.P.42 in practically all testing fields, resulting m a so— called 'universal' selection.

Certain of these clones and clonal seedling stock are still being used. Among the clones were some especially selected as most adaptable as grafting stocks. Possibly the best example is R.Bgn.124.01, that also resisted nematodes. Another was from the variety called Canephora that was grown in Madagascar, and had the designation C.Bgn.Mad.3. The Dutch were thoughtful, studious, and conservative, and became second to none in their understanding of coffee. They had been at work on it for centuries, and they concluded, for one thing, that attention to horticultural research and applying the methods found best could be expected to raise production by 50 per cent, and, for another, that coffee yields per acre, especially of C. *canephora,* could be expected to increase at least 15 per cent from selection alone.

The improvement (and apparent future) of Canephoras has been such that it is startling when first encountered by those long immersed in nothing but Arabica. Through scientific industry they might even supersede that first species. Leaving aside Robusta's much easier and more abundant production, Canephoras are resistant to many diseases and pests and fill a recent technical place in soluble coffee manufacture. Much criticism of the small bean-size is being answered. In Java, breeding increased bean length by 2-4 mm. in three generations. This work has continued and some of the large-beaned clones are B.P.42, S.A.94, and S.A.176. A seedling from a cross between B.P.42 and S.A.94 was secured which produced beans that were larger than in common Arabica, and S.A.814 is a clone especially noted for size. As for aroma, Robusta has been crossed with the highly aromatic Maragogipe, and with common Arabica, and back-crossed to Robusta. Research on these is continuing. There is a promising Robusta-type hybrid of C. *congensis* and C. *canephora*, that is said to have a bean approaching good Santos coffee in flavour. Arabica and Congusta have been successfully crossed, combining aromatic qualities from both parents but still within the Canephora group.

The unhappy truth is that the vast Robusta coffee research background, vested for so long and so well in the Netherlanders, has been dispersed. But there is excellent redevelopment of it. Some has been started again by the Indonesians, and some of it is well in hand in Africa under the Portuguese, French, English, and Belgians. Usually planters and research men start with Canephoras as a last resort, because Arabica may have failed. But they end by liking the tree; and housewives find it more to their liking to drink the less expensive blends in which Robustas are employed (Coste, 1956). Some actually turn away from Arabica in favour of Canephora. According to Vallaeys (1956), seeds of Robustas were brought to the central part of the Congo during 1929 to 1935, and serious work was started that last year. Belgian scientists had the old Java clone S.A.34, which they used as their basis for comparison. From all of their introductions, they sorted out sixty-six mother trees of which S.A.158, L.36, L48, L.93, L.147, and L-215 showed up as outstanding during 1947 to 1954. Of these, the best were L.147, with its great vigour, and L.215, with its large beans 11 mm. long, 7-5 mm. wide, and 5-0 mm. deep.

The most recent methods used in breeding and selection for coffee improvement have been outlined by Maistre (1955). As they are followed, they will undoubtedly bring positive results. The Belgians and the French are carrying on, simultaneously, several large programmes in coffee improvement, and seem to be in a fair way to take the lead in the sciences concerned with coffee production. That some of their most serious difficulties are yielding to research is already evident In 1927 there was much trouble with the vascular disease called 'Tracheomycose'. In an extensive selection and breeding programme, in which some 17,000 have been tested, they have isolated four highly resistant clones, Excelsas A.86 and A.161, and Robustas B.io and A.445. In India, Narasimhaswamy (1950) announced the consistently high yield of the dependable selected Robusta S.274.

A THEORETICALLY GREAT COFFEE

The development of a great clone or variety is not quickly arrived at. It was over twenty years ago that Maher (1937) first outlined the requirements for a good coffee variety. This was under the headings of yield, vigour, adaptation, and quality of the bean. Coleman (1934) indicated some of the important desires in coffee varieties for India. Chevalier (1947) presented what he considered should be required of the choicest selection for a great coffee. C. A. Krug *et al.* (1950) state some of the more recent needs in coffee varieties for Brazil. These, and others, have done much thinking on this problem.

It would appear, from a concensus of the above and many more publications, and also from discussions with workers, that some of the requirements of any great variety of coffee are about as follows. The yield needs to be high and arrived at fairly soon, but not to the point of quick exhaustion of the plant. The maximum production should be reached shortly after the tenth year; it should be good but physiologically reasonable, and with careful attention it should be retained at that level for at least a score or more of years. A good average yield in fertile soil, with fertilizers and proper husbandry, would appear to be about 4 or 5 lb. of clean dry coffee grain per tree per year, and more or less year in and year out. It may be felt necessary to select, in some places, for production under adverse conditions. Others consider this a false premise and that starting trees with starvation conditions will forever harbour difficulties. Varieties that might be developed for specially poor soils may soon consume the little left in the soils. While biennial bearing, so commonly encountered, is, perhaps to some extent, due to soil poverty, it is probable that it is also partially hereditary, and a great variety will have little of such a characteristic. Vigour would have to be good to produce the quantity of grain required in a great variety. This vigour would not be of the excessively vegetative type but one in which the tree could make efficient use of the fertility it encountered or was furnished and, in addition, compose abundant carbohydrates with its well adjusted photosynthetic system. This vigour would be selected, not only as it was found in the top growth, but also as manifested in the root system. This would be a vigour especially eflfective for productivity under adequate conditions of growth.

All great varieties of coffees would need special attention to adaptability. Of prime importance are types of coffees that, with rational growing, will produce well, perhaps with a replanting scheme, for extensive periods of time—a century or even centuries in the same fields—without ruining the soils. There will have to be selection for twenty or more main ecological zones, from the standpoint of coffee horticulture. The closer the variety is adapted to the place where if is to be planted, the less are the difficulties to be encountered. Adaptability should take into consideration deep-roofing types to allow for growth in droughty conditions, and for rnechanical cultivation that would injure a minimum of feeder roots. A reasonably strong fruiting branch should also be carried—one that had resistance to die-back, and one able to withstand shock of harvest and spray practices, Great varieties would have to he well adapted to the necessary pruning practices and would, probably, not be too tall-growing in character. There should be incorporated into any great variety unquestioned resistance to the Hemilea rust disease, and, whenever possible, resistance to many other diseases too, and at least some of the insect pests. It is not considered possible that any variety will be developed that is fully resistant to all diseases, pests, and problems.

Great varieties should he such that they will allow economical harvesting, for example with the fewest possible number of pickings, and when, or if, harvested by machine, the fruiting habit should be such that the machine can gather what is needed, Fruits should also be easy to process, and bean liquoring or cop quality should be acceptable, The caffeine content of the grains should be in sufficient quantity. In selecting for greatness, varieties should be such that the grains they bear will have the kinds of soluble and aromatic contents that would satisfy the growing demand for manufacturing of the instant and soluble coffees.

TABLE III

SOME OF TOE STRIKING DIVERSITIES BETWEEN THE THREE COMMERCIALLY MOST IMPORTANT SPECIES OF COFFEE IN THE WORLD

Comparison	Arabica	Species Canephora	Liberica	Authority cited
Date species described, and author	1753 Linnaeus	1895 Pierre	1874 & 1880 Bull ex Hiern	
Dates of earliest plantations	6th century	1900–1910	1864–1881	Portères (1939) Ferwerda (1948)
Chromosome number	2n = 44	2n = 22	2n = 22	C. A. Krug (1937)
Number of stomata per unit of leaf	167·18	338·86	325·93	Franco (1939)
Pollination habit	Self-fertile, at times some insect pollinations but not necessary	Self-sterile, wind and insect action necessary	Self-sterile, wind and insect action necessary	Ferwerda (1936)
World export production (per cent)	92	7	1	Chevalier (1947)
Conditions of origin:				
Altitude	3,300–8,200 ft.	'Low'–44 ft.	'Low'–4,260 ft.	Chevalier (1947)
Vegetation	Moist closed forest	Open forests	Dense forests, open glades	
Elevation for good growth in cultivation	2,000–5,000 ft.	600–2,400 ft.	Sea level–1,800 ft.	Zimmermann (1928) Van Royen (1954)

TABLE III—*contd.*

Comparison	Species Arabica	Canephora	Liberica	Authority cited
Root distribution in wild	Go deep into soil, not confined to top layers, no distinct tap root	Shallow rooted, largely in upper soil layers, distinct tap root		A. S. Thomas (1944)
Height of tree in wild	26–33 ft.	6½–16 ft.	18–36 ft.	Chevalier (1929)
Height of tree under naturalized conditions	20–30 ft.	25–30 ft.	30–45 ft.	Wellman (MS.)
Good pruned height in cultivation	about 5 ft.	6½–8 ft.	8–10 ft.	Zimmermann (1928)
	—	10 ft.	30 ft.	Bunting & Milsum (1930)
Bearing age (years)	2 or 3	—	4 or 5	Chevalier (1929)
	—	3 or 4	—	Cramer (1957)
Accepted planting distances	11½ × 12½ ft.	10 × 10 ft.	13 × 13 ft.	
	6½ × 8 ft.	11½ × 11½ ft.	13 × 16½ ft.	
	5½ × 5½ ft.	13 × 13 ft.		Fauchère (1927)
	8 × 8 ft.	10 × 10 ft.	13 × 16½ ft.	David (1935)
	8 × 8 ft.–680 per acre	10 × 10 ft.–435 per acre	12 × 12 ft.–320 per acre	Malaya Dept. Agr. (1934)
Average pounds of cherries to 1 lb. of clean coffee	5	4	10	Anon. (1912)
Relative size of cherries	Medium	Small	Large	Anon. (1912)
Relative care required for production	Most	Medium amount	Least	David (1935)
Drought hardiness	Fair	Good	Best	Chevalier (1929)
Wilting during drought	Least	Most rapid	Intermediate	Wellman (MS.)
Average production of clean coffee per acre	288 lb.	713 lb.	400 lb.	David (1935)
Number of seeds per pound	1,200	1,600	800	Malaya Dept. Agr. (1934)
Caffeine content of beans (per cent)	0·85 to 1·7 0·7 to 1·6 0·8 to 2·2 1·0 to 1·2 1·47	1·5 to 2·5, 2·07, 2·4, 2·79, 2·57, 2·39, 2·0, 2·2	1·4 to 1·6, 1·52, 1·45, 1·53, 1·21	Knaus (1930)
Relative leaf size	Smallest	Largest	Medium	Anon. (1912)
Relative flower size	Small	Medium	Large	Anon. (1912)
Ripe cherry-drop	Drops cherries	Holds cherries	Holds cherries	David (1935)
Place of blooming	Only new wood	New wood	Old and new wood	van der Meulen (1939)
Time of flowering	After blossom showers	Irregular	Throughout year	Anon. (1912)
Resistances:				
Hemileia coffeicola	Susceptible	Resistant and tolerant	Immune	Wellman (1954*a*)
Koleroga	Susceptible	Tolerant	Tolerant	Wellman (MS.)
	Susceptible	Immune	Immune	Flores *et al.* (1955)
Scolyte borer	—	Resistant	Severe attack	Portères (1939)
Nematode	Susceptible	—	Resistant	Ferwerda (1932)
Fusarium in roots	Susceptible	High tolerance	—	Wellman (1954)
Blister-spot virus	Susceptible	Tolerant	—	Wellman (1957)

DIFFERENCES IN THREE SPECIES

There are some very interesting contrasts and inequalities among the three commonly used coffee species. These are presented in tabular form in Table III. The small Arabica tree, with its little blossoms, has a chromosome number of $2n = 44$, is self-fertile, and does not need insects or wind for pollination. The two large species, Canephora and Liberica, with their relatively gigantic blossoms, both have chromosome numbers of $2n == 22$ and are largely self-sterile, needing cross-pollination by wind and insects. It is notable that, although Arabica has the smallest leaves, it has, along with small leaves, much the smallest number of stomataon the leaf surface. Whereas Libericas and Canephoras have more stomata on their leaf surfaces, under certain conditions Arabicas show greater hardiness to drought. It seems that in Liberica and Canephora the large tap roots act as storage organs for moisture. Arabica has very little tap root development. Its lateral and feeder roots go more deeply into the soil, whereas laterals of the two other species are markedly more superficial in habit of growth. This also gives some indication of the fact that, relatively speaking, Arabica can better withstand stirring of the soil in cultivation than can either Canephora or Liberica. When it comes to the relative amount of care required to grow these three species, there are great differences. Arabica is, by far, the most finicky and can be spoiled by bad husbandry. Canephora is less readily damaged by bad treatment. Liberica, although it grows poorly under submarginal conditions, can still produce crops under some of the crudest and most thoughtless management.

Liberica is more likely to become adapted as a lowland coffee than Canephora or Arabica. But all three adapt themselves well to various elevations, soils, climates, and various shade and sun exposure cultivations. Heights of trees seen in the wild clearly indicate that some observed results depend upon where the trees may have been growing. The tallest seems most certainly to be Liberica, though Arabica and Canephora both stretch up greatly in dense cover—especially the latter. Under cultivation it is most likely that Libericas will be grown and managed as the tallest trees, the Canephoras as the next tallest, but bush-like, and the Arabicas as shorter trees with bush-like growth. In Arabica, the ideal height for plantations is often spoken of as that which would allow harvesting from the ground. To a lesser degree this is the case with Canephora. In Brazil, there is quite a little ladder-harvesting of Arabica, and in Angola highlands much of the Canephora (Robusta) is gathered without ladders. A great part of the harvesting of Liberica is accomplished from bamboo ladders or by beating with bamboo poles.

The amount of coffee that may be taken from an acre varies greatly from country to country, from year to year in a country, and from region to region in a country. There are often marked differences between adjacent fields, and between sections in fields. Soils, plantation treatments, ages of the trees, many things cause differences in harvests. These three . coffee species are all somewhat at the mercy of environment and care. However, relative quantities of harvest are characteristic of species differences. Conservatively speaking, where Arabica might produce 300 to 400 lb. per acre, Liberica would produce 20 to 25 per cent more, and Canephora could be expected to produce more than twice to nearly three or four times that expected from Arabica. The sizes of the ripe cherries of the species also differ considerably. The common Canephoras are, by far, the smallest, Libericas the largest, and Arabicas intermediate.

The ratios of fruit to dry grain, or beans, are characteristically as follows. It requires about 500 lb. of ordinary ripe Arabica cherries to make 100 lb. of clean coffee, something like 400 lb. of Canephora cherries are needed for 100 lb. of clean coffee, and approximately 1,000 lb. of fresh Liberica cherries are needed to make 100 lb. of clean coffee. Of the seeds, there are some 1,200 in a lb. of Arabica, 1,600 in a lb. of Canephora, and 800 in a lb. of Liberica. With respect to caffeine content, beans of Arabica and Liberica average i-o to 1-5 per cent, with some rising to a little more but not much. However, Canephora is considerably richer in the alkaloid, its beans averaging about 2*0 to 27 per cent.

Some of the most interesting comparisons that can readily be made between the three leading coffee species, deal with resistances and susceptibilities to conditions and diseases. For example, ordinary Arabica is characterized by its great susceptibility to the common rust, *Hemileia vastatrix,* but there is high tolerance in Canephora, with only medium resistance in Liberica. As regards the other rust, *H. coffeicola,* there is severe susceptibility in Arabica, but high resistance and even immunity in Liberica. Arabica is susceptible to Fusarium root infection but Canephora may be highly tolerant. Arabica is more susceptible to Koleroga than Canephora. In fact, although the latter may be attacked, it is rarely badly damaged by the disease; Liberica contracts the disease but it causes little damage. A disease in Angola, known as Mort Subita, kills Canephora trees rather rapidly, while Arabica appears quite highly resistant. The virus blister-spot, found in Costa Rica, severely attacks Arabica, but Canephora is only mildly affected and apparently recovers completely from seedling inoculation. The Arabicas, as a rule, appear more adapted to acid soil conditions than Libericas. On the other hand, certain strains of Liberica are able to withstand amounts of cold weather that are completely out of the question for Arabica. In heat-tolerance Liberica is best, Arabica is poorest, and Canephora is intermediate.

It can be seen from the above often valuable comparisons between the three important coffee species, that they show remarkable differences. Some differences are of great help in the problems of production, and, through them, one species may lend itself to adaptation in localities where another species has failed. However, the fact remains that Arabica, where it can grow, is the most popular of the three leading species, and it will remain so for some time. Meanwhile the values and uses of the other two species are not being wasted, and selections, interspecific hybrids, and mixtures, may yet completely change the coffee grower's future.

VI

COFFEE SOILS, CLIMATES, AND ROOTS

A REVIEW of the literature that deals with the kinds of soils in which it is possible to grow coffee, indicates the most extraordinary latitude in this respect. Mohr (1944) stated that, in the Dutch East Indies (Indonesia), Robusta coffees could be planted and would produce well on poor pseudo-sand soils at approximately 4,000 ft. elevation, and they could be expected to continue to give good results for years. At that elevation and down to 2,000 ft., the soils that were darker and somewhat heavier, of brownish ash, could be used if handled with great judgement and care. Below 2,000 ft., it was found better not to put coffee on volcanic ash soils. Robusta was, and is still, grown with considerable attention to soil type. Fig. 3 shows the geographical limits of coffee production.

SOILS FOR COFFEE

In a somewhat general review of coffee soils, Jacks (1936) concluded that one ideal for coffee would be a deep, slightly acid, well-drained loam, and it should be rich in nutrients, especially potash, with an ample supply of humus. Coffee is known to flourish well in top-soils of friable nature over a reasonably good, fairly heavy subsoil, and in which the transition is gradual between the two. A great deal of the world's finest coffee, especially Arabica, is produced on rather recent volcanic deposits. Examples that he gave of such were in Costa Rica—deep, sandy loams containing adequate humus but poor in lime. Another example was of a soil from a volcanic eruption in Java in 1901. The soil that resulted was of light-coloured, grey sand and gravel composition, that soon showed the first signs of weathering, and had a good supply of humus rapidly formed after it was laid. An example of coffee soils from deeply weathered lava could be pointed to in part of Kenya. The soils formed were deep and well drained, uniform, slightly acid, rich in potash, and poor in phosphorus. The best of them were in the regions where rainfall was high and temperatures were cool. The well-weathered coffee soils of the slopes of the Jamaica Blue Mountains were mentioned as from old conglomerates. They are noted for being drab brown in colour, acid, and badly leached. Coffee soils from conglomerates also occur in the Congo and the Ivory Coast.

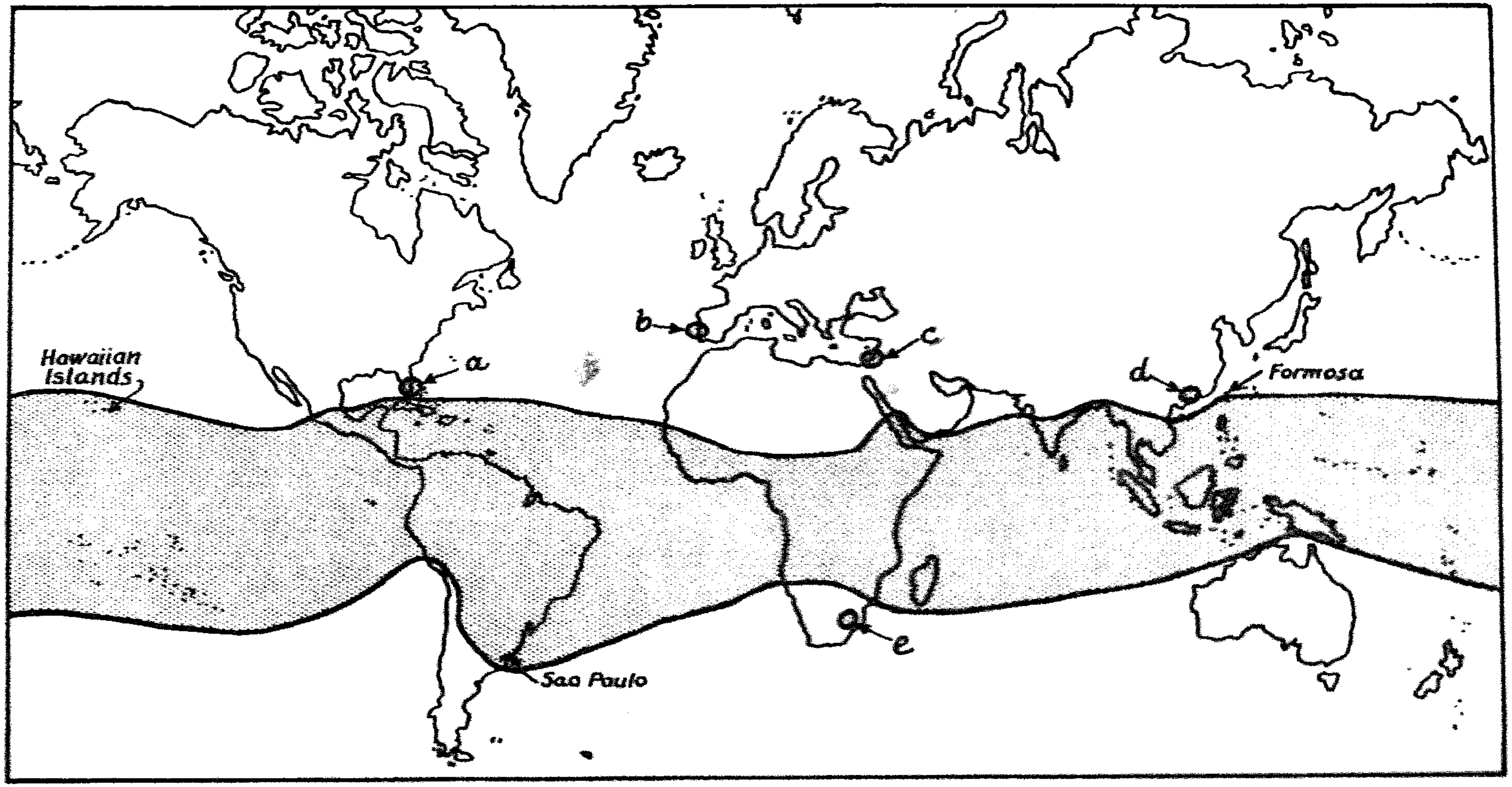


FIG. 3. Map showing the geographical limits of commercial coffee production. *a* = Southern Florida; *b* = Portugal; *c* = Palestine; *d* = Southern China; *e* = South Africa.

Savanna soils, such as those in Kenya, if they occur in regions of high temperature and low rainfall, are less fertile and not so good for coffee. On the other hand, the savanna soils in the Ivory Coast, where there is a little more rainfall, are weakly acid to neutral or slightly alkaline, and are better for coffee. In Uganda, good grassland soils are planted to coffee. Deep forest soils are also used. Some of those used in the Ivory Coast are very acid, poor in nutrients, and not the best for coffee. Forest soils, however, are usually very good for coffee, and such are the excellent deep red-brown, sandy forest loams of Angola and the Belgian Congo. These are slightly laterized, but some are rich in humus content.

One of the soil groups common in the tropics is that referred to as lateritic. Such soils are much planted to coffee. Jacks gave as some examples the deep lateritic deposits of the Kenya highlands, and the excellent coffee-producing regions of Java, with their famous loamy lateritic top-soils overlying porous subsoils. By far the greatest expanses of lateriticr soils being used for coffee are those in Brazil. The best of them are from original granites, gneisses, and diorites. They are rich in nitrogen and humus when first reclaimed from the forest, but are poor in lime, potash, and phosphate. Under conditions obtaining there, they yield well at first but soon become exhausted.

With respect to some of the discussion on soils, especially for Arabica coffees, Mohr (1944) noted that this species seemed to be even less dependent upon soil type than Robusta. Mohr named, from a comparatively small geographic area in Indonesia, eight very widely divergent kinds of soils upon which Arabica was grown. They ranged from soils out of andesitic complexes and conglomerates through soils from tuffs and limestones, to those from granitic detrituses. It was notable that Mohr felt that the humus content of the soil exercised the predominating influence in Arabica growing, and that, with good humus, you could overcome tremendous handicaps in soil types. One can find coffee growing well in certain Central American soils of very recent volcanic origin, composed of newly deposited white ash, and covered with a thin cap of soil darkened by organic content. In such white soils it seems of the utmost importance to preserve the dark superficial layers.

Gethin-Jones (1932) early observed that Arabica coffee grew well in Kenya in soils rendered acid from deep weathering of lava under humid tropical conditions. According to Livens (1951), the most outstanding requirement of soils for Arabica coffee was a good amount of humus, Franco (1947) intimated that, in Brazil, moisture was generally the most important limiting factor. Livens included, in his Arabica coffee-soil requirements, good aeration, some acidity, and a good supply of potassium; but the important thing was humus.

This was somewhat corroborative of coffee production studies in Uganda some fifteen years before, when W. S. Martin (1937) pointed out that, in his judgement, an evident; clone relationship existed! between organic matter content and easily soluble nutrients upon nfttdt production depended. On the other hand, Milne (1937) had made long-time studies of soils planted to coffee in the adjacent country of Tanganyika, and analysed records covering several decades of observations on this problem. There, in the Usambaras, a criterion used by the early Germans, for first and quick determination of adaptability of the soil to coffee, had been to observe the relative luxuriance of wild forest growth. Reasoning from analogy, they concluded that, the better the wild free growth, the better the soil for coffee. This was their measure of soil richness. However, it was repeatedly shown by bitter experience that a luxuriant tropical forest did not necessarily signify correspondingly high fertility of the ground when it was put to agricultural use. Some of the very rich-looking jungles gave the poorest results when cleared and made into coffee plantations.

It was observed in India by Meppen (1938) that much of the good coffee soil was under the evergreen forests, particularly when they grew well and had reasonably high rainfall This has been seen in other countries and indicates a more complicated matter than Milne's findings or the mistakes of the Germans in Tanganyika, although such negative results as his have been duplicated elsewhere. Consider the so-called better, red loam coffee soils of Brazil. These all started as forested lands (Pendleton, 1955; Setzer, 1945) and began under cultivation with a good supply of organic matter. Shade was taken away because of competition for moisture, and the soil was cleanly cultivated between the coffee tree rows. Then came the effects of weather: the rains and the sun destroyed the organic matter, and in a few years the soils were irreversibly deteriorating.

Following such observations, Pendleton, Mohr, and several cither soils scientists have pointed out repeatedly that tropical soils, and these include those used for coffee, are characteristically low in nutrients. Gourou (1953) speaks with reason of most tropical soils as fragile in comparison with those of the temperate zones. Vageler (1933) considered that, in tropical soils, humus content might be much more important than in temperate zone soils. The hope and necessity in the tropics is to prolong the productivity of soils by keeping them covered with crop vegetation, never allowing organic matter depletion. It appears that once the organic content is lost it is almost impossible to put it back into the coffee soils, as can be done so well in many crop soils in the temperate zone. A thoughtful observation was stated by Van Royen (1954) in his review,, that the best coffee soils are generally from forest lands that, at least at one time, were rich in humus. Gethin-Jones (1932) has pointed out that a coffee soil in Kenya should be fairly well supplied with nutrients; that a 5 cwt. crop of Arabica removes from the soil 25 lb. of nitrogen, 5 of phosphoric acid, and 25 of potash. In general, clays are not good for coffees. The world-famous red 'terra roxa' soils of Brazil come from diorites rich in feldspar, with much of the originally intermixed organic matter burnt out The best black and brown soils of Colombia, and of some Central American countries, are in many cases of highly complex volcanic origins aided by organic matter cover. Again, in Brazil, Suarez de Castro (1953) spoke of a good coffee soil as a sandy loam, not rich, and ordinarily considered as deficient in phosphorus, but with good moisture-retention capacity.

VARIABLE ECOLOGY OF COFFEE

It has been quite impressive to me to notice the breadth of ecological conditions under which the species *Coffea arabica* can grow well and produce good crops. The range for growth discussed here largely refers to cultivated coffee and, in many cases, the success of a crop is very much due to the horticultural art of those who are growing it and improving difficult conditions. There are some who hold that the soils must be naturally rich, deep and friable. In some cases it has been specified that they should be of somewhat new volcanic origin. However, Arabica coffee is not always thus well treated. It is true that there are regions in such countries as El Salvador, Guatemala, Nicaragua, Java, Uganda, and Tanganyika where excellent coffee is grown in comparatively newly formed volcanic soils. On the other hand, some of the highest productions reported in Uganda and Brazil have been from soils of ancient water-laid character.

It is common to see the old red lateritic soils in Costa Rica or in Brazil, for example, growing good crops of coffee. Similarly-coloured poor soils growing good coffee can be seen in India, in the French Cameroons, in El Salvador, and in the old regions of Ceylon where coffee flourished handsomely until it was driven out by the rust disease. Those who hold that coffee soils must be deep and friable should go to Panama, Kenya, or parts of Brazil, where good coffee grows in excessively thin top-soils with poor subsoils. In Ceylon, before the occurrence of rust, large crops of coffee were taken from plantations on thin, hard, clay soils. A striking example of a unique coffee soil is the Kona district in Hawaii, where coffee, of very high quality and producing excellent crops, grows in small quantities of fertilized soil, originally of very poor fertility, that is pulverized and wedged between and mixed among the rocks composing the piles of blue volcanic stone ballast that covers the district.

It is a common statement that Arabica coffee requires fairly high elevation and is, in fact, a mountain crop growing best on steep slopes. Certainly, there are countries where planters consider that the only suitable areas for coffee-growing are on hillsides. In Puerto Rico, it is even the habit to restrict coffee-growing to the hills where it is needed for water and soil conservation reasons and appears to grow well under those hill-side conditions. Experience in Brazil is that tremendous stretches of flat or only slightly rolling land are dedicated to coffee. In Kenya, flat and moderately undulating topography is chosen as preferable to steeper hillsides. Indeed, it is unlawful there to plant coffee on any land with over 20 degrees slope. Some of the highest coffee production is Costa Rica comes from plantations at elevations of 2,000 ft., and less, from the sea level and on the flatter lands. In Ecuador, some Arabica coffee grows and produces crops on flat lands, almost at sea level, in well-drained parts of the great Pacific littoral that was deposited by the sluggish Guayas River. In Panama, some fine quality coffee grows on high and rugged hills but there, also, coffee has grown for decades in flat lowlands under far from mountain conditions.

Returning to the findings reported by Mohr (1944) on Arabica coffee in Indonesia, it was, and still is, well recognized there that a good humus content exercises a predominating influence. It is almost inevitably at the higher elevations, where there is sufficient moisture, that there is more organic matter, although the humus content does not need to be in extreme quantities. In the Idjen Plateau of East Java, where Arabica is grown under a notably dry climate, the surface soil is grey to black, the subsoil is light yellowish-brown, and it is friable in texture throughout, but the actual humus content is not strikingly high. On the other hand, Arabica has often failed in the Celebes, an island near Java with European planters who clean-cultivate, but is grown well by natives of the island who give special attention to humus accumulations. These they develop by piling trash, from their fields and from adjacent forests, around the bases of their coffee trees. There it is held with stones weighing it down to keep winds and rains from blowing if away or washing it down the slopes. It is thus held tight to the soil, where it decays and is used sucessfully. In Kenya, where Thorold (1947) worked on soils producing good Arabica coffee, he found some characteristics that were common to all of them. They were mostly red sandy loams, were volcanic in origin, were quite acid, were low in phosphates and lime, but were significantly high both in potash and in organic matter. It has been suggested by several workers that relatively high availability of those soil nutrients may well have been dependent upon the interrelation between high organic content and soil acidity.

SOIL REACTIONS SUITABLE FOR COFFEE

It has been difficult to obtain scientific proof of many of the basic features of field nutrition in tropical crops. In addition to controversies in numerous countries about the relative importance of organic matter content in coffee soils, there has been much preoccupation with the effects of relative acidity in those soils, with divergent findings. Thorold (q.v.) found in Kenya a *pH* reaction of 4.7 in good coffee soils, which is considered unusually low for most arable fields. From Tanganyika soils growing good coffee they have reported a *pH* of about 6. Haarrr (1950) considered good coffee soils those with a *pH* of 7.1 to 6-8 in the upper 6 in., and with a subsoil of about 5.5. Much of the best Central American coflfee is grown in soils with *pH* values of near 5.5 to 6.5, and I have seen Arabica growing in soils with a *pH* of 4.2 in Costa Rica. Nutman (1933*a*), in his detailed investigations of Arabica root systems in British East Africa, found that good root growth was in neutral to slightly acid soils. He considered that *pH* 5.8 to 6.0 was near to the acid limit of good growth, but he observed an exception in the Kiambu region where it was much more acid, and the roots behaved well in soil at *pH* 4.8. These soils, however, had a history of much fertilization, and he believed the extreme acidity was ameliorated by the nutritive additions. From a review of literature and physiological studies, J. Small (1946) concluded that coffee belonged to plants in his group III, the 'mesophilous', which grew between *pH* 5.0 and 7.0, with the optimum usually at close to *pH* 6.0.

It is evident that coffee does grow over a wide range of soil acidities, but a common opinion is that the soils should be acid. Reports on liquid-culture studies may be of interest in this regard. De Camargo *et al* (1937) investigated the matter by growing Arabica in liquid cultures at different reactions. Under their conditions they found that the plant preferred a somewhat acid medium, between 4.2 and 5.1. Van der Veen (1940) reported that in his liquid cultures the very lowest limit for Arabica coffee was *pH* 3.5, and for Robusta 4.0. Wilson Mayne (1940) found an acid reaction of *pH* 4.5 to be necessary for use of iron in the nutrient solutions, and van der Veen (q.v.) concluded that the reason why Jacob could not grow coffee in liquid at a *pR* of above 5.5 was because iron was not then available. Sylvain (1955) reported significant findings in Ethiopia on the *pR* of soils growing *C. arabica* in the wild state in forests from which it first came. He found a number of these soils to be from *pH* 5.4 to 6.0, which, he pointed out, was quite close to findings of Italian workers a few years prior to him, who sampled thirty-four coffee-growing soils there and found that they varied from 5.3 to 6.6. From combining his observations with those of others, Sylvain concluded that the soils of the coffee forests on the high Ethiopian plateau are, for the most part, slightly acid. They are generally lateritic in formation, red-brown and dark brown to chocolate in colour, of considerable depth, and correspond well to some of the good soils growing coffee in other parts of the world.

NATURALLY NUTRITIVE SOILS

Many reports on natural nutrition in coffee soils refer to Arabica, but it is also important in Robusta. Haarer (1950) was of the opinion that this latter could advantageously use a somewhat more nutritive and heavier soil than is used for Arabica, and that it should be slightly more acid. He considered that a very good soil for Robusta was a type in Tanganyika, which was a dark reddish-brown, deep friable loam from volcanic materials, and with high water-holding capacity. From the descriptions of coffee research stations listed by the Commonwealth Agricultural Bureaux (1952), it is of interest to note that in Kawanda, Uganda, there is a light loam soil. This is used for Robusta studies and is not like the types which Haarer and Mohr presented as best for the crop. In Bukalusa Farm Station, also in Uganda, where other work on Robusta is carried on, the soil is different from the others mentioned and belongs to the so-called Red Earth Series. A soils study of all the areas in which Robusta grows now, or such a study of the areas in which the variety was found originally in the wild state, would considerably widen the known range of soils on which it might be depended to grow.

A long list of research workers in the Netherlands East Indies came to the conclusion that, despite general appearances, coffee is an exacting crop (Cramer, 1957). To produce well, soils must be deep and well drained, with a good basic amount of nutrients, but most of all they must have adequate humus. Probably the coffee soils have been studied more in those islands than in any other part of the world. Some of the first work there was accomplished long before the end of the last century, a portion of it being published in 1900. Study on these soils went on for over fifty years, until the time of the Second World War. Although the studies of the Dutch soil investigators mostly applied to the species *C. canephora*, or Robusta, they are of equal value to those interested in other species. These reported findings are given here in an abbreviated form.

From the early studies down to more recent date, it has been clear that classifications of Indonesian coffee soils range from heavy clays, for example those at lower elevations in central Java, to loose volcanic ash deposits, such as those on the sides of the Keloed mountain. However, the soils men believed that the thing which makes these good and long-lived coffee soils is the humus they contain and also what is being added. It is the experience in Java, that Robusta grows best in rich, new volcanic soils, although with proper husbandry it is highly productive on the quite different, older, lateritic soils. In some parts of Java, after coffee had been grown for decades and crops had gone low, work was instituted to rejuvenate those soils. The main requirement for soil rehabilitation has been resting it, adding humus by mulching or growing green manures, coupled with terracing. In some extremely old plantations ('coffee gardens' as they were called) the growers, who were working in continual contact with their government specialists, carried out well-designed applications of chemical fertilizers and applications of barnyard manure before replanting. On the whole, however, those old lands had never been allowed to 'ran out' irretrievably. For many decades, in some cases two centuries, the growers had worked with great industry to retain a good soil-humus content. This was done through highly intelligent shade-tree growing and management, and the inclusion of what they called 'green manurers' to be grown between coffee rows at the right season.

There has been some argument concerning what is so extremely important about humus in coffee soils. According to one school of thought, of which Vageler (1933) is a proponent, coffee trees are plants that require mycorrhizal fungus development in their roots. These fungi grow into the outer absorbing tissues of coffee roots, and thus bring into them nutrients not absorbed in any other fashion. According to students of the mycorrhizas, there are two great necessities for the growth of these special fungi: one is the fungus food in the decaying humus content of the soil, and the other is moisture that humus helps to maintain.* In any case, coffee grows well in soils with adequate humus, and these soils become thus endowed because of the proper climate in which they are. While no one yet knows all the variability in the ecology of coffees, they are known to grow in a remarkably wide range of elevations, temperatures, exposures, and various patterns of precipitation.

RAINFALL AND THE CROP

It is believed by some that common coffee has to have a growing year clearly divided into two seasons, one wet and one dry. Yet there seems to be no special seasonal variation necessary for coffee production. There are those who are most fervently set in the idea that, to produce best, coffee must have half the year composed of a long dry season followed by a similar wet one, that finally tapers off to the dry. By many it is held that this results in the most economical crop production, giving the trees less strain and thus raising production year after year. People with such a prejudice should investigate parts of Colombia and places in the Orient, such as in Sumatra, where instead of a 'normal' year, half wet and half dry, there are four seasons—a wet followed by dry, with another wet followed by another dry. They should also visit the Turrialba region of Costa Rica where it is seldom really dry. In all such places, production is comparable and, in some cases, even surpasses that of regions nearby, where there is the regular 'normal' two-seasons-per-annum distribution.

Much Arabica is grown where yearly rainfall is around 75 in. (1,905 mm.). This is often thought of as rather ideal, and perhaps it may be. However, some of the highest production of coffee in the country of Costa Rica comes from a region where the rainfall often reaches no in. (2,794 mm.) and even more a year. Yet, in areas of the best coffee lands in Brazil, precipitation is 30 and 40 in., and sometimes less. Some of the most spectacular failures in well subsidized plantations in Costa Rica have been in heavy rainfall regions, over 200 in., where production was, at first, phenomenally great; but, as the years progressed, disease increased quickly, and the plantations were finally abandoned. Arabica

* For an up-to-date account of the whole intriguing subject of mycorrhizal association, reference may be made to Dr. J. L. Harley's *The Biology of Mycorrhiza* (Plant Science Monographs, Leonard Hill, London, pp. xiv + 233, illust., 1959)—Ed.

coffee may not require drought to make it bear, but it withstands long and severe dry periods, such as occur in Uganda, Kenya, Mexico, Guatemala, and Brazil, where leaves actually wilt. But, when the rains come again, the trees revive, leaves become turgid, and the plants continue vigorous growth and fruiting.

The problems related to rainfall and soil moisture have been studied for some time in coffee as well as in many other tropical crops. It is of interest to find how coffee compares with some others. It has been reported by Vageler (1933) and Livens (1951) that coffee requires rainfall of about 60 to 90 in. a year. As can be seen by the student, and must be realized by the reader of the foregoing pages, there is no hard and fast rule. In cool locations, with such conditions as abundant clouds and good soil mulch, the precipitation requirement could be very much less than 60 in. In fact, under relatively clear skies, careful horticulture will produce good coffee crops even in fairly warm conditions at an annual rainfall of much less than 60 in. In warm areas, however, where shade is poor, soils are thin and lacking in humus, and there is little or no soil protection, coffee might require much more than 60 in. of rainfall to keep growing even reasonably well. But Arabica and Robusta coffee do grow successfully in countries where rainfall averages well over 100 in. a year. Under some situations coffee can withstand a lot of rain, although it is highly susceptible to stagnant ground-water. As can be seen in the accompanying table, coffee has general moisture requirements that are about intermediate when compared with some other important tropical crops. Grapes and cereals, for example, need only about half as much rain, and such a product as oil palm needs nearly twice as much rainfall as coffee.

TABLE IV

THE RELATIVE MOISTURE REQUIREMENTS OF COFFEE COMPARED WITH CERTALM OTHER CROPS IN THE TROPICS*

Crop †	Water consumed ‡ per annum, mm.
Grape	100-150
Cereals	120-125
Oil seeds	120-150
Maize	200 - 250
Coconut palm	200-250
Coffee	250-300 ‖
Cocoa	300-400
Root crops	300-400
Tea	350-400
Sugar cane	400-500
Oil palm	600-700

Adapted from Vageler (1933) and Livens (1951).

† On the whole such crops consume about 400 units of water for each unit of dry-weight.

‡ Only a little over 20 per cent of the water that falls is used by the plant. The numbers in this column should be multiplied by a little over four to indicate approximate annual rainfall requirements *(see* Vageler, 1933; Livens, 1951) to include waste and evaporation.

II Calculating at a little over 20 per cent, in the case of coffee it could probably be considered that the 12 to 18 in. of water consumed would necessitate 60 to 90 in. of rainfall per annum.

MOISTURE AND NUTRITIVE EFFECT ON ROOTS

In the final analysis, what a climate or a soil will do for a crop is determined by what the effect is upon the root system. An understanding of how coffee roots act is thus important, and a review of some of the studies on them is presented here. Planters and research workers wanted to know what was happening with roots in the dry soils of Kenya, and this was investigated 20 to 25 years ago. Some early and sound deductions by Le Poer Trench (1934) were that Arabica trees, for good production, had to have abundant deep feeder roots, and many side roots. He dug coffee trees but did not find the long tapering tap root that might have been expected. He was an early observer that, under certain conditions, Arabica is far from being a surface feeder. Beckley (1935), also reporting on work in dry parts of Kenya, had been studying the basic features of two types of leaf chlorosis in Arabica. One kind was associated with an inadequate nitrogen supply, during the time of its maximum demand, but showed no root-effect. The other kind, that occurred along with inadequate carbohydrate tissue content, caused both die-back of fruit branches and killing of roots. There seemed to be a soil moisture relationship.

Over a decade later, Pereira (1948*a*) reported evidences that further assist us in understanding the soil-moisture relations of coffee roots. He had also been working on coffee leaf chlorosis that seemed to come along with drought. But there was no absolute certainty that the leaf-yellowing was actually a matter of lack of soil fertility or lack of available soil moisture. Fertilization, mulching, and other treatments were carried out, and it was proved well enough that growth was first dependent on sufficient soil moisture. If the soil were too dry the foliage yellowed, even with perfectly adequate amounts of nutrients remaining unused in the soil below.

From studies by Jones (1949) on absorption of nutrients, it was learned that, in relatively dry regions, fertility in the top-soils was practically inaccessible to the tree roots for a great proportion of the year, owing to a too rapid and severe drying of the surface soils after fertilizer applications. Pereira (19490), working with dry soils, related fertilizer absorption with availability of soil moisture. It was found that the amount of what he called the 'soil moisture reservoir', where roots could reach deep in the soil below the trees, was more important than the application of nutrients. He had already demonstrated (1948) that 'subsoil reservoirs' used by coffee roots ranged from 6 to over 15 ft. down into the soil.

This was corroborated in the work of Franco (1947, 1952) who found, in relatively dry Brazil, that Arabica easily suffered from competition with shade trees, and that the factor most responsible was the small amount of available soil-water. He demonstrated that, if much of the time the soil moisture content was at the wilting point in the soil depths that contained most absorbing roots, the coffee could not possibly thrive. He took soil moisture readings in coffee soils at 1 m. depth (about 3 ft. 3 1/2 ins.), which is an important field level in relation to coffee roots. Where coffee showed itself to be suffering in the shade, but doing well in the sun, he found marked differences in soil moisture. In soil where the roots of both coffee and shade trees were drawing on available water, the soil moisture percentage was 9.0. But in the area where only coffee roots were drawing on the soil, there was 12.8 per cent moisture. In the coffee where roots seemed to be receiving sufficient moisture, both in shade and in sun, he found a different situation. The soil where Inga shade grew well and where coffee also grew well under it—the soil that contained both Inga and coffee tree roots drawing on it—had a moisture content of 16.5 per cent. Close by, in the full sun, coffee was growing well without shade. Where there were only coffee roots drawing on the water, the soil moisture content was 15.0 per cent—a little less than that in the shade, but ample for growth. P1. 15 illustrates some of these principles.

The permeability of soil also makes a great difference as to where roots penetrate, especially with young coffee. Jones (1949) planted seedlings in, what must have been, rather stiff soil, judging from reports. For some, the holes were 3 ft. square and 3 deep, filled with relatively permeable weathered soil and surface trash. For others, the holes were smaller, as small as 1 ft in all dimensions. The extra help from the better start in the larger holes resulted in an increase in crop of 2 cwt. per acre per year. Soil porosity was also found to be a limiting factor in coffee root penetration in Brazil (Franco & Inforzato, 1946). Such a report as that by A. S. Thomas (1940), that coffee roots follow old dead root channels of shade trees, also indicates how a good porous medium is relished by coffee.

It is probable that, in addition to porosity, the old root channels retain the leavings from tissue decay. In this respect, coffee roots react in a positive manner, growing towards and into areas of more readily available nutrients. Some direct effects from nutrients on coffee roots (Jacob, 1938*a*; Wilson Mayne, 1940) are quite obvious. For example, withholding nitrogen causes the roots to be checked in growth. They cannot elongate without this element. If roots are fed with a solution low in nitrogen, they grow but become long and thin. On the other hand, with high nitrogen content the roots that develop are short and thick and much branched. Another chemical that affects roots in an obvious manner is calcium. Without calcium the root tips die and within 2 weeks the weakening of the roots can be seen with the naked eye. Similarly, roots are quickly weakened in growth in the absence of magnesium.

Field temperatures make considerable differences to root occurrence. In a report of the Kenya Coffee Board (1945), their soil scientists showed that Arabica roots, in the lower and hotter soils, go down. In the soils of plantations in the higher regions, where it is cooler, coffee roots tend towards growth near the surface. At about the same time, reports from work some distance away in Tanganyika (McMaster, 1946) indicated the same findings. There, the coffee at the higher, cooler locations had rather superficial roots. With the same coffee only a few miles distant but at a lower, much warmer altitude, the roots grew down. The farmers have taken advantage of these findings. At cool altitudes, heavy mulching is used in coffee plantations to protect the surface feeding-roots. Stirring of the soil is injurious. In the warm altitudes more cultivation is done, to the betterment of coffee. The soil is stirred deeply to 'drive' the roots downward into the moister soil.

ROOTS OF DIFFERENT SPECIES

It has already been pointed out that, generally speaking, Robusta coffee, C. *canephora,* is more shallow rooted than Arabica *(see* A. S. Thomas, 1944). The root distribution of C. *excelsa* is somewhat similar to that of *C. canephora*. The work done on the comparisons of these root systems was on wild trees growing together in mixed woodland on the Boma Plateau of the Anglo-Egyptian Sudan. The soils of that fairly warm region, judging from an earlier description (A. S. Thomas, 1942), are slightly acid to neutral, friable loams that are chocolate-coloured and low in phosphate but reasonably well supplied with potash and lime. The fact that the trees were in woodland would indicate a good supply of humus, and the soil must have been at least somewhat porous. Using an augur for root sampling, Thomas removed cores at specified distances and depths, and these were taken to the experiment station and examined and analysed for coffee root presence.

It was found that, in the wild, the Robusta tree systems of feeding roots are very shallow and largely confined to the upper soil layers. The main lateral roots radiate near the ground surface, and have attached to them abundant feeding roots. This makes an interlaced 'mat' in the superficial layers of the soil. Roots also occupy the deposit of debris and leaves on the ground under the trees. In Robusta, more roots were found in the top 6 in. of soil than in the layer 12 to 18 in. below the surface. Farther down, there were very few roots. In Arabica growing close by, there were few roots in the superficial soil layer, and many more farther down where Arabica did not occur under Robusta. Arabica trees are not distinguished by a spectacular tap root, whereas Canephora trees have such roots, distinct and well developed. Thomas further found, in Uganda, that, when Robusta roots were mulched, they responded readily and, if undisturbed, produced extraordinary growth in the surface layer of the soil and in the contiguous mulch. If the mulch was 'dug into the soil' it caused severe root injury.

ROOT SYSTEMS AND SOILS

One of the most extensive research programmes on root systems of Arabica, was that in relation to East African areas, carried on by Nutman

(1933, 1933*a*, 1934). These soils tended to be heavy, slightly acid, poor in humus, and were in the drier areas. This type of research is difficult, because of the kind of problem that it is, and because it entails so much excavation. What the worker does not do himself has to be constantly watched There are also the root separations from soil, measurements and weighings, plotting of soil sections, and book-keeping of findings. What Nutman did is of classic nature and, although it is not the only such study, was so presented that it has gained the most fame. To it will be given rather full attention here, as it is a clear presentation and, although some may not consider it the most important study, is the one with which the others may be compared. To me, it is the most complete and most basic of these studies.

Some of the main conclusions of Nutman about the structure of the 'normal' coffee root system are as follows. A large proportion of coffee roots are the cutinized 'permanents', that are more than an eighth of an inch in diameter. This is an arbitrary size limit, but these roots form the main framework of the root system. Another fraction the 'feeder bearers', roots that are also cutinized; smaller in diameter than the permanent, they actually branch out from those larger roots. From the feeder bearers arise the white, turgid, uncutinized 'feeder' roots with root-hairs. The total absorbing area of the roots is enormous. Nutman calculated that the absorbing surface of one grown Arabica tree is of the order of 400 to 500 sq. m. (1,313 to 1,840 sq. ft).

The 'typical root system' of Arabica coffee, as Nutman finds it, consists of several distinct components. The tap root is a short and stout central root, sometimes forked and multiple, not more than a foot or 18 in. long. Branching out from the region of the forking of the tap root, and going down from there vertically, are some four to eight slender axial roots.. These go down to 8 or 9 ft. from the surface. Extending from the axis in all directions, are many long lateral roots that run slightly downwards but more or less parallel to the soil surface. They go through the soil mostly in a horizontal plane, but branch otherwise, too, and form what Nutman aptly calls a 'surface plate' of roots inhabiting the upper layers of the soil. The surface plate is most developed in cool moist soils. A few of the laterals branch and may become verticals, assuming the character of axial roots.

There is another set of lower lateral roots of great importance. These nether laterals do not run parallel to the soil surface, but go down deeper into the soil. They ramify evenly in the soil, branch in all directions, and are numerous well below the surface plate. These are the roots that develop most strongly in drier, warmer soils. These 'feeder-bearer' roots are more slender than the laterals, and branch off from them. They are cutinized, are longer when from the deeper laterals, and tend to be shorter from the more superficial laterals. The active 'feeder' roots are found on feeder bearer roots at all depths, but may be more numerous in the more

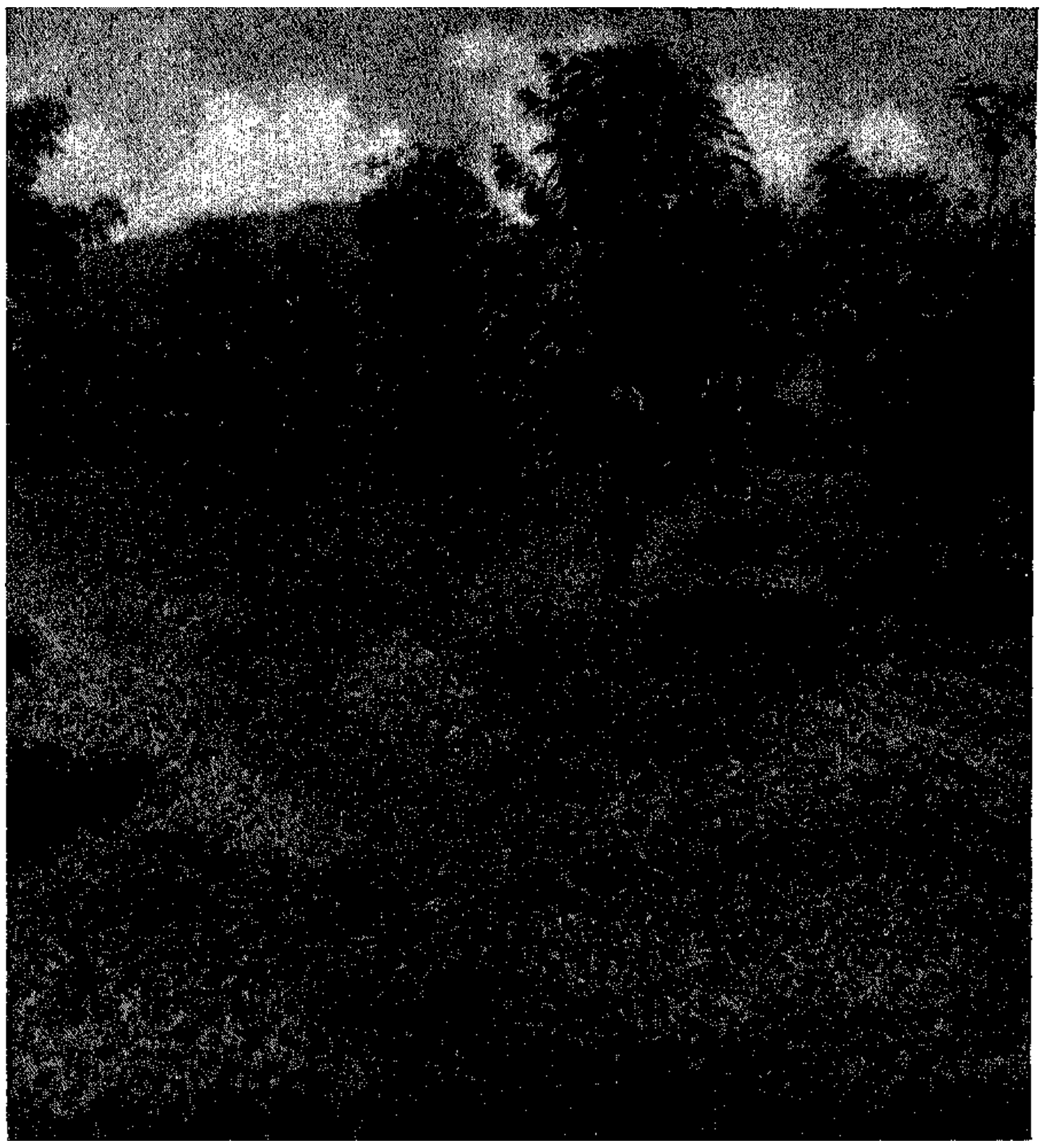


PLATE 15.—*(a)* Remains of a closely planted experimental field of coffee trees grown in the sun in an area where they are generally produced under shade. Grass must be constantly eliminated and the trees well fertilized and sprayed or they will soon succumb (as have many of these) to various difficulties. I.A.I.A.S., Costa Rica.

(b) Arabica coffee, growing where it is so dry that the presence of shade trees would extract too much soil moisture from around the coffee roots. The soil is of a red lateritic type, kept free from weeds. These trees are of the Bourbon variety, grown in covas. Brazil.

(b)

Photo James Mitchell

superficial part of the soil. The greatest concentration of roots is not found in the first foot of soil, but in the foot just below it Usually in Arabica Nutman found that there are more roots in the third foot of soil than in the top foot.

Nutman found that Arabica coffee appears to develop fully the main lines of its root system in 5 to 6 years after planting. By this time, extensive growth of the main roots has virtually ceased. In relatively dry East African soils, the root system penetrates rather deeply. A coffee tree has a great many roots attached to it, as can be seen from measurements Nutman made on four trees. The total length of feeding roots from one tree was over 15 km., another had a little more than 20, another had nearly 24, and the fourth had almost 33 km. If there is a hard-pan layer in the soil, it seems to have no great inhibitory effect on roots; they grow right through it. Roots also readily penetrate a stratum of lava, mud, and stone, going between the crevices. However, a stratum of clean gravel and pebbles will effectively inhibit penetration. Aeration, from whatever reason, such as termite activity, old shade tree root channels, or subsoiling, will increase the growth greatly, but the opposite occurs in waterlogged soil. A high water-table causes severe root injury, and roots will not develop very close to the permanent water-table.

With respect to soil acidity, Nutman found that feeder roots were numerous in neutral to slightly acid top-soil, and almost lacking deeper down where the subsoil was quite acid. He made observations, throughout his root distribution studies, that convinced him that 'careful treatment on an unsuitable soil will produce plants as good as those on an ideal soil but maltreated culturally'. He also noted that in some areas very poor coffee growth was associated with intense soil acidity. This, he found, was especially the case if the top-soil had been badly washed away and depleted by erosion.

Other strenuous coffee root studies on Arabica were carried out in Puerto Rico by Guiscafre-Arrillaga & Gomez (1938, 1940, 19420). They used a somewhat similar pattern of approach to the problem as that of Nutman, but employed different techniques. The soils in which they worked had more humus than the usual coffee soils in East Africa, where much coffee is grown in the sun. In Puerto Rico, the soil was more moist, and trees were grown in the shade. Under Puerto Rican conditions, the general coffee root distribution pattern of a 'typical root system' was corroborative of what Nutman found. The Puerto Ricans attempted to work out a tops-to-roots ratio in coffee, on a weight basis. The variations were great, and no fully satisfactory conclusion was reached. In six young 7-year old trees the ratio was about 8 to 1, in another group of six of the same age the ratio was 3 to 1, and in six old trees aged 21 years the ratio was 4 to 1.

In this digging in the soil in Puerto Rico, account was taken of the depths of root distribution. It was found that under those moist conditions, 94 per cent of the coffee roots were in the topmost 12 in. of soil. Moreover, root systems of both old and young trees followed the same distribution in the soil. This is a much more superficial distribution than that shown by Nutman, and there seems to be a good reason for it. From all the findings of previous workers, reviewed above, it seems that it is the habit of coffee that grows in cool, moist habitats, and with shade, to bear its roots in a much more superficial manner than do trees growing in drier, warmer regions, and in the sun.

The Puerto Ricans discovered that, in their older trees, the finer primary roots comprised nearly 60 per cent of the total root system, and were in the top two feet of soil. The secondaries made up about 25 per cent of the root system, and the tertiaries, the coarsest roots, made up the rest. They also found that, the thicker the trunk of a young tree, the larger the amount of roots that could be found in the soil below it.

In Brazil, Franco & Inforzato (1946) carried on further work with Arabica coffee root studies under local conditions. In that country, the soils are dry, in some ways similar to those in Kenya, and coffee is grown in the sun. What was determined in Brazil again corroborated the general findings on structure of the root system by those previous workers in Puerto Rico and British East Africa, using the same coffee. It was clear from the excavations of the Brazilians that the key characteristic of the best producing soil was that it had porosity going deepest. The best and most porous soil allowed large amounts of roots to penetrate 8 to 9 ft. down. Another soil, not so good, allowed penetration of 6 1/2 to 8 ft., and another that was studied, a little poorer still, allowed roots to go down 7 ft. In none of the Brazil studies were feeder roots superficial in occurrence. They all 'went down for moisture'.

The last, but not the least interesting, root-distribution study of Arabica to be reviewed, was by Suarez de Castro (1951,1953) in Colombia. He was in a moist climate, with shaded coffee that had its roots protected with a natural leaf mulch on the soil surface. He found the same general construction outline of the root system as that found by others before him. An important observation of his was that, on sloping land, the root distribution followed parallel with the slope. There was no influence of slope on distribution. He also found, as was seen in the moist soil of Puerto Rico, that the root system occurred mostly in the top layer of the top-soil. His data showed that the first 4 in. of soil held 52 to 55 per cent of the absorbing roots, and close to 40 per cent of the total root system. The anchoring and other roots went down quite a long distance below this concentrated surface plate of roots.

A significant point of interest in all these studies is that roots of good coffee trees are powerful organs that make the most of all opportunities to gain their ends of anchorage and food absorption. Ripperton *et al* (1935) noted that some of the best coffee in the world was found in deep soils, but in Kona in Hawaii there are soils on top of rocks or wedged between them. The Hawaiian workers also admit that world literature has indicated that coffee soils should contain a good quantity of leaf-mould; yet, in their Kona soils, the crop has been grown for generations without leaf-mould and, furthermore, no special efforts have been, or are being made, to introduce it. Beaumont & Fukunaga (1953), also from Hawaii, reported on a visit to Central and South American countries. They saw in the western hemisphere apparently rich virgin soils producing fine crops of coffee. Yet these coffee workers concluded, with approving wonder, that the very old Hawaiian fields with heavy use of artificial fertilizers produced as good coffees as the better virgin soils of the American Tropics.

Before the close of this chapter it seems not out of place to mention that, to understand above-ground appearance of sickliness in coffee trees, a pathologist may find it imperative to dig out roots for examination. In El Salvador, during the years 1945 and 1946, detailed attention was given to marked debilitation in Arabica trees of the Typica variety. These were in an experimental field, about an acre in extent, that was under Inga shade. These Arabicas were of various ages and conditions of pruning. The climate was characterized by approximately 75 in. of rain per annum, with dry seasons of seven and eight months' duration. Soil was of young volcanic origin, unfertilized, and kept clean-cultivated by regular cutting of weeds and sweeping of all shade tree and weed debris into numerous conveniently located silt pits.

Eighty-two pairs of sick and healthy trees were studied. Although the debilitation seemed to be from chronic die-back effect, efforts were made to isolate parasitic organisms, and microscopic studies were made. No pathogenic bacteria or fungi were found that, alone, could have been the primary cause of the serious infirmity noted. Symptoms were not suggestive of a virus.

Crop histories were traced back for three to six years, and in a few outstanding cases farther. In all instances of most serious failures, there had been one or two extremely heavy crops, apparently followed by excess leaf-fall and acute die-back. Of some eighty selected trees, twenty-two were dug, some only partly, to examine roots. Two representative pairs of completely exhumed root systems are shown in the accompanying sketches (Figs. 4 and 5). Roots from trees considered healthy, and shown here, were not the most vigorous ones examined. The roots from die-back trees shown here were both from serious cases.

The records of the growth structure of healthy and vigorous Arabica roots were essentially those given by Nutman. It will be seen that the sketches were not in such detail as his. Digging was slow, without sieves or water, using shovels, machetes, trowels, and wooden awls. I found one unusual tap root in a well-matured tree that was unbranched and went down 3 ft. This is the only one of its sort out of hundreds of tap roots I have seen in C. *arabica*. In that species they are normally short, with a few stubby branches.

The feeding mots found were not so superficial as those reported from cither Colombia or Puerto Rico, and not so deep as in Kenya. The general arrangement of the plate that is comtposted of laterals permanents, feeder-bearers, and feeder roots, was much as Nutman had described. In good trees, the shallowest feeder roots were approximately nine inches

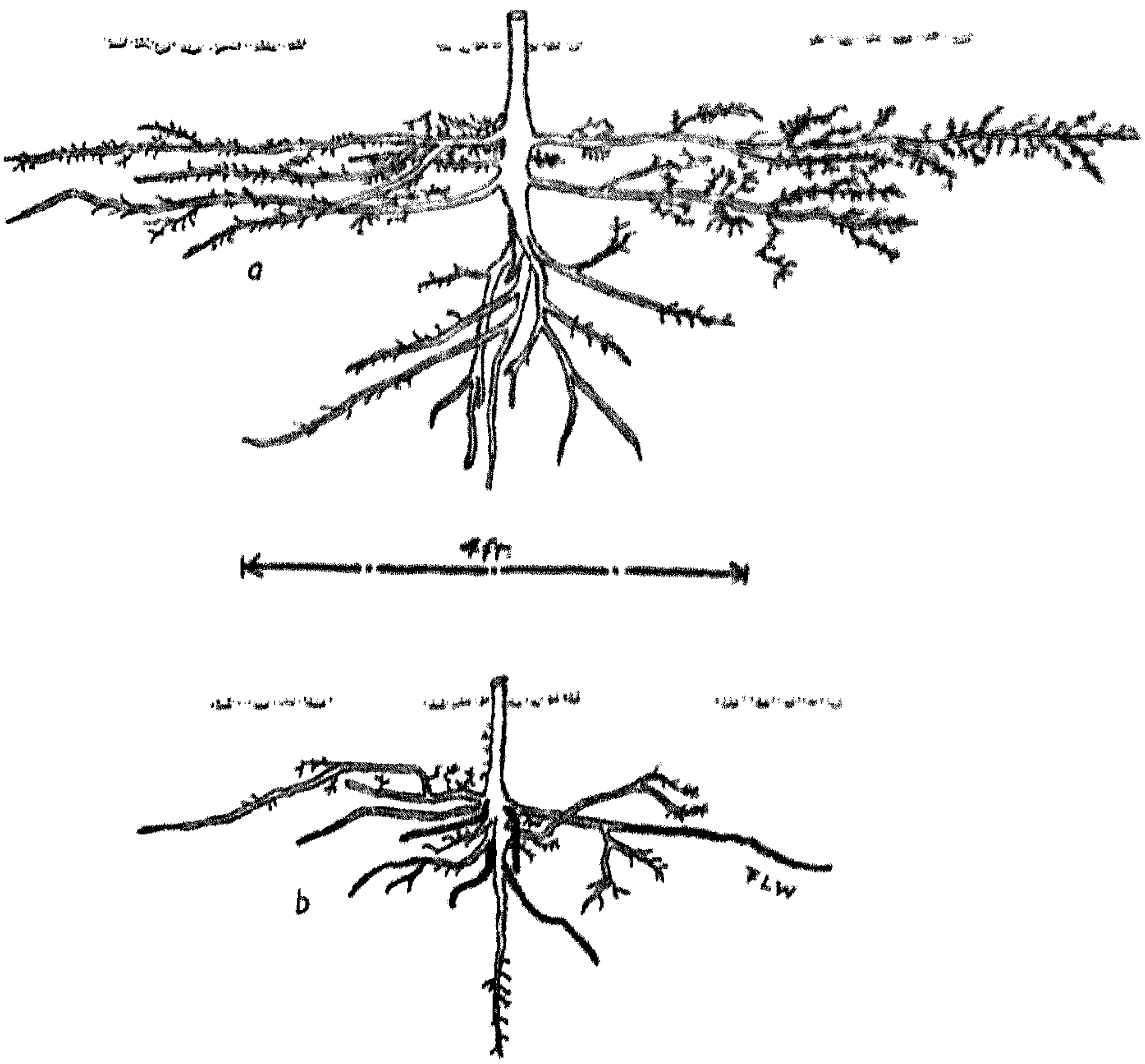


Fig. 4. Roots of eight-year-old Arabia trees, side view. *(a)* Was producing a medium crop on four stems. The surface plate of roots is clearly noticeable here, as are the short tap root, its stubby branches, and the axials descending at an angle. *(b)* Had been maintained on one stem, unpruned. Heavy production had caused phisiological die-back three years previously. Root decomposition indicated in black. Santa Tecla, El Salvador. January, 1946.

below soil-line. Laterals, of which a few branched downwards, were generally about 4 ft. long. These, and the feeder-bearers and feeders, 'wandered in and out' through what might be imaginatively described as a disk of soil 14 in,, or more, thick, having approximately art 8-ft. radius with the tap root at its centre. From branches of the tap root, axial roots were found to extend downwards on all widen, penetrating at an angle. These arranged themselves into a roughly cone-shaped growth, with its widest part deep in the soil.

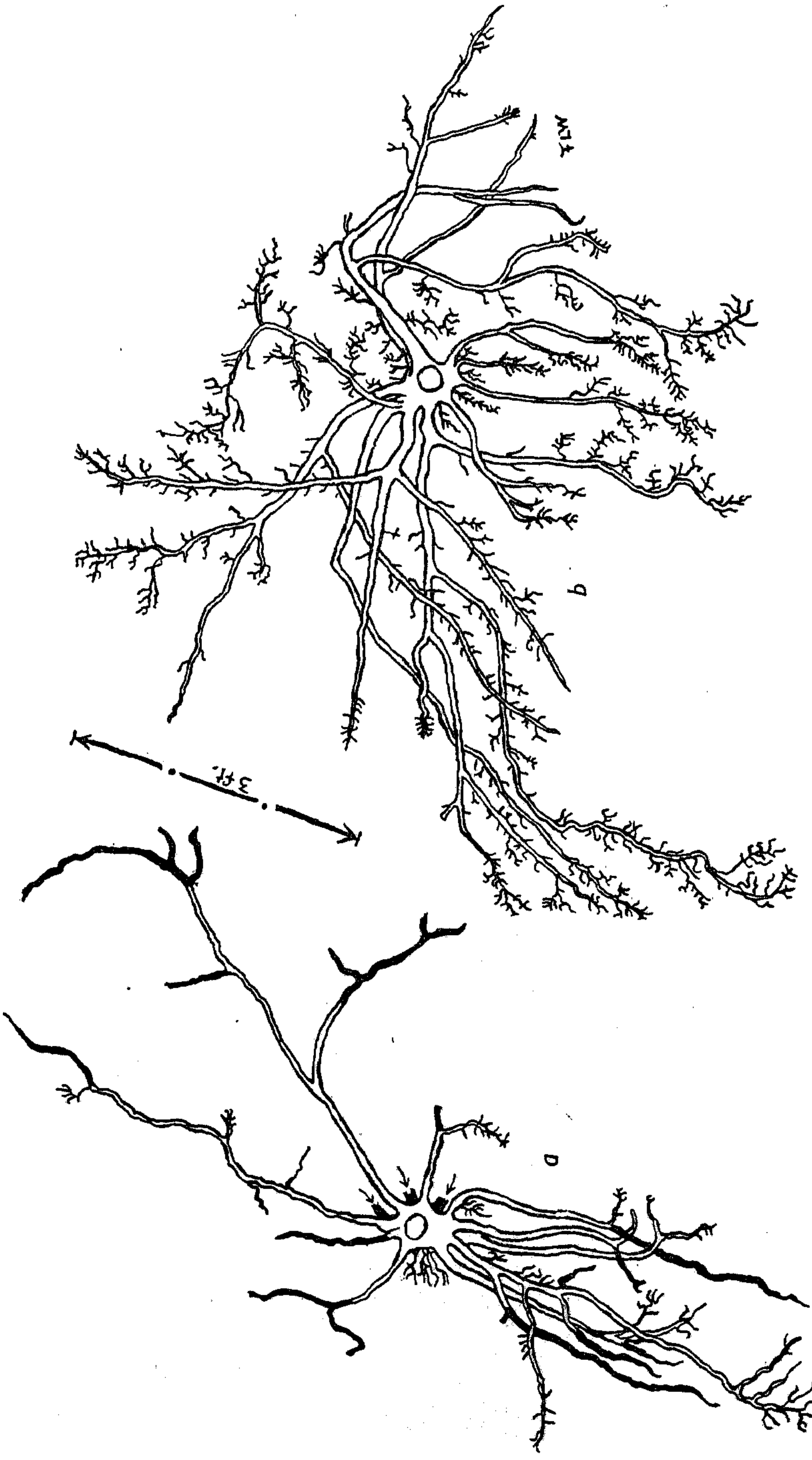


Fig. 5. Roots of fifteen-year-old Arabica trees, from above, showing spread of roots and distribution of surface plate. (*a*) Tree exhausted from over-bearing. Three main roots have disappeared (*see* arrows), and other decay is progressing (indicated in black). (*b*) Tree growing well, producing a medium-heavy crop. Feeder-bearer roots common on all laterals, out to their tips. Santa Tecla, El Salvador. January, 1946.

In my digging, I do not believe that, in any case, I followed the strongest axial roots down to their ultimate depths. Four feet was the deepest that was excavated below the tap root, and axials at that depth were still going down and had occasional feeder roots on them as far as they were dug. A point of special interest in the digging was visible effect on roots of trees extremely weakened by die-back. Under those conditions, there was practical disappearance of certain roots lit all dir-back trees, Feeder roots and the more slender feeder hearers were the firs* to suffer. In the earliest stages, they exhibited decoloration, and then they seemed to vanish in the soil, The largest laterals and axials were the last to succumb before the tree finally collapsed. In many cases, it was impossible to isolate fungi from newly disintegrating root tissues. The organisms which I did obtain in pure culture from newly disorganized tissues were a highly miscellaneous lot, and not of pathogenic nature.

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VII

SEED SELECTION, STORAGE, AND GERMINATION

IN the history of any plant, the first step in its development from a wild growth to a cultivated crop is the use of its seed for multiplication. Seed carries the crop from season to season, and aids in distribution from place to place or multiplication from selected ancestry. It can be surmised that it was only after the primitive coffee growers began to strive towards a betterment of the crop, that the tradition of seed gathering included the taking of seed only from the best trees. We have evidence that this occurred first in Ethiopia and Yemen, and later in other countries. This system of improvement is the most common folk method and is simple and well understood. Through the thousands of years of development, most of our great crops owe their success to folk selection.

FOLK SELECTION

The first coffee trees, whose desired product was the dry fruits for chewing or grinding and eating, were jungle trees, and the 'buni' therefrom was jungle gathered. Legends from the continent of coffee's origin have it that African chiefs were originally the only owners of coffee trees. The fruits and seeds, when chewed, were wonderful in causing an increase in a feeling of well-being. This could be attributed to nothing less than magic, and the fruits were used in religious ritual, such as that of blood brotherhood. All this coffee came from special trees in the wild. The 'Chiefs' Trees' changed little from the character of wild coffee, but some were inevitably multiplied by seed and cultivated.

There are a few famous, superior, old coffee strains that are fairly evident as being from folk selection. In Ethiopia there is a coffee with a large bean that has gone to market for centuries, and is known as 'Harrar' or 'Harari', and also 'Harar'. It has apparently been grown there from the days when Harar was a province of Arabia. The early coffee agriculturists in Harar, among the first sophisticated coffee growers anywhere, learned that it could be reproduced from seed.

It was the seed of Harar coffee that was originally obtained by the Dutch merchants who took it to Europe and from which a tree, grown for Louis XIV, spread its seed so widely over the tropical world. It is possible that it was the region of Harar in Ethiopia from which our commonly produced commercial Arabicas came. This was likewise the source, for ancient horticulturists of the irrigable part of Arabia Felix, for what was called 'Mocha' or 'Mokka'. These were grown in their protected hill-side gardens, to be watered from the perpetual trickle of wadis, and fed from the mountains above them. Sylvain (1956) has given us evidence that Ethiopian growers have isolated and stabilized a number of other ancient Arabica coffee selections.

There are other old strains of Arabica in Latin America and other parts of the world that are the apparent results of folk observations and selection. Certain dwarf types, found genetically to be mutants, have proved to be high in yield and economical in growing requirements. They were first seen by farmers and then brought to the attention of coffee technicians. A few are such dwarf types from C. *arabica* as: 'Caturra' from Brazil, 'Villalobos' and 'Pinto' from Costa Rica, and 'Pache' from Guatemala. Some other examples of folk finds, all of earlier selection, are the famous gigantic-beaned 'Maragogipe', seen first by a farmer in Brazil, the 'Pasamoeh', that was selected by an acute grower in the Dutch East Indies, and the 'Bourbon', first isolated long ago by a farmer in the island of Riunion, which was then known as Bourbon.

The manner in which certain of these selections have become recognized and used is of interest. An outstanding example of one such discovery is a fairly recent selection of the Mundo Novo variety of C. *arabica*. In some places in Brazil, it is superseding both Typica and Bourbon, and the Ministry of Agriculture in Costa Rica has proved it to be heavier in production than any other Arabica type or variety they have obtained (and they worked with several). It is being tested in other parts of Latin America. Its history and characteristics *(see* Carvalho *et aL,* 1952, and Anon., 1953) have been reported in some detail. It was found first by an able planter who recognized something unusual and good, which is the first step in such selection. Locally, the special strain has been called Mundo Novo. It came from what was known as Sumatra coffee, an isolation from Typica. The special strain was grown in the region of Urupes in Brazil, a place that, in the old days, was known as 'Mundo Novo', and this gave the selection its name. The second large step in this selection was when the farmer's field was first seen by technically trained men. This came about in 1943 when these scientists were brought to the field where there were about 14,000 individuals that were then 12 years old. This was not the only planting of it but it was the one specially studied.

Seed of this strain was given to scientists of the Instituto Agronomico in Campinas, and this was the third step in development of the strain. Those scientists then took it into the fourth big step when they made studies of its botanical and agronomic characteristics. It was seen to be a type related closely to Bourbon, but heterogeneous in appearance, with characteristics of both Typica and Bourbon. The fifth step was a genetic study in which the scientists found that, while it was genetically closer to Bourbon than Typica, it was not a pure Bourbon. They traced the strain back to a chance, or natural, cross between Bourbon and Typica. It is now undergoing a sixth step—refinement and fixing of desirable characters. An undesirable feature of it is the production of numerous fruits with one or two empty locules. Through selection techniques, it has been found in both Brazil and Costa Rica that lines of the strain are obtainable that are genetically free of the empty-cherry character.

For some years, there has been work in Latin America towards comparing Typica and Bourbon varieties for productivity. Individual farmers and experiment stations agree that Bourbon is by far the heaviest producer. An example of such results is the conclusion presented by Triana (1955) in Colombia. From data secured during the period 1935 to 1946, it was clear that two Bourbon lines out-yielded two Typica lines, and the large-beaned 'Maragogipe' came last. In separate comparative studies of Typica and Bourbon *(see* the accompanying Tab. V), Triana showed that

TABLE V

COMPARATIVE PRODUCTIVITY OF BOURBON AND TYPICA VARIETIES OF *Coffea arabica* IN COLOMBIA*

	Production! of dry pergamino	
	Series A	Series B
Variety	3-year average	5-year average
Bourbon	558	617
Typica	361	361
Increase	54 per cent	71 per cent

* Adapted from Triana (1955).
t On the basis of kilograms per year per hectare.

Bourbon gave a superior production of 54 per cent in one series, and 71 in the other. Bourbon has also been proved to be equal to Typica in cup quality. It is for such reasons, Triana pointed out, that Brazil has been replacing Typica with Bourbon to the extent of about 80 to 85 per cent, Guatemala about 46, and El Salvador close to 50. It can be added here that almost all new plantings in Costa Rica are Bourbon and, at present, the variety is being introduced as superior in Nicaragua, Panama, Paraguay, and Ecuador.

Such are results from basic folk isolations of Arabica varieties, followed through the years by popular acceptance, and earned by performance. There are also many growers who use elaborate methods of deciding which fruits to collect on the tree, actually believing that the place where seeds are on the branch, affects the vigour and subsequent bearing of the tree that comes from the selected fruit. Approved advice has long been to select only fruits from middle branches, and the fruits from those branches must be borne on the middle nodes. In Latin America, a common practice with Arabica is to choose only good trees, of middle age; these good or outstanding trees are to be selected, presumably, on the basis of more than one year's observation. In some plantations, no round or 'peaberry' seeds are ever planted; at one time this was believed to be important in Java. Schweizer (1927) studied this and took from the same tree round beans and normal beans. They germinated identically; with the smaller beans there was slightly quicker germination. After two months of growth all seedlings looked the same. Later they appeared identical genetically.

There is a considerable body of research, the results of which cast much doubt on the value of any type of dependence on seed selection purely on the basis of shape, size, or where the fruit hangs on the tree. It has been proved repeatedly that Arabica coffee is, for practical reasons, self-pollinated; it results from countless generations of selfing, so that inheritance is fixed, and seed coming from one part of a tree is just as good as seed from another part. Any seed is, in all probability, identical in inheritance with any from any of the grown trees of a field, and with all trees around it. This problem will be discussed more fully in the next chapter. About the only chance that a grower has to encounter a superior tree in his selfed populations, is to find an outstanding mutant. The grower who would search out and find such a mutant would not ordinarily use it in his regular commercial fields or for replantings until he knew of its performance in test plantings. The chances would be slender indeed that any healthy-looking seed from a good field of Arabica would produce anything but a field of trees just as good as, but no better than, those from which it originated. In Arabica coffee there seems to be no 'running out' by such methods of seed selection. Above all, it is not necessary to pick only certain fruits on the tree for the genetically best seed.

SEED PROBLEMS

It was found in Central America (El Salvador, Centro Nacional de Agronomia, 1949) that the weight of Arabica coffee seed varied in relation to its different placement on the fruiting branch. Seed from nodes nearest the trunk weighed most. They were increasingly lighter as they occurred farther and farther out towards the tip, and were lightest at the apical node. Slightly more rapid germination was evident in the heavier seeds from the first nodes, in comparison with the lightest seeds at the apical nodes. This was different from what Schweizer noted, but makes no difference in the inheritance.

As a personal sidelight, I did some seed treatment work in 1950 in Costa Rica. From one tree I found 11 per cent of significantly larger seeds. These were mixed at all nodes along the branch. On sectioning, it could be seen that they contained more than one endosperm. These large seeds were planted side by side in the soil with the normal one-endosperm seeds. They emerged and grew at the same rate. The slightly larger seeds appeared to be the result of polyembryony, with two to four plants coming from a seed. Subsequent nursery growth of the plants from multiple-plant seeds was as good as that from normal one-plant seeds.

In a search for any work of others on such an observation, literature review showed that, from Java, Hille Ris Lambers (1930*a*) had discussed the possibilities of such seed as I had seen. He considered it polyspermic if there was only one endosperm involved, or polyembryonic if two or more endosperms were found in a single locule. He reported that this latter condition had been seen by others, as well as himself, in C. *arabica*, C. *liberica*, *C. laurentii*, and in Robusta or C. *canephora*. He had also found, in *C. horsfieldiana*, a case in which two endosperms were in juxtaposition, without any intervening seed-coat, in one locule. These would all seem to be cases of polyembryony.

True polyspermy had been rightly described by four workers in 'Menado' coffee, a variety of C. *arabica*, in C. *liberica*, and in the coffee relative *Lachnostoma densifolia*. In Arabica, it had also been seen in Bourbon seed which had nine sectors of apparent locules in one seed. Lambers also had found several Robusta fruits that were truly polyspermic, in one case observing fifteen seeds in one fruit. In crosses made between a normal tree and one that gave three-seeded polyspermic fruits, he found the first selfed progeny to be normal, but their progenies were 12 per cent polyspermic. In reciprocal crosses, the abnormal character showed in 25 to 35 per cent. These were results from nine workers in the Netherlands East Indies.

A few years later, C. A. Krug & Mendes (1935) studied what they called 'false polyembryony' in Arabica coffee seeds in Brazil. They reported that, in those they saw, there occurred two or three ovules in the same seed locule inside a single parchment cover. They pointed out that this parchment is, in reality, not the true seed-coat, but the fruit endocarp. Within it is the 'silver skin', a more delicate structure that protects the quiescent seed and is the true seed-coat. In the seed with 'false embryony', each of the seedlings in the parchment shell comes from an embryo with its separate silver skin. These workers considered 'false embryony' to be genetic in character. They found two trees in which one produced 24-2 per cent 'multi-seeded fruit cells' and another produced 27-5 per cent. Fortunately, this is not a very common occurrence or it would make difficulties in harvest and processing programmes.

The highly uniform genetic composition of the field-run supply of Arabica seed has its good and bad points. In a crop produced under such widely variable ecology as is Arabica coffee, heterogeneity would be very good for use in selecting for adaptation to differences in environment and disease resistance. Fortunately, as has been mentioned, out of the billions of Arabica trees, from the one nobilized individual, that are growing in cultivation, there are occasional mutations that emerge from the long lines of naturally selfed progenies. In the expanding plantings of Canephora, which is naturally an open-pollinated tree, mutations are less readily found. In fact, they are very difficult to recognize. They are submerged in appearance, as there is continuous occurrence of regular normal variations due to cross-fertilization and constant mixing; of the tree C* n <i riJ f*t*i*f &

ARABICA SELECTION FOR PRODUCTIVITY

It becomes clear from the literature thai much truly intensive selection study has been, and is continuing to be, carried on in coffee (in cite* a few suggestive works, *see* Thirinn, 1952; Coleman, 1932; J. E, T, Mendes, 1951; Carvalho, 1952; Chevalier, 1931; Stoffels, ntfft, 1941; Kerwerda, 1948; Commonwealth Agricultural Bureaux, 1952; Commonwealth Bureau of Plant Breeding and Genetics, 1933, 1936). In Arabica selection studies in the Congo, it was found soon after work was started that, in genetically identical trees, yield variations could be very great. This was also known in other countries, both in Africa and in the Americas, Effects of differences in soils, in climates, and in cultural methods make great divergences in production that appear unrelated to heritable characters.

The two most commonly grown varieties of Arabia in Central America are the Bourbon and the Typica; the latter is also called 'Arabigo' in some countries. I have assisted with, and been intimately interested in, seed selection studies in these varieties in three countries. In total, there have been hundreds of apparently special 'high-producing' mother trees selected and tested, Out of all the progeny trials, there is, as yet, not one worthy of setting apart: as of special value for commercial development, There is one apparent mutant and one or two possible extra-early or extra-late producers, but it appears that there is little variability to be selected out of these strains of long self-fertilized types in Central America. In the last few years, a large number of variable *C.arabica* collections have been, and continue to be, secured from Ethiopia for seed selection. These are a different matter, entirely. Their heterogeneity in plant and fruit characters is great, and their variations from the standard Bourbons or Typicas of Latin America are marked.There is increasing hope for what may come from them.

Studies with Arabicas in the Congo Republic have resulted in good selections, because there were readily available sources in the Congo of more variable materials out of recently secured wild African collections. It was learned that, in Arabica, simple information on comparative yields of trees in pounds of fruit was not sufficient to give the true idea of their capacities. The growing history of the trees had to be known: what: had happened to them in pruning, in fertilizing, in pest attack, in juxtaposition to shade, in adjustment: of shade, in soil disturbance, and like matters. Selection in Arabica requires access to much variable material more than that which comes from the 'noble' tree. The statistician has his part in it, but it is the plant man who has a 'feel' for the tree, who senses what is important in the betterment: of this species. A purely office decision is likely to be misleading, to say the least.

A superficial selectionist can be easily brought to error in what he picks out of commercial Arabica plantings. In them, for the main part, there appears to be an 'elite' tree population of about one per cent of those in plantations. These are recognizable and, if they are consistently the 'elite', it is because of circumstance rather than for genetic reasons. Those who have really studied Arabica in the fields come to know this. After years of apprenticeship, it is the practised eye, along with production data, that selects. Most often, indeed usually, the true specialist brings out, as his choice, an irregular and outstanding tree: irregular from its appearance and different in its performance. He gets to know what to look for because of long familiarity with the expected characters in his perpetually selfed populations. He learns to look for something of a breed outside of the ancient Arabica types of either Bourbon or Typica, without its being a mutant.

That is how the famous 'Kent's Arabica' came to light. The selector was a sharp-eyed grower who knew his fields of usual Arabica like the back of his hand. It is not known from where the seed came of the special tree he found. He knew, after study, that this was something different and of great potentialities (Meppen, 1938). It has been sent far and wide since that time. In Kawanda, in Uganda, for example, it proved itself twice the producer that any other Arabica was and, according to A. S. Thomas (1947), even after nine years of testing retained its vigour undiminished. Relatively speaking, this is true of that variety under many conditions far distant from the place of its origin. It would have been called a 'hibrido' in Central America.

During the last 10 years or more, that most remarkable *tour de force* of the geneticists, hybrid maize, has had much wide publicity as the fabulous producer of riches in the market. Since then, the name 'Hybrid' has been used in connection with undeniably desirable strains of Arabica. There are several of these and the name 'hybrid' has added greatly to their popularity. Oddly enough, all of these 'hybrids' are from the variety Bourbon, and all are excellent lines. But they are not hybrids. I have heard two of them spoken of, with authority, as hybrids of Arabica and Robusta. But they are no such thing. They are all just good Bourbon selections.

As is well known, and discussed elsewhere in this book, there are many true hybrids between C. *arabica* and other species. Such true interspecific hybrids have differed so much from pure Arabica that they have never been used directly as a replacement for Arabica. They have always had to be back-crossed and recrossed until, after a good period of selection and re-selection, a variety of fixed characters could be secured. Such varieties required scientific attention, and were not obtained from simple, albeit acute, judgement in isolating, on a lucky day, an Arabica strain. But good selection has isolated and purified such Arabica strains as the 'hibridos', the 'nacionals', the 'Jamaica Blue Mountain', 'Padang', and 'Sumatra', to name a few.

SELECTION FOR DISEASE RESISTANCE

Another point respecting selection is that regarding choice for resistance to diseases and pests. This is increasingly difficult to find in populations of such pure ancestry as are the long selfed, usual commercial Arabicas. Genes for many resistance characters are commonly lost in selecting for quality and horticultural features desired in a crop. In the work of such as Hille Ris Lambers (1930), Wilson Mayne (1932, 1935), Stoffels (1936), Hendricks: & Lefevre (1946), Wellman (19544), Triana (1955), Olivcira (1955), Vayssiere (1955), and Cramer (1957), there is clear evidence in coffee of resistance to many different diseases, insects, and nematodes. The challenge to the plant breeder in these matters is still to be well met. One of the difficulties has been that Arabicas used commercially have extremely pure, and well fixed, susceptible characters-, By searching among different Arabicas from those commonly grown in the Congo, selectors secured resistances not found before.

It is well known in the history of coffee in India that there were parts of the country where the high-priced Arabica coffees were produced in quantity. The lands were rich, conditions were excellent, and the standard types flourished. When the Hemileia rust appeared these coffees were wiped out, and the whole coffee economy would have been destroyed but: for the introduction of certain selected strains of Canephora that tolerated the rust. It remained for the bringing in, likewise, of selected resistant strains of the Arabica to give, once more, hope of producing a supply of the more aromatic Arabica grain. It has recently been reported by Mathias (1956) that in the Malabar-Wynaad area of India, on the slopes of the Western Ghats, they are once again starting to grow Arabica, but it has to be from seed of selected, rust-resistant strains.

There are some 3,800 acres of the rust-tolerant Canephora species now growing in this area of India. In 1954, one acre of an Arabica seleo * tion, S.795, was planted. It is one of those highly resistant to rust. Common, standard Arabicas wither away and die from this disease. But S.795 stood so well that in 2 years' time the acreage was increased to 200, and more have been planted since. This, and similar resistant strains, will not replace all the Canephoras. It was Mathias's belief that the latter were there to stay. However, he felt that some of the old types of Arabicas, special 'jats', would never have been able to return, even if there were no rust. But the newer seed selections, chosen for special adaptability, had a good future.

In a review of breeding and seed selection of coffee in south India, Narasimhaswamy (1950) has described the work of Coleman, Wilson Mayne, himself, and other of the scientists attending to those coffee problems. The breeding material with which they started was C. *arabica* selections from 264 widely variable and different sources, each selection being put into 1/20 acre plots. The mother plants were selfed, crossed, back-crossed, and re-back-crossed to commercial varieties; meanwhile rigorous seed selection was continued. This soon expanded into a great mass of progenies. The mass was eventually reduced to a certain few choices as follows: original mother plants S.26, S.31, S.71, and S.73; certain selfed progenies S.288, S.353, S.433, and S.434; and from these, out of hundreds and hundreds of crossings and back-crossings, they selected the progenies S.333, S.645, and S.795. This was the first Arabica breeding and seed selection by professional scientists in India, and it started in 1928. The first selection for commercial use was distributed from this work in 1938, after ten years—an exceedingly short time, and attesting to the hard, brilliant work and economical use to which they put their efforts. The breeders and selectors in India also selected and made crossings to improve their C. *canephora*, or Robustas. Out of this they eventually obtained rather well-fixed strains that had quality, resistance, and were consistently high in yield. They made crosses and back-crosses between their two species of coffee, and certain of the resulting trees were of special vigour, exceptional disease resistance, and, for Robusta, had excellent bean size, This work, leading to improved Robustas, is still in progress, and from the progenies comes the best hope of selection for resistance to rust and for good horticultural adaptability.

CANEPHORA SELECTIONS

A great deal of work has been accomplished in Africa in the past, and is being even more vigorously carried on at present, in breeding and selection of Canephora types and varieties. The work in Java is remembered for this, but the scientists in the Dutch East Indies, in later years, were more interested in clones from specially selected individuals. The species *C. canephora* is composed of such named varieties as Robusta, Quillou, Kwiluensis, Ugandae, Bukobensis, Sankurensis, Touba, Laurentii, Chari, and Congensis Hybrids. Some of the countries with coffee research stations giving major attention to seed selections among these C. *canephora* types, are as follows: India, Ceylon, Tanganyika, Uganda, Kenya, Java, Congo Republic, Angola, Ivory Coast, Sierre Leone, and French Equatorial Africa. Probably among the most important selection work with Canephora was that by the Dutch in Java and Sumatra; the French in Sierre Leone, Ivory Coast, the Gabon, and the Ubangui-Chari; the Portugese in central Angola and the island of San Thome; and the Belgians in the middle Congo. The outstanding present work
to be that now in progress by the French and Belgians.

With Canephoras, the type of seed selection work that has been followed successfully in several countries, is somewhat similar and exemplified in the writings of Cramer (1948, 1957) and Ferwerda (1948) from Java, and the discussions of Thirion (1952) from the Congo. These methods of selection are of special note in view of the increasing prominence of coffees of the Canephora species in the present-day world market. This coffee species is open-pollinated and characteristically quite variable. It is vigorous, and, compared with commercial Arabicas, relatively resistant to many adverse climatic conditions, diseases, and pests. Mother trees of Canephoras are selected through careful observation, comparisons, and field history. Those selected have come from superior stock, usually known through previous experience and close observation. The next step, after mother-tree selection, naturally, is multiplication of progenies, and study of their field and harvest performances. Productivity, of course, is of great importance, but is to be considered relatively. Absolute figures of selection by harvests alone are a dangerous basis from which to draw conclusions. All must be interpreted as dependent upon what a district was expected to produce, and what selections do in comparison.

With their selection criteria clearly in view, the Dutch compared their 'elite candidates' with regular averages of the general ran of trees growing around those under scrutiny. From this comparison a 'productivity index' or 'PI' was calculated. If a PI was given as 200, it indicated that the production of the candidate was twice as much as the average of the coffee garden in which it grew. As a rule, mother trees with a PI of less than 300 were discarded. Other criteria included regularity of bearing, size of bean, cup quality, resistance to disease and insects, ratio of clean dry bean to fresh fruit or harvest, habit of tree, and its adaptability to horticultural management. After several years of observation, a promising mother tree was accepted and became a part of the real breeding and seed selection programme (*see* p. 85).

The coffee trees in a breeding or selection programme have to be kept alive in the same way as are mothers of animals in herd improvement programmes, and must be producing from season to season. There are some world crops in which the mother plants are destroyed, and seeds can be harvested and stored for years. These are planted for new growth, to be used again in later unfolding of flowers as sources for genetic manipulations. One of the difficulties in carrying on long-term improvement campaigns of either Arabica or Canephora coffees has been the impossibility of protracted seed storage and shipment.

KEEPING SEED ALIVE

It has been found that coffee seed spoils if kept moist and yet often it seems quickly susceptible to excess drying. At one time, it was stated by McClelland (1917) that, in his work in Puerto Rico, seed never retained its viability for more than 3 or 4 months. To keep it even that long, storage had to be done very carefully, with especial care to avoid serious drying. This is just one publication of the experience that is characteristic of many growers and scientists working on coffee in many parts of the world—working, both a long time before McClelland and in the decades since, with these sensitive seeds.

Coffee seeds are almost nut-like things. If living, they are bulky and ordinarily not too hard. A living seed of coffee is not the horny, flinty structure that is characteristic of the cured 'grain', 'bean', 'oro', or 'gold' of the product in storage. The word 'seed' so often connotes the ivory-hard grain of a cereal, the chaffy ovules of certain grasses, the flinty reproductive elements of the pulses, the small shot-like cole seeds, or the stone or pip of a fruit. The living seed of coffee is hard but usually can be torn apart with the finger nails. As it comes to the horticulturists' hands it is half round in shape, covered with its moderately resistant endocarp or parchment-like shell. Removal of this discloses the more delicate, silvery integument, or true seed-skin, over the endosperm within.

Both the parchment shell and silver skin are permeable to water. They are hygroscopic and allow drying out or collection of moisture from the air. A good deal of attention is given to preparing seeds for planting or for keeping them during the relatively short storage period which they can withstand. Correa (1945) described a common method. After gathering, the fruits are hand pulped and the seeds from them dried in the shade as rapidly as possible. Some have found that a very short fermentation period, after the seed has been taken from the fruit, makes a cleaner job of it. However, many know that long soaking, too-slow drying, an extended period of fermentation, high temperatures, and considerable exposure to bright sun, are all likely to injure germinability.

There are still many things to be learned about coffee seed storage. It would appear that this phase of coffee horticulture is incompletely studied, and, considering its importance, relatively little has been published about it. Working in Central America, and that means with seed from Arabica coffee, researchers (El Salvador, Centro National de Agronomia, 1949) dried the seed, and then placed them in cloth bags to be stored under various conditions. Some were kept in a refrigerator that retained a temperature of about 5°C. (4o°F.). The latter conditions were the best for longest storage of seed for germination. In some preliminary work, controlled moisture and temperature chambers were used by Dr. E. H. Toole, of the seed investigations laboratory, U.S. Plant Industry Station, Beltsville, Maryland, U.S.A. In carefully controlled chambers, he found that a temperature of 5o°F. and a moisture content of 50 per cent, were best for storage of Arabica coffee seed. This work was never published.

The problem of the relatively short duration of viability in coffee seed is still not well studied. The experiments on it are not numerous. An example of one study (quoted by Haarer, 1956, Chapter 6) along this line was carried out in Lyamungu, a cool coffee research station in Tanganyika. Arabica seed was stored and samples withdrawn for germination at intervals of a few weeks. The Table VI shown here is from this work.

Under these conditions seed was kept for about twenty-one weeks without serious damage to germination. From that time on, germination was notably affected. After over seven months, there was much deterioration, although even after more than ten months there was still over 20 per cent of seed alive that could grow, but germination was very slow.

TABLE VI

VIABILITY OF SEED FROM *C. arabica*, AT DIFFERENT AGES

Age of seed in weeks	Germination of seed Per cent	Weeks required after sowing
7	95	10.1
12	96	15.7
16	94	11.6
21	87	16.1
25	60	23-1
29	62	16-3
34	27	16.7
38	40	23.0
43	24	23.3
47	22	26.0

The actual moisture content of the seed also has an effect on germination, as can be seen in the two Tables VII and VIII presented here. This

TABLE VII

GERMINATION OF COFFEE SEED* AFTER BEING DRIED FOR VARIOUS PERIODS OF TIME TO DIFFERENT MOISTURE CONTENTS†

	Period dried in the shade					
Treatments	No drying	1 day	2 days	3 days	5 days	To 'glass hard'
Moisture content ‡	47-49	41-44	38-40	33-34	30-34	8-10
Germination ‡	97	86	87	97	97	43

* Canephora species; the seed was a mixture from several sources,
† Adapted and condensed from Ultee (1933, part of Table III).
‡ Data expressed as percentages.

TABLE VIII

COFFEE SEED* GERMINATION AFTER STORAGE AT DIFFERENT MOISTURE CONTENTS f

	Period of storage before germination			
Moisture content of seed	1 month Germination	2 months Germination	3 months Germination	4 months Germination
per cent	per cent	per cent	per cent	per cent
46-49	91	90	74	29
38-40	85	86	53	28
30	96	86	43	5
8-10	43	10	0	o

* Canephora species ; the seed was a mixture from several sources,
f Adapted and condensed from Ultee (1933, part of Table III).

work was by Ultee (1933) in Java, with Robusta: coffee. He removed the pulp from the coffee seeds and dried them in the shade for varying lengths of time, taking out samples for germination and for moisture determination. The seed germinated well when taken fresh from the cherry, and just as well after five days of drying. If seed had been dried in the shade to what Ultee called 'glass hard' condition, its moisture contents varied between 8 and 10 per cent. From that condition, something less than half the seeds germinated, and after a month's storage most of them died. All seed dried for periods up to 5 days had moisture contents of 49 to 30 per cent, and all germinated about equally well. The seed dried for five days began losing germination ability after 2 months of storage, and seed that had not been dried, with a moisture content of 46 to 49 per cent, kept a fair germination percentage to past 3 months of storage.

Ultee finally concluded that, to keep it alive, coffee seed should be held at a moisture content of 40 per cent. In some rather extensive and elaborate studies, he further demonstrated a practical method for keeping coffee seed alive for a longer time under the warm conditions where he worked. His best treatment was to mix dry coffee seed with dry ground charcoal and place it in jute bags. Such a mixture was then stored above water in a cool room. The seed retained its germination capacity up to 80 per cent, for 10 months and even longer. In some cases, dry seed was packed in ground charcoal at a special moisture content. This was a mixture of water and charcoal at the rate of 150 gm. water to 1 kg. dry ground charcoal, freshly made and changed at monthly intervals.

This work on seeds was continued in Java by de Fluiter (1939) who made more studies of the moisture content of seeds and their germination. He arrived at the conclusion that, in the main, what Ultee had found was a good practical method for storage. However, it was evident from what Ultee had demonstrated and from his own later findings, that seed could be stored at a moisture content well below 40 per cent, and still keep well. De Fluiter felt, however, that it should not go lower than 25 per cent. He found that Canephora seed was a little more delicate to store than Arabica. He also discovered that seed of some of the special Robusta clones, when prepared for storage, was prone to dry quickly, beyond recovery, so that it would not germinate.

Difficulties of storage relate directly to seed shipping problems. For reasons still unexplained, there has been, at times, unusual loss of germinability in seed shipped long distances by air. There have occurred similar difficulties from shipments over shorter distances. It is possible that, in some such cases, seed has been sent away when it was near the end of its life-span in storage, and simply died on the way, or was delayed in being taken to the field on arrival at destination, and succumbed before planting. In certain cases some seed may have undergone more drying in transport than expected. Both the person who ships the seed, and the one who receives it, should know the time of collection. On the average, coffee seed should be sent in such a way that it is less than three months old from the time of its collection to the time it is to be planted in the far-off location, and the receiver should be warned of how soon he should plant.

SEED DEVELOPMENT

To understand more about the seed, a brief resume is presented here respecting its development on the tree and its germination when planted. The time required from flower opening until the seed is mature and the fruits are ready to be collected depends a great deal on temperature and other factors. With some Arabica coffee in Central America, at the low edge of a medium altitude, for example 2,000 ft. elevation, it requires about seven months for seed to develop; at an altitude of approximately 4,500 ft., or more, it requires about 8 or 8| months. Canephora coffee needs a little longer for fruit and seed maturity than Arabica. However, there is not an exact time that can be given. Judging from information quoted by Di Fulvio (1947) respecting dates of flowering and picking in numerous countries, 7 or 8 months for Arabica is a good figure. It appears that in some of the cooler parts of Brazil it takes nearer to 9 months. The shortest time is judged to be in Jamaica, some parts of which seem to require less than a full 7 months. These data are loosely compiled and, it is to be noted, are all from Arabica growing countries.

A careful investigation on coffee seed development is that of A. J. T. Mendes (1941). His material was from Brazil. He found that on the day the flower is pollinated, pollen tubes sink into the pistil and grow rapidly down into the embryo sac at the base of the pistil Each pollen tube has in it two male zygotes or bodies, one of which unites with the ovary nucleus, the other with the endosperm. As is common in flowering plants, there is, therefore, a double fertilization at this period. The endosperm starts actual growth about 21 to 27 days after the flower is pollinated. At this time the tissues are very young and changing rapidly. About 60 to 70 days after the pollination, when the male zygote has entered the ovule, the embryo starts developing, and it becomes shield-shaped and recognizable in 3! months after flower opening. Meanwhile, the compact endosperm tissues that are destined for the cotyledons (and this is the main part of the seed for which coffee is actually grown), are well differentiated in 4 or 5 months after flower opening. It is at this time, which is when the fruit is well grown but very green in appearance, that the silver skin can be found. A seed is then completely formed. This requires something over 5 months under Brazilian conditions, and ripening progresses from then on without further change in the seed's anatomy.

There are times when it would be most convenient if a seed collector could gather green fruits and ripen them artificially and still keep the seed viable. This was studied by van der Veen (1934), who used well-grown but very green cherries of the Congusta, Arabica, and Robusta varieties. They were treated with ethylene gas in chambers. The gas content was 1 part to 1,000 of air. The cherries treated in the chambers ripened in

10 days. The cherries outside the ethylene chambers remained green. The treated fruits contained seeds that, on the average, were 40 per cent viable. They germinated in 6 weeks, and were normal as seedlings. Untreated fruits produced seeds, but of the seeds only 6 per cent germinated.

PROCESS OF SEED GERMINATION

The progress in seed germination has been noted and described in numerous pamphlets and bulletins. Two well-known examples in Latin America are portions of the coffee growers' manual from Colombia (Federaci6n Nacional de Cafeteros, 1932) and the description and drawings by Alvarado (1935-6). It is an interesting process, but occurs so much under the responsibility of labourers that, at times, little is known about it by the owner-planters, or even technicians for that matter. In many farms, especially where labour has been inexpensive, they still plant the seed in shallow grooves in the moist soil with the crease or 'face' of the seed turned down. Tests have shown that this is an unnecessary use of labour time, but it aids in the feeling of care that the planter prefers for the seed-bed and nursery phases of coffee growing.

Germination of coffee seed is often spoken of as requiring 4 to 6 weeks. This is true in cool soil, and if the seed has not had the parchment 'peeled off' and is reasonably dry at the time of planting. If seed has had the parchment removed and has been soaked 24 hours in clean water, and held at 25°C. (77°F.) temperature, it starts germinating in 4 or 5 days, but will require about a month for emergence. It needs a good deal longer than that at lower temperatures and with the parchment intact.

It requires a warm soil temperature of about 28°C. (82°F.) for Arabica coffee seed to germinate most rapidly. At that temperature it has been found possible to have coffee seeds emerge in 3 weeks. Such warmth can be found at a low elevation, but here careful attention is required to proper irrigation, if there are no rains, and protection from drying. At 20°C. (68°F.) it requires 6 weeks to 2 months for the fastest to emerge. On colder soils it takes even longer than that. Arabica seedlings germinating in the dark are often notable for a reddish-brown colour that requires 2 or 3 days of exposure to light to turn to green.

From recent work at the California Institute of Technology, Went (19550) reported that the presence of the 'pergamino' or 'parchment shell', although it is loose on the seed, retards germination for at least a week. At one time this parchment was thought to contain a 'retarding' substance. From tests made with extracts from this shell, and studies on effects of taking away parts of it and leaving other portions intact, it became evident that the retardation experienced is of purely mechanical consequence.

On the start of germination, the seed appears as a grey endosperm, with its embryo embedded on one side and showing no great changes for some 3 or 4 weeks, The cotyledons then begin to enlarge and they grow, absorbing the endosperm, and converting it all to cotyledonary tissue. At this same time, the hypocotyl and seed-root, or radicle, start to grow towards their destination in the soil

The first outside appearance of the radicle from a germinal intf %xd is the root tip pushing through a flap of the parchment in the ereasc of the seed, Cramer (1957) described the first appe.ir.mcr of the seedling root as being after 12 to 28 days. This was undoubtedly in unpeeled seed, probably of Canephora, and the range of days indicates that he had under consideration a variety of conditions Whoever has observed the process has found that it is soon evident that the primary rootlet is strongly attracted downwards and 'pushes' its way into the soil. The root first grows for a few days, after which the stem begins to elongate slowly in a bent shape. This develops into what is called the hypovotyledonary hook, or arch. During this growth the young plant pushes the seed up, and, with the root end firmly fixed in the ground, breaks the soil surface with its arch. It then pulls the seed out of the ground, still enclosed in its parchment shell, and straightens the curve, now holding the seed directly above the root.

At this stage, seedlings are called 'little soldiers' The cotyledons begin expanding within the parchment shell and the inner silver skin. They tear open this covering in an irregular fashion, and the cotyledons are soon green, slowly freeing themselves from the seed wrapping. Thrive green cotyledons are shiny and are held closely edge to edge, so arranged that they suggest a cup. After a few days the 'cup' straightens and these cotyledons are then orientated in a more horizontal position, resembling a stylized 'butterfly'. Pl. 16 shows two stages in the germination of Arabica.

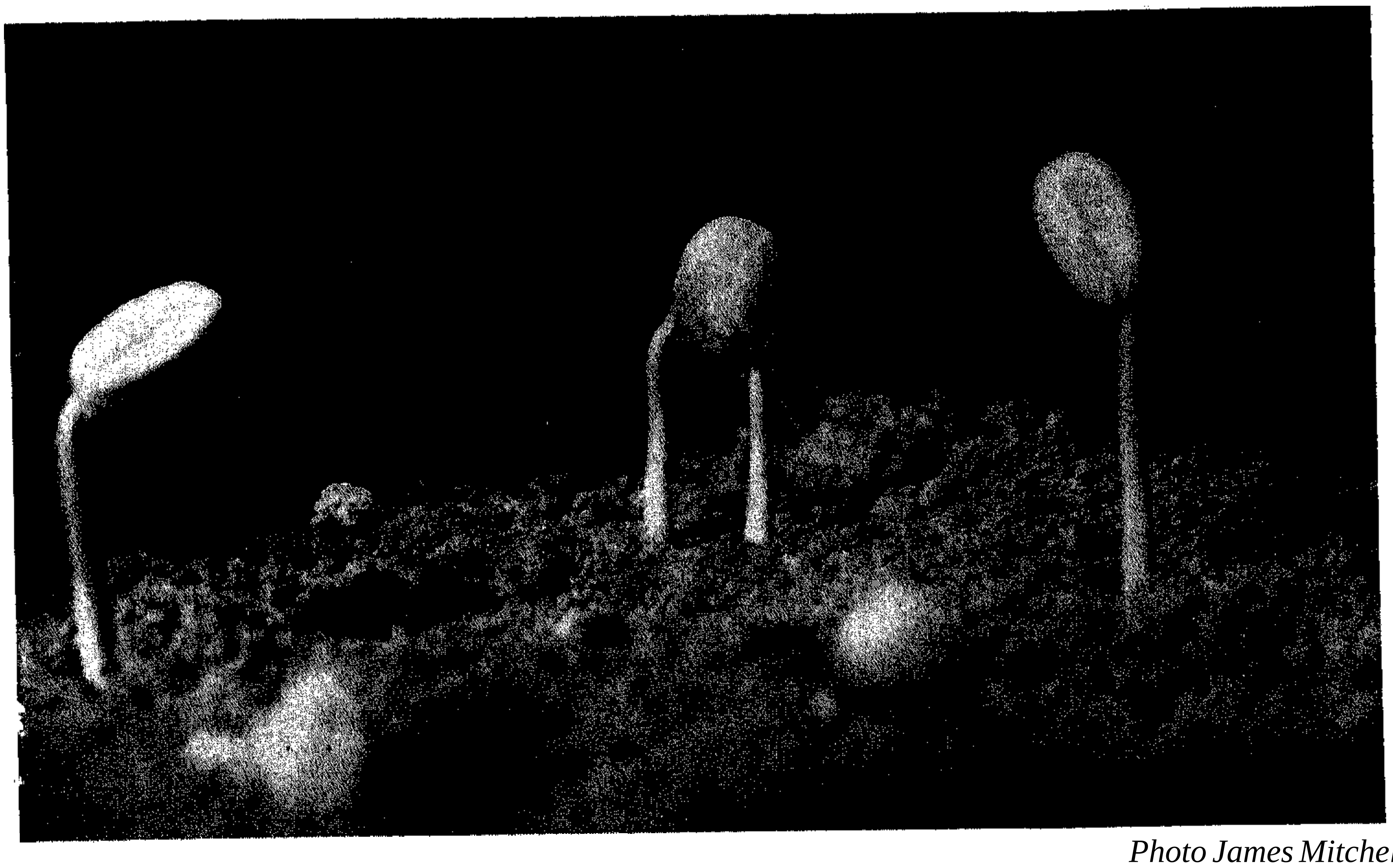


Photo James Mitchell

(a)

PLATE 16.—(a) Seedlings of Arabia, three months from time of sowing. At this stage, seedlings are called 'little soldiers'. In the centre is a polyembryonic seedling, with two plants coming from one seed. (About natural size.) El Salvador.

(b) Seedlings of Arabica are grown each year for regular replacing of old trees in Central America. Four-months-old seedlings here are at the mariposa or butterfly stage. Shade has been recently removed, and they are ready for transplanting to the nursery. Guatemala.

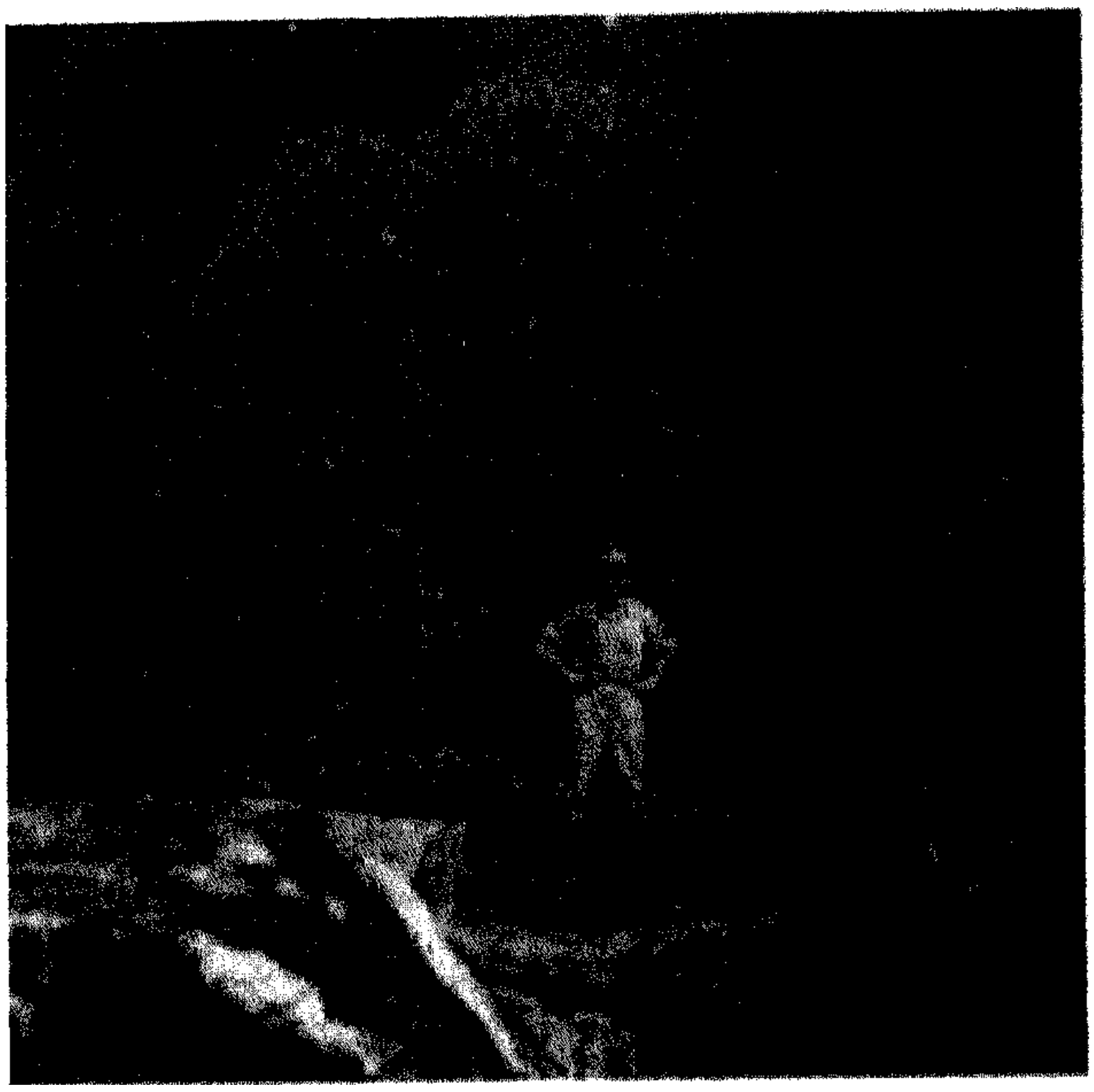
(b)

Photo James Mitchell

PLATE 17.—An exceptional Arabica coffee tree, typical of many selected for high productivity and seed saved. (Mature leaves averaged over 12 cm. in length.) Progenies gave good results but nothing exceptional over field averages. El Salvador.

Photo P. J.;S. Cramer, by courtesy of Mrs. Cramer

PLATE 18 - A n exceptional Canephora coffee tree, variety Robusta. (On average leaves are about 7 cm long)' Such a one as this might often give progenies of exceptional merit. Sometimes, three or four times regular field averages are obtained. Indonesia.

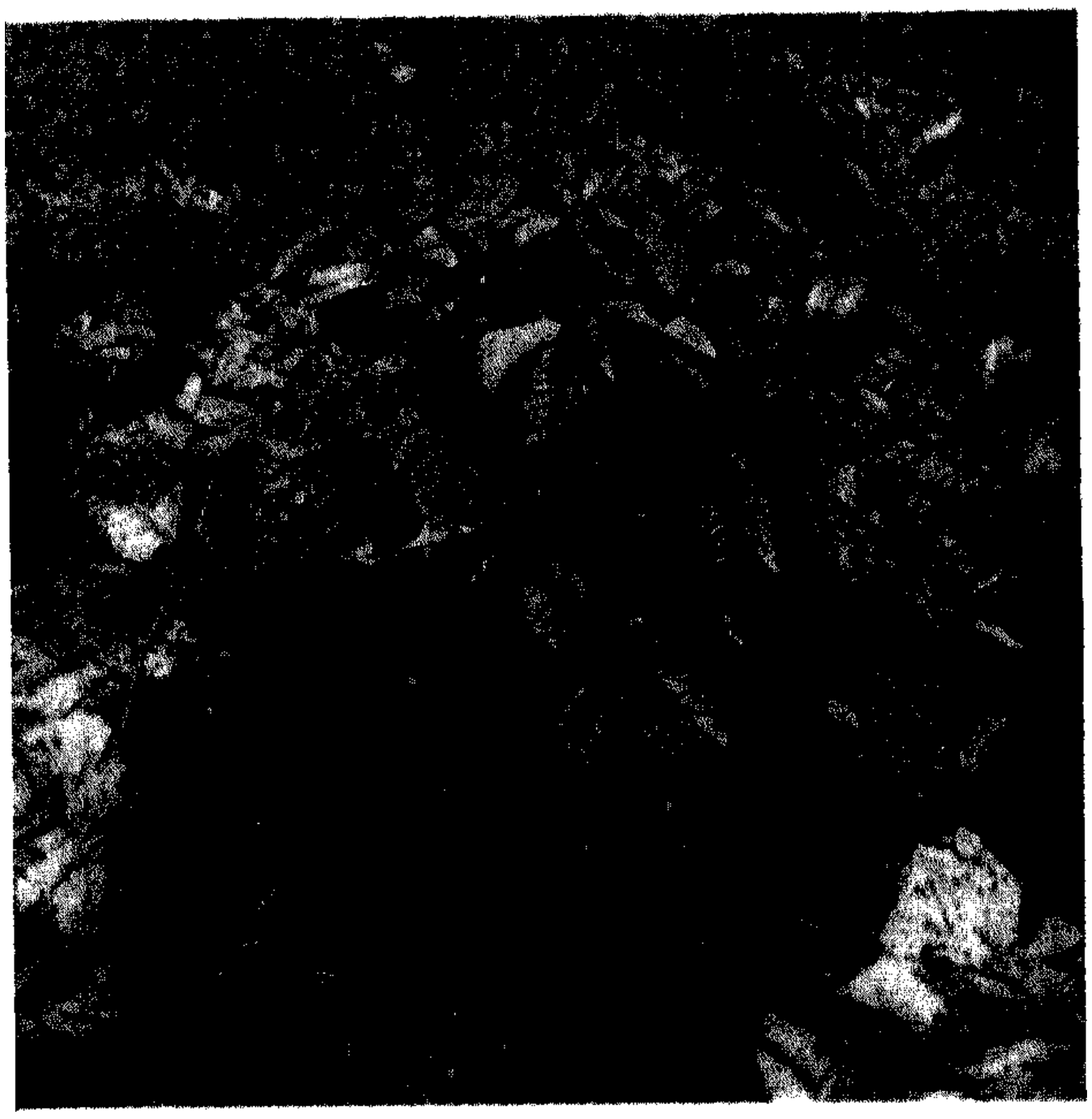


(a)

PLATE 19 - (a) Commercial plantation of the Columnaris mutation of Arabica, Boquete district of Panama,

(b) A year-old seedling, less than 1 m. high, from a hybrid between the Coffea *arabica* mutant (Caturra and C canephora, The dwarf character of Caturra is apparently dominant in this first generation, J.A.I.A.S., Costa Rica.

(b)



VIII

GENETICS AND BREEDING

ON previous pages there has been given some of the history of the discovery, world distribution, and the development of coffee in the centuries of its use as a world crop. An astonishing feature of the story, not always well appreciated, is that probably much over two-thirds of the coffee of world commerce comes from an extremely narrow range of genetic material. It is apparent that practically all of the trees producing commercial Arabica probably came from only one tree. That was The Tree, the tree of noble connection with Louis XIV of France. Even if this exact story were not quite true, a most conservative guess would be that, at most, the original 'brood' of *Coffea arabica* could not have come from more than a very few trees of that species, all from the same handful of seed; and I believe that the one-tree theory is a greater probability.

GENETICS OF *COFFEA*

Of the genus *Coffea*, the species C. *arabica* has been the backbone of coffee drinking the world over. This is interesting as there are a number of species in the genus. It appears that in total, according to Chevalier (1942, 1947) and Coste (1955), there are about sixty species of *Coffea*. Cheney (1925), Zimmerman (1928), Lebrun (1941), and Cramer (1957), indicate disagreement respecting this number. However, comparisons of findings cause one to return time and again to Chevalier. In recent years there has been no botanical study that has much changed the accepted concept that this genus has some sixty, or a few more, species (cf. Ch. IV). In any case, C. *arabica* has remained the one to which scientists have given the greatest amount of attention respecting genetics.

One of the important scientific tools in developing a crop is breeding, and this necessitates careful knowledge of its chromosome content, and of the manner in which these chromosomes interact. Cytological studies have been carried out by a number of workers. It has been found by A. J. T. Mendes (1938) and others that the family Rubiaceae is predominantly self-sterile. The genus *Coffea* of the family likewise has this character and, with few exceptions, cross-fertilization is required between plants before seeds develop. In this genus, the species are mostly diploid, with a basic or haploid chromosome count of 11, and therefore the diploid $2n=22$. This diploid character is found in C. *canephora* and C. *liberieica*, and both species require cross-pollination. This is not the case with C. arabica, which is normally tetraploid (4n=44) and is one of the few possibly the only, species to be commonly self-pollinated. There is a fundamental point; of interest respecting the normal diploidy of the genus. In the case of C *arabica*, which is commonly the tetraploid, if, has been shown by Carvalho (1952a) that the diploid, 2*n*= *22*, is encountered, when searched for, even in the mutations. Ik* reported instances of this in varieties *typica, bourbon, maragogipe, semperflorens, laurina, erecta, caturra,* and *san ramon*. Under natural field conditions, crops of C. canephora and C. liberica are highly variable, while C. arabica is characteristically more uniform in type. Pls. 17 and 18 show exceptional trees of Arabica and Canephora, respectively.

There have been scientists in several countries who have worked on the cytology, genetics, and breeding of Arabica coffee. If is logical that the most intensive study of some phases regarding it should be made in Brazil, for that is where a few billion trees grow. This occurred particularly as to cytology and genetics of this species. The modern work of C A Krug and his co-workers in Campinas has become, and will remain, the classic study on these aspects. In presenting their results, Krug & Carvalho (1951) point out that C *arabica* is self-fertile altnost entirely self- pollinated, and what they call a polymorphic species with many distinct varieties, Because of its great commercial value in Brazil, they confined their work in large part to this one species.

Special studies were made on cytology of coffee by Krug (1937), Krug *ct at* (1939), and Krug & Carvalho (1951). *At* the inception of special genetic research, it had been believed by certain previous eytologists that C *arabica* had either a chromosome number of 2n= 16 or 2n= 22, with, in *C\ liberica 2n*=44. However, others disagreed and the controversy was resolved through Krug (1934, 1937) and A, J T. Mcndes (1938,1938a,1941), It was established without question that most species of *Coffea*, which included *canephora* and liberica had diploid chrosnosomes, an 2n= 22. This would seem to be the 'normal' number. The most recent species, C. *lebrmiana*, is a diploid plant; (Germain & Kesler, 1955), as are most of them- In the case *of arabica*, there was an unusual condition of tetraploidy, 4n=44, Polyploids of more than 4n occur but these are abnormalities and none are of commercial use. Moreover, cytology has demonstrated that the sizes and configurations of the chromosomal bodies differ in species, as of course do their numbers. Such facts explained why there was such great difficulty in making successful interspecific crosses. In the case of C *cxcelsa*, there is the added obvious difficulty that, in it, chromosomes are of three classes based on size and shape. This further serves to set it; specifically apart from C. liberica which does not have these types of chromosomes. While interspecific crosses may be desired among many of these species, their occurrence is very rare.

INTERSPECIFIC AND VARIETY CROSSES

In early studies it was taken for granted that *C. arabica* did not cross readily with other species. However, Chevalier (1929) noted that there were very marked differences in the coffees of the group classed as C. *arabica*. *lit* further reported that the first of these to be thought a hybrid was the one given the designation Bourbon pointu, which was certainly quite different from common *C. arabica*. He also considered that what was classified as *C. laurina* Hort., must have been actually an interspecific hybrid of C. *arabica* and C. *mauritiana* which had occurred on the island of Reunion and which was given the name Leroy. He also pointed out that, much earlier than the find of Cramer in Java, there occurred in a plantation called Kalimas a coffee of what appeared to be a different type from anything seen before.

On tracing this Kalimas coffee back, it was believed by Chevalier to be one of those unusual accidents that result in a natural crossing between widely different species—this time between *C. liberica (dewevrei)* and C. *arabica*. The variety from this cross had extremely variable descendants, some of which were like *liberica* and some like *arabica*. He noted that, as early as 1907, Cramer reported such coffee crosses as *abeoeuta* with *liberica*, Java (presumably Arabica pollen) on Robusta, Java on Kouillou, Java on Mokka (this being the true C. *mokka*, considered by him a species different from C. *arabica),* Bourbon on Maragogipe, *liberica* on Robusta, and other crosses. Meanwhile, Chevalier had observed crosses between C. *canephora* and *congensis*, which developed into a distinct type and came true from seed. This he subsequently named C. *crameri*. These findings appeared fairly early in the history of modern genetics and quite a long while before the investigations of Krug and his co-workers.

Apparently it has been difficult to obtain satisfactory results from studies of inheritance of characters in C. *liberica*. This has seemed curious. Partly, it is because the species is not so important as either C. *canephora* or C. *arabica,* and, as a consequence, has not had commercial interests calling for studies. Partly, it is because it is a large tree, and it requires patience and decades for conclusions to be reached in genetics of trees. In addition, both *canephora* and *liberica* are mostly self-sterile, with rarely occurring selfed seed. For such reasons, the obstacles are great in obtaining enough numbers of selfings and crossings to prove genetic effects and sorting of characters. With the large field-space requirements and the long periods of growth necessary, much as they are needed, such genetic studies will be slow in being realized.

GENETICS OF MUTATIONS IN ARABICA

There has been much more reason to work on *C. arabica*. It is a self-fertile tree, it is grown in astronomical numbers in large areas because of

Its immense commercial popularity, if *k* a relatively small tree, and it is sufficiently easily handled hortieuhurally. Findings respecting genetics in this species may he gathered from Zimmermann (upH)f Chevalier (1929, 1947), A, J.*T. Mendes (1938, if|jHii, 1941), Knitf el *al (mm% C,* 11 T. Mcndcs (KJSO), Cramer (1913, 1957}, Kruj* (IQ.M, i<»5, "Ml* 19370), Krug & J. K. T. Mendes (K)35)t Kru« & A. J. T. Mcmles (1940)^ and Krug & Carvalho (1951). Some of the first systematic genetic work on *Coffea* started with the establishment, in 1924)* of a pcnetics section of the Institute? Agnmomico, in the State of SSo Paulo, Bra*/ilt under the leadership of 1L Taschdijian. Full advantage was taken of older field observations and analyses of effect^ published early by such *m* Frochner, Cramer, McClelland, Chevalier, atul a few others. It was from kleas of these previous workers that there sprang the first *kkm* of what could come out of (A *arabka**

Chevalier states that imitations in C*\ *arabka* were noted as early *m* 1773 on the tie de France. Hie dwarf free Mokka is considered a muta* tton by some, in any case, tt was an introduction front ktiuopta and was known in Arabia, even before coffee was spread from there as a world crop, It was in 1870 that the mutant Marngoffipe was found on a Brazilian coffee fazenda in the municipality of Maragogipe, Bahia. It was somewhat later that the yellow-fruited Amarcllo or Botucatti (PL *uyi)* was found in the municipality of Botueam, Sffo Paulo. The type Polyspermy had also been observed early and studied *m* a curiosity* Cramer described Krecta from Java in 1913. Numerous others had been found at about that time and

[illegible] devoted to the hereditary behaviour of mutant mcmtjcr& of tlie socEClii* Review of inheritance analyses shows that the mutants can be grouped

uncicr cue zouowixig lianoi/tcci iLGaciingSt

(i) Recessive genes/The largest class consists of those in which the mutant character is dependent upon its expression through the effects of recessive genes. These have apparently been selected from countless generations of selfing, as is the habit in C, *arabica.* (1) A type of plant of fairly common occurrence in nurseries of *arabka* has been named *angustifoHa** It is variously described as narrow-leafed, peach-leafed, and dcgenerote*leafed. The seedlings have narrow leaves, and as larger trees they have poor fruit crops. The genes involved are of two kinds* the *agx agx* pair that results in multiple stems in addition to the narrow leaf character, and *wg*Z mg2** which produces single stem and narrow leaf (2) Another mutant plant* rather rare in occurrence, has very mis-shapen leaves and has been named *anomak.* The genes, that govern this are designated *an an** When crossed with 'normal', the Ft generation plants all have normal leaves* Results in the Fa generation are in the proportion of 9 normal to 7 with *an* genes. (3) Another recessive gene is represented in C. *arabka* of the

(a)

PLATE 20.—*(a)* Fruits of the Arabica variety known as Botucatu or Yellow Bourbon. (About & natural size*) I.A.I.A.S., Costa Rica.

(b) Cherries of a hybrid between *Coffea arabica* and C. *mokka.* (About £ natural size,) In true Mokka, the cherries are small and flattened, the beans being much smaller than in Arabica and having a distinct and exquisite flavour. In this hybrid, the size and shape of the cherry is much nearer to that of Mokka and the flavour is also exquisite, like that of Mokka. I.A.I.A.S., Costa Rica.

(b)

form called *cera*. The plant is characterized by yellow endosperm in the seed. This yellowness is dependent upon full effegt of the recessive genes *ce ce*, with alleles apparently recessive to one dose of *Ce*. When *cera* plants are used as female parents, with normal green-seeded plants as male parents, the resulting hybrids are all green seeded. The gene constitutions of *Ce ce ce*, and of *Ce Ce Ce*, all result in equally green-seeded plants. (4) A distinct form called *lamina*, because of its fancied similarity to laurel, is a slender tree, conical in shape, and with small leaves. The genes that govern this type are *Ir Ir*. When normal plants of the *typica* variety were crossed with *laurina*, the Fi generation appeared completely normal. The F2 back-crosses with *laurina* segregated into both *laurina* and into distinct 'normal' *typica* individuals.

(5) One of the most spectacular forms, dependent on recessive characters for its expression, is the tree with purple colour in young tip leaves, and streaks of this on red fruits. This makes a showy plot in a collection. It is called *purpurascens*, with genes *pr pr*. When a *pr pr* plant is crossed with a dark-bronze-leafed plant, which has genes *Br Br*, the result is a Fi generation with a slightly darker bronze leaf. On analyzing the F2 generation of this darker bronze-leafed plant, it was found that the progeny broke down, or segregated, into purple leaf, green leaf, and mixed bronze. If true *pr pr* is crossed with normal green-tip, which is *br br*, it acts as a recessive. (6) A type that has long been known and is characterized by the extraordinary ease of flowering, but does not necessarily require extreme change in climatic effects to cause blossoming. It seems to be due to a weakness in the buds, and has been called *semper florens*. When strains of this have been segregated, and then crossed to 'normal*, they give all normal phenbtypes, and will not blossom without regular seasonal change. On growing the F2 segregates, it was found that they were composed of three normal plants to one *semper florens*. The mutant genes in this *semper-florens* character are *sf sf*. (7) It is a remarkable experience for anyone who is used to seeing nothing but red-fruited coffee, suddenly to come upon a group of trees producing brilliant yellow cherries. This yellow colour of the surface is a mutation given the name *xanthocarpa*, with genes *xc xc*. The red colour is governed by genes *Xc Xc*, and is almost completely dominant over yellow. However, in Fi hybrids between the two, the red fruits are recognizable as slightly paler, more yellow in colour than the normal red. If *purpurascens* is crossed with *xanthocarpa*, the hybrids are phenotypically *purpurascens*, with yellow fruits only having a slightly darker colour. The yellow fruit colour genes *xc xc* seem to have commercial value, as they contribute to increased yield in varieties into which these genes have been introduced. Another colour variant is the yellow shades in the bronze leaf character. From appearances, it seems that these might be related, in some way, to the yellow in *xanthocarpa*. However, this is not the case, as the two effects are inherited entirely independently. (8) In one form, *crespa*, the effective genes are apparently *Cr cr*. The trees of this form

arc rare in occurrence, ami art* marked by *simll*, crisped or * unMf d (caws. When such plains arc h\bridi/ed with either IMIVIIMI H>%^ or norm.*) *hmrbm^* half of the progeny se^re^ates into 'notmal and halt mfo -*v«/w plants. This would indicate its hetero/ypai* mrvMe constituftoti *M* expressed by the signs *drcr* f4ivi.it above. SVllinjj: of /f^/u prodneed both crinklcd-Ieaf and normal plants. In some of these proems, tin* rniilkif* leaf plants were quite small, which was interpreted, in such ea-;es, as indicating probable hommygosify for the recessive penes * f «T,

*(it)Dominant$etm.* (9) In Arabica coffee, there are a mtmbrr of inherited characters that are dominant in action. One of these is the form *idtyijn* themtt)* with genes (X\ Thin character is the source of a rare variant$_9$ in which the plant is found to bear lar^e and couupii *wmn* flowers with petaloid calyces, When such plants were crossed *%%* «ib plants having normal flowers, the progeny could he divided into half with flowers of normal appearance, and half with flowers having the hnjje petaloid calyces. On further crossing, the normal plants just mentioned were fiiuiul to lie double recessive, *.r, for iho *culyawtftenM* character, Analyses indicated that, in the ease of this form, there was complete dominance, (to) A second completely tlcittufutttt character from mutants in Arabic a is the form *cat una, U* has jteneN designated as Cl O. The name means 'small[1] in Brazil, and the *itxa* are undersized compared with C *ttrttNut*, with somewhat broader leaves of dark green colour. Thene trees are also similar in *kmrhtm m* colouring, comportment of lateral branches, and free sha|H\ The young leaf (lushes are green in colour* 1 dkewisc, the trees are heavy bearers, like *btmrban* can be *mi* close together in the field, grow well in the sun, and are of considerable and increasing commercial interest in Itra/il. This variety has been given flic name Catttrta and is being tested in a few other countries under various conditions. When the form *cut una* was crossed with *normal[?], it; produced all *mturmAlkc* trees in the Fi, ()n back-crossing these phenotypes to 'normal*, the result; was that half of the progeny were 'normal* and half were *caturra** When these latter plants were back-crossed to *catena* to be pure, the progeny were all *catena** PI. 20,£, shows a, year-old seedling from a hybrid between *catena* and C, *mmphom**

The dominant mutants are an interesting group* and the *hut* two to be mentioned hero are very cut ifcrcnt m their appearance** Ct t^ CJ^ie of the forms is known as *trecta*, and was first seen in Java towards the beginning of this century. These plants have lateral fruiting branches that grow upright rather than horizontally. There was some contention,, at one time, that the erect fruiting branches might be of orthotopic character* Carvalho *et al* (1950) proved that *erect a* trees are true dimorphic plants. Grafts of *erecta* laterals continued to grow upwards,
from lateral branches developed into characteristic low shrubs, This *erecta* character is a great disadvantage to the plants, for they often break, and, at fruiting, may be tangled in a haphazard manner, When such plants are

crossed with 'normal', the Fi generation is all *erect a,* and in the F2 generation there is clear segregation of 3 *erect a* to 1 normal. (12) Another character of unquestionable dominance is found in the variety *maragogipe.* This variety looks the part of being a dominant character. It is a giant form, with abnormally large leaves and stems, unusual lengths of internodes, large flowers and fruits, and extra-sized seeds. In markets several decades ago, *maragogipe* beans were specially prized because of their big size or boldness, as in those days a special premium was paid for such appearance. This mutant was found in Brazil as early as 1870, and since then has been grown in many parts of the world. The genes for its expression are designated *Mg Mg.* When a *maragogipe* is crossed with a 'normal', the Fi is indistinguishable from a pure *maragogipe.* On selfing these Fi plants, segregation occurs in a manner that indicates Complete dominance of the character by genes *Mg Mg.*

(Hi) Incomplete dominance. There is a group of mutants, or forms, the action of whose genes results in incomplete dominance. There are at least three mutations in this category. (13) One of these is given the name *anomala*$_y$ with genes *Am Am.* Trees of this sort are rare in occurrence. They are marked with unusual, subdivided leaves that are of various sizes. The fruits contain seeds with corrugated surfaces of characteristic and unmistakable appearance. When such a tree is crossed with 'normal', the Fi result is an intermediate type of plant. These progeny are notable for the high degree of variability in the heterozygous individuals. (14) There is another incompletely dominant character that is of considerable importance, apparently, in both the eastern and western hemispheres. This is one of the markers that is recognized as a separation between the two varieties *typica* and *bourbon,* and is the bronze colour of the young tip leaves in *typica.* There are other fairly well marked morphological differences, but the American planter almost always looks first for the bronze tip of *typica.* It is possible, also, that bronzeness has pathological significance, as researchers in Africa have isolated strains of coffee significantly resistant to attack by *Glomerella (Colletotrichum),* and these coffees have the strong bronze-tip character. The occurrence of this colour character is governed by genes *Br Br.* Plants with this well expressed have young tip leaves that are dark bronze in colour. There is apparently only one pair of genes that controls this colour character. It will be recalled that in discussing the recessive colour variant *purpurascens* above, it was pointed out that when the purple colour is crossed with bronze, the result is simply a darker bronze in the Fi. Plants, such as the variety *bourbon,* which have tip leaves that are entirely green, have genes *br br.* Those with light bronze colour are *Br br.* Dark bronze crossed with green has been found to be incompletely dominant over green. In studies by Narasimhaswamy (1940), the bronze or copper colour was dominant over light green. (15) A third clear type of incomplete dominance is the mutant *fasciata.* In this, stems ?ire flattened and grow into irregular, somewhat fan-like shapes with

multiple bud characters and other abnormalities. This is a^ disturbance sometimes elassecl as a disease, and known, Iwtanieally, as fascist ton. In coffee, there are two types of fasciation, one being of undetermined dominant inheritance. The genes that govern this are *Ps Fs*. On careful Helling and re-scgregati<m, plants are produced that have extreme fasciation. C)n the other hand, this extreme effect is easily reduced by crossing with 'normal*, riving further evidence of the incomplete dominance of the mutant form.

(fa) Apparently more complex types. There are some of the mutations or forms that appear to have more complexities in their genetic constitution than those described in the three groups treated above* Considerable study has been given to these more complex* types, for the unravelling of their genetics is difficult. (16) Possibly the most interesting of these is what Krug *d al* designate as their form *mokhh* This is at least similar to the small-seeded, little-leafed, and dwarfed tree that in sometimes given full specific ranking, and was described by Cramer. This is discussed in a more detailed manner elsewhere in thw book, r or purposes of genetic interpretation, the phenotype 'mokka* from C *arabka* is often described as a true mutant form. This being a form around which considerable controversy has grown up, it has had careful study, with maintenance of thousands of progenies in Brazil lor several years, If seems that one recessive gene, *It (laurina),* and another j;ene, *mo (nioMut),* are involved in this, the latter being of some degree of incomplete dominance. In the final analysis, the genetic constitution *ot*moli>a* was found to be *It It mo mo**

(17) Another of the forms with somewhat: complex types of inheritance is the one called *murta*. It appears as a bush with small leaves, and these leaves have unusually prominent veins. The trees are poor bearers, grow slowly, and many do not flower for years on end. The flowers are abnormally small, but when they do set fruits these are normal in size and appearance. Perhaps some of the earliest genetic work ever attempted on *arabica* was that of McClelland (1918) who demonstrated its typical Mendelian character. In selfed progeny of *murta* plants, three genotypes were obtained. They were in proportions of 1 part *bourbon* (// *Net Na),* 2 parts *murta (tt Na na),* and 1 part *nana (tt na na).* (18) Ordinary fruits of *(L arabica* have a clean round disk formed at the blossom end, but, in rare cases, plants have appeared that: give fruits with spectacularly long, persistent foliaccous calyces. The form that: produces these is called *goiaba*. Common Arabica fruits rarely have rudimentary sepals on the calyx end, but if these do occur they are very small, and quickly rub off. The normal fruit is considered as of no sepal character, and the *goiaba* has the 'sepal development* gene, designated *sd*. When 'normal' is crossed *mthgoiaba,* the Fi generation produces fruits with sepals of intermediate size. In the F2 generation there is segregation to one part normal calyx, *Sd Sd,* two parts intermediate calyx, *Sdsd,* and one part *sd sd* or the well-developed sepals.

(v) Variety typica. (rcj) While the studies in Brazil were in progress on the mutations, odd forms, and varieties of Arabica coffee, Krug and his

co-workers were perpetually engaged in various attempts to clarify the genetic composition of C. *arabica* L. var. *typica* Cramer. It will be recalled that this is the enormously popular variety variously given such names as 'National' or 'Nacional⁵, 'Mission⁵, 'Arabigo⁵, 'Java', 'Sumatra⁵, etc. It is considered by many as the basic type from which all the others have emerged, and it is known to be the one Linnaeus used to describe the species. Typica is noted for its adaptability. It has rather flexible, more or less drooping, lateral branches, and bronze colour in young leaf flushes. It was reported by Krug & Carvalho (1951) that, when *na na* was crossed with form *typica*, the Fi product looked very close to 'normal⁵, if not completely so. When these Fi plants were selfed the result was a differing series of types that could be put into five forms: *typica, bourbon, nana$_y$ murta*, and an 'abnormally large leaved *murta!*. These workers held that it can be assumed that the form *typica* carries the genes *Na Na* along with the dominant genes *T T*, and since *nana* plants are double recessive for the latter genes, they must contain *na na tt*. On being crossed, the resulting Fi was composed of *Tt Na na* plants. When these were selfed they demonstrated reactions that were listed in the following manner:

T T *Na Na* = *typica*
11 Na na — almost *typica*
11 nana = almost *typica*, similar to *bourbon*
TtNaNa = *typica*
Tt Na na = almost *typica*
Tt na na = *murta* with large leaves
tt Na Na = *bourbon*
tt Na na = *murta*
tt na na = *nana?*

It will be seen from these studies that genetic differences are recognizable in these progenies on a visual basis. This has considerable practical bearing. According to Brazilian workers, *bourbon*, a variety that is heavy bearing, sturdy, perhaps of the larger-leafed type, with a tendency to brittle lateral branches and with green young tip leaves, has the double recessive *tt*. The true *typica*, a variety that is more conservative in bearing, flexible, somewhat delicate-leafed, with more flexible lateral branches, and with bronze young tip leaves, carries dominant alleles of the *T* gene. From this work it seems possible to group varieties and forms of *C. arabica* into two classes, i.e. those with *tt* or those with *TT*. From the Brazilian studies, it appears that varieties *caturra*, *semperflorens*, and *laurina* are derivatives of *bourbon*, all with genes *tt*. Varieties such as *maragogipe, goiaba*, and *calycanthema* contain the *T* genes, and, therefore, come from *typica*. The much used genetic tester for this, in these studies, has been the common *murta*. PI. 21 shows a dwarf mutation from *C. arabica* var. *typica*.

Krug *et al.* (1939) mention work being carried on, in addition to all the nineteen forms described above, *mauritiana, monosperma, pendula,* *polyspermy* and *teiramera.* These, and many others, recently obtained from Africa and Asia, arc being studied and analysed in Brazil for {genetic composition. Some of this work will undoubtedly result in further elucidation of the basic form from which *Qtffia arabica* first sprang.

ARABICAS OF THE ETHIOPIAN FORKSTS

The mutations, forms, and varieties of Arabica, in which cytology and genetics have been studied most successfully, are front the extremely iidrruw rwfiiujv* 01 iicreuicy mac U«IN uvvii iiiv»iv*icv\i 111 i.i*e %*iiw|*ivi *n* ^/iiuiii* In spite of the popular repetition of the phrase regarding its wide adaptability, there are many things unsatisfactory with the common commercially-grown C. *arabica.* This is an extremely homozygous type* On the whole, it is almost uniformly susceptible to a long list of both diseases and mbecto. JL lie tree crop iiccus to nave me ueivaniut^e 01 more v%»rtfioitiiY, WMU W AAAIL JijiU'Iiv A AJ A 1 "I" ' V %#AA v l l l Hi. AI PI tlWtl§ *liA>»'AlAl,y \\i Vrt* IWllo till* I i%»%i»A 1.11 til il»*%.l nusoanciry practices, it is a species greedy tor nutrient^ anci not specially v^U*A\J*,l.i.Iv*ifcl 111 lift Ul'JWCJl* « Ilvle Iff C»*fclw*Iili Iil*v*V3WiCy i»*4 IAllIIAl#i'I44f*§ vtlAivv • , il * * 1 i iii »i * i » 111, * 1 j r l»*AtHi ill v * *»\| vllA vUi llv'li vol *%**>* til Ay 1,111 " J^%>tl?lll I* AtlA, vrivvl' I HflJliMiy * All* Ik UsAvULivCllMA, UClL JH'Ai vi*llr)l«lvilli IJvtlXiilIX Wllill/llC llie eXCI*Milv IwnifTV'f't li'AITl C^AAAtlUlaA.AUAl, 1,AA4l< ill v TTUW VAJ/VA Av4lvv%* il.AA.v4 AIvltlVY Vil'IPHJMiU# V 'tlflWV' IyiVvli Ui high caffeine content; would be valuable, as would be those that produced aromatic seed with practically no stimulant Differences in soluble solids, superlative flavour, and that quality called body, are beginning to be QV/LlfcpAAC* 11 AM AwA dlAL'AA A V'^lSV/lAiSl €%Q UAVISIVM CAAAVIL AAI^IAAV L/LAAV&39« LAACAL LAilv AA A vjilAAiAA C *arabica* coffees growing wild in Ethiopia are of such interest. In some instances, there should be actual preservation of stands of these in their natural habitats. Isolated ax cas V/JL ttflwJtVi' A\vf A *PAtUfciO \./A iUAACAA» A4AAAVA VV AAA l l v v a intensive attention very soon, and more and

out for investigations and tests.

Sylvain (1955) recently completed two years studying and collecting materials of C. *arabica* AAA VpA> AfiK AAACAA forest habitats in Ethiopia. Before his work were some others, such as the collections secured by English horticulturists for testing in British East Africa. There were the reports of the Italians, Spaletti, Branzanti, and Ciferri, to which Sylvain refers, and the collections of Archer for the United States Department of Agriculture. Since that time a number of collections have been made by the United Nations Food and Agriculture Organization, and by other agencies working or visiting in Ethiopia. The Italians saw marked varietal differences and described them with their Ethiopian : (1) The variety Ii jTiritiri&i or Naria. It is a wild type, with small green .grains, and with exceptionally fine aromatic qualities. (2) Variety Anaro or Amino. It has a larger, more rounded seed. The variety is subdivided into the Long Berry Harrar with long, large beans, and the Ittu which has smaller beans. (3) The Zeghie variety is noted for big flat beans, that are less rounded. (4) Another named variety is Gentel, but there is belief by some that the difference is more from preparation of the beans than from true plant differences. (5) In the Jimma district, one of the best-known and most highly prized varieties is Malo. This name is another, Ethiopian, name for the Jimma district from which it comes. The seeds are elongated and of excellent appearance. The leaves tend to be slender and long, and the young shoots of bronze colour. This variety is famous for its higher productiveness and more marketable beans. (6) Another variety the Italians have mentioned is Jimma. This is well known. The foliage has marked characters, as the leaves are large, thin, and tend to be orientated in a hanging fashion. In addition, compared with others, the seeds are rounder and straighter in configuration.

Sylvain has made numbered collections of twelve distinct and interesting varieties in Ethiopia. After proper health clearance, these are now growing in Turrialba, Costa Rica. For convenience they will be listed in numerical sequence, following those just described above. (7) Sylvain's Ennarea or Ennaria, his S.2, is apparently from the same source as the Ennaria or Naria of the Italians. He described it as being a tree with green colour of the young leaves. He considered that it corresponds to Chevalier's C. *abyssinka*. It apparently has the largest fruits of any Arabica excepting Maragogipe and Polysperma. The collections of Sylvain were from a forest at an altitude of 1,700 to 1,800 m., and reports on quality were satisfactory. (8) The next distinct variety would probably be classed under what the Italians called Malo. Sylvain combined in this his Jimma, S.3, and his Kaffa and Anfilo, S.12. He called it the Jimma-Kaffa group, and considered it the coffee most commonly found in the forests. He believed this was one of his most important collections, as, in his judgement, this type was much the most likely to be the original parent type from which came the world-renowned *C. arabica* as we know it. (9) Another named, and apparently recognized, variety of Sylvain was Agarro or Agro. It was represented in his collections as S.4. The tree was somewhat similar to those of the Jimma-Kaffa group but he only found it in cultivation. It had large leaves, and the calyx end of the fruit was free from sepals. (10) His Cioiccie, S.6, differed from his S.4. in having much rounder fruits and seeds, but it was a distinct variety. (11) The S.io, Harrar or iriarar. was typical of what is, probably, the best-known of the later importations of varieties from Ethiopia. It came from cultivations near the city of Harrar, and is found in other parts of the province of Sidamo. Generally, it is considered the best horticultural type in Ethiopia, and it has been of much interest for that reason. It is a rank grower, a good producer, has large bold seeds and rather large leaves that are bronze in young tip flushes, but it is susceptible to leaf diseases.

Another group of his collections are from the Irgalem-Dilla region. (12) The variety Irgalem, Sylvain's S.14, is a rather small-leafed tree, and the young growing leaves in flush are green. It has a more bushy habit than most. It comes from the region of Irgalem, the capital of the province of Sidamo, and was introduced years ago into Kenya under the name of Dalle, which is a synonym for Irgalem. The variety Dilla, which was imported into Kenya, according to Sylvain, would be the large-leafed coffee common in the province of Sidamo. It is marked by bronze of the newly-growing tip leaves. (13) Another collection was Tafari-Kela, Sylvain's S.8. It has characteristics intermediate between the Irgalem and Dilla varieties, its young leaf flushes being lightly coloured with bronze. The leaves are of medium size. Tafari-Kela comes from a village found between Irgalem and Dilla and the variety may, indeed, be a hybrid of the two varieties originating in those two places. (14) The S.9, Arba Gougou, Red Tipped, is a mutation, with typical reddish colour of young leaf flushes. Trees having this were rather scarce, and Sylvain considered the mutation probably analogous to the Purpurascens variety described by Cramer.

The remaining four varieties, collected and studied by Sylvain in Ethiopia, are probably the most unique. (15) One of these is Zeghie, S.13, which he believed was probably a derivative of Ennaria, No. 7 above. He saw it growing on the shores of the mountain Lake Tanna, and found that it was specially noted for producing coffee of the poorest quality in Ethiopia. Fruits are somewhat smaller than in Ennaria, but it showed possibilities of value in a breeding programme aimed at finding differences in horticultural adaptabilities. (16) In Loulo was found S.14, a most unusual coffee. It is well known in the Sidamo province, particularly for the high fat-content of its pulp, and, as well, for the exceptionally low ratio of clean coffee to fresh cherries. (17) The type Wolkitte or Volchitte, S.15, is from the province of Shoa. The tree is rank in growth, with good-sized fruits. The young leaves in flush are green and rather large. From what Sylvain could determine, he believed that this variety is probably a direct precursor of Harrar, his S.io mentioned above. (18) The last of these forest selections from Ethiopia, the type Wollamo, is different from all. The tree grows well, and has foliage that is either green or bronze in young flush growth. It seems mixed in this respect. Its fruits are characterized by a very flat apex, and have a distinct rectangular shape.

A point worth emphasis here is that the wild Arabica coffees brought out of Ethiopia, and recently placed in experimental gardens, are remarkably diverse in their characters. Their heterozygous appearances are even greater than suggested above. These variations are a welcome promise of things to be realized in breeding and selecting for the future, modern Arabica plantation. It is from them that we will secure more help in connection with disease and insect resistance, in adaptation to horticultural practices and husbandry, and in quality and quantity of bean production.

ARABICA BREEDING AND INTERSPECIFIC CROSSES

With all that is known about the genetics of mutant forms in C. *arabica,* true-breeding programmes in Arabica, outside of understanding mutant characters, are practically non-existent. One of the first, if not the first, use of Arabica in breeding, but even then mostly selection, appears to have been carried out in Java. This occurred after the rust had driven 'Java coffee' out of the more productive lower planting belts to the cooler highlands of the Idjen plateau. The Dutch sent specialists to Ethiopia *{see* Indonesie. Centrale Proefstations Vereeniging, 1954) and these returned bringing collections of Arabicas. It seems that studies and some crosses were made, and what resulted is very different from the classic Java Arabica. The new variety is more resistant to *Hemileia vastatrix,* is known under the name Abyssinie, and has variable types within it. But these new Arabicas have to be grown in the cooler coffee regions.

In the hope still of bringing a resistant substitute down again to the more productive lowlands, interspecific crosses were made in Java in the early years of this century (Ferwerda, 1948; Cramer, 1957). Both natural and controlled or known, 'legitimate', pollinations produced progenies from Arabica X Robusta, Arabica x Congusta, Liberica X Arabica, Robusta x Arabica, and Arabica X Stenophylla. The work on these crosses has stopped, and, without much more work, such interspecific combinations have been found to be virtually useless. In almost all cases, occurrence of high percentages of empty beans is a common cnaracterisxic 01 species hybrids with Arabica. This effect, apparently, is for cytological reasons. The inequality in chromosomes is realized (A. J. T. Mendes, 1951), but valuable application of the knowledge has never been carried out. Quite a while ago, Ferwerda (1936) reported hybrids of Liberica X Arabica as self-fertile. Such, for example, are the long-known Kawisari Hybrids B and D. If they are handled as clones, they produce well, though always with some empty cherry locules. They are eminently resistant to rust, and otherwise grow in some places where pure Arabica fails. It was shown (Cramer, 1928) that these Kawisaris grew better as grafts on roots of Robusta than on most other types, or than on their own roots. When reproduced as seedlings the Hybrids were unrecognizable as kawisaris.

The securing, from standard Arabicas, of strains with greater genetic advantage, has been by chance and out of billions of trees. Such are the Mundo Novo (Carvalho *et al^* 1952), Bourbon (Triana, 1955), and Caturra (Krug & Carvalho, 1951), based on the use of mutants, the convenience of self-compatibility, and clone-like growth henceforth. Improvement programmes such as those of Hendrickx & Lefevre (1946), Stoffels (1936, 1941), Thorold (1947), and Carvalho (1952) all add more proof that standard Arabicas are so clone-like in character as to be almost hopeless as sources of desired variation. In the Brazilian work, a model study, Carvalho used 1,107 trees of standard Bourbon. For nineteen years he secured individual tree records. Those that appeared early as undoubtedly outstanding trees were used to produce progenies. Trials of these went on for twelve to fifteen years. At the end, his conclusion was that it was very difficult, and, at the least, uncertain, to establish any relationship between exceptional yield noted in his observed specially good mother trees, pd the yield of their progenies. In addition, extreme production variability is an apparently fixed characteristic of standard Arabicas, as many coffee workers know, to their confusion, in Africa, the Americas, and Asia. An example of the extreme variation in tree production is presented in the accompanying Table IX from work by Stoffels. PL 17 shows an exceptional Arabica coffee tree, typical of many selected for high productivity.

TABLE IX

COMPARATIVE YEARLY PRODUCTIONS OF INDIVIDUAL TREES OF ARABICA COFFEES # INDICATING VARIABILITY IN PRODUCTION

Year	Number of trees	Cherries per tree: mean in kg.	Standard deviation	Coefficient of variability
1935	723	177	179	101-13
	1034	2-013	2-60	i29*45
1936	722	5-843	2-99	5i"54
	1018	4*984	2-88	57-89
1937	721	1-338	1-42	106-35
	1016	1-572	2-43	154-80
1938	721	5-505	3-12	56-69
	1016	5-643	3-24	57-43
J939	721	5*970	3-55	59-56
	1015	4-882	3.804	77-92

* Adapted from work done in the Congo by Stoffels (1941), from his Table 4.

In Stoffels's research, he used material from what he called nineteen lines. These came from types spoken of as Mysore, Bourbon Ordinaire, Mbirizi, Blue Mountain Kenya, Local Bronze, Bourbon Mayagese, Jackson, Blue Mountain Jamaique, and Kabare. Even with these, that seemed different, the majority of his work was simply selection out of selfed strains of mother trees from different regions. From 1,736 trees, he selected each year the top 1 per cent as the 'elite' Changes from year to year were presented in tabular form, *see* Table X. Of seventeen, selected as *elite* the first year, not one showed as *elite* the second year. Nine *elite* appeared three times during the five years. Two, four times. On the other hand, there were thirty-three selected in the first four years as of *elite* calibre, but they appeared only once as of this class, which would leave doubt as to their true 'eliteness'

With regard to the best of the *elite,* a most important factor in long-time performance was their resistance to die-back and Colletotrichum infection. Stoffels also began true breeding, making crosses between widely divergent mother trees of different origins. At least in one case, a Blue Mountain and Local Bronze cross, the progenies clearly out-yielded selfed parentage progeny. Large bean types were crossed with

TABLE X

DESIGNATIONS OF INDIVIDUAL ARABICA COFFEE TREES THAT HAD BEEN SELECTED AS OF *ELITE* CALIBRE, OUT OF 1,736 INDIVIDUALS, DURING FIVE YEARS OF OBSERVATIONS, AND SHOWING FROM YEAR TO YEAR THE CHANGES IN THOSE STANDING AS *ELITE* [m]

Elite selectionsf during years:

1935	1935 and 1936	1935 to J 1937	1935 to % 1938	1935 to J 1939
S.81	--			
166	—			
168		168	—	168
170				
171				
337		337	—	—
397		397	—	397
S.76		5.76	—	S.76
S.77		5.77	—	S.77
S.123		0.123	0.123	0.123
0.124		0.124		—
S.125		S.125	—	—
[illegible]				
0.222		0.222	-"-"'	0.222
S.24I				
0.255				
S.405		S.405	—	s.405
	I.399			
	I458			1.458
	1.633			1*633
	S.220			
	S.224	s.224	0.224	s.224
	S.226		s.226	
	S.252		s.252	s.252
	S.263			
	S.388		s.388	s.388
	239			
	S.5O		s.50	
	S.75		s.75	
	• S.78			
	S.98			
	S.I16			
	I.O39			
	1.005			
	1493			
		293	—	293
		338	—	338
—	—	35°	—	~"
—	—	395	—	~
—	—	963	—	—
™	—	S'399	--	—
—	—	—	288	—
—	—	—	409	—
_	-	-	S.74	""

* From Stoflfels (1941), part of Table 15, with table heading and headings of columns somewhat adapted.

t The *ilite* are the one per cent of best yielders that produced twice the average yield of the whole plantation.

% Meaning 'to and including'.

TABLE X—contd.

Elite selections t during years:

1935	1935 ^d 1936	1935 to $ 1937	1935 * t0 x938	1935 % to 1939
—	—	—	S.254	
_	—	~~	S.394	
,_,	—	—	0.223	
—	_	-	S.389	
—	—	—	S.392	
_	—	—	S.395	
_ ..	—	—	S.396	
_	_	—	S.397	
—	—	—	S.403	
				I.563
				i.y
				177
				983
				984
				1.454
				1.634
				s.49
				s.386

f The *Mite* are the one per cent of best yielders that produced twice the average yield of the whole plantation.

% Meaning 'to and including\

smal bean, and it was found that large bean is a dominant character. It is from such legitimate crossings, from wild and untried collections, that real progress will be made with Arabicas. Selectionists, who do not make crosses, can spend their time for ever in selecting 'the best' trees from the standard Arabicas, and will end, largely, with what they first saw. They will be millions of monetary units poorer, much older, knowing more about the purity of standard Arabicas with their heritable, clone-like behaviour and characteristic large coefficient of variability, but no nearer to a greater Arabica strain or variety.

In Arabica, rust diseases are limiting factors, but it has long been known *{see* literature review, Wellman, 1955) that there are many Arabica coffees of high rust-resistance. Works of Wilson Mayne (1936) and co-workers showed fully (e.g. Narasimhaswamy, 1950) that rust resistance could be isolated from lines of C. *arabica^* and breeding showed that one type of inheritance followed a pattern of simple Mendelian dominance. In other cases, it appeared more complex. Later work by Oliveira (1955) proved certain strains of Arabica to be immune from *Hemileia vastatrix* attack, although Rodriguez (1956) showed that the other rust, *H. coffekohy* attacked many of these, and especially all Arabicas. This is leading away from dependence on simple selection, and there is a re-awakened necessity for the use of true crosses and interspecific hybrids. In all of thiSj *C. camphor a* seems destined for an important role, and out of it may yet come a satisfactory hybrid, with Arabica quality and Robusta vigour and resistance.

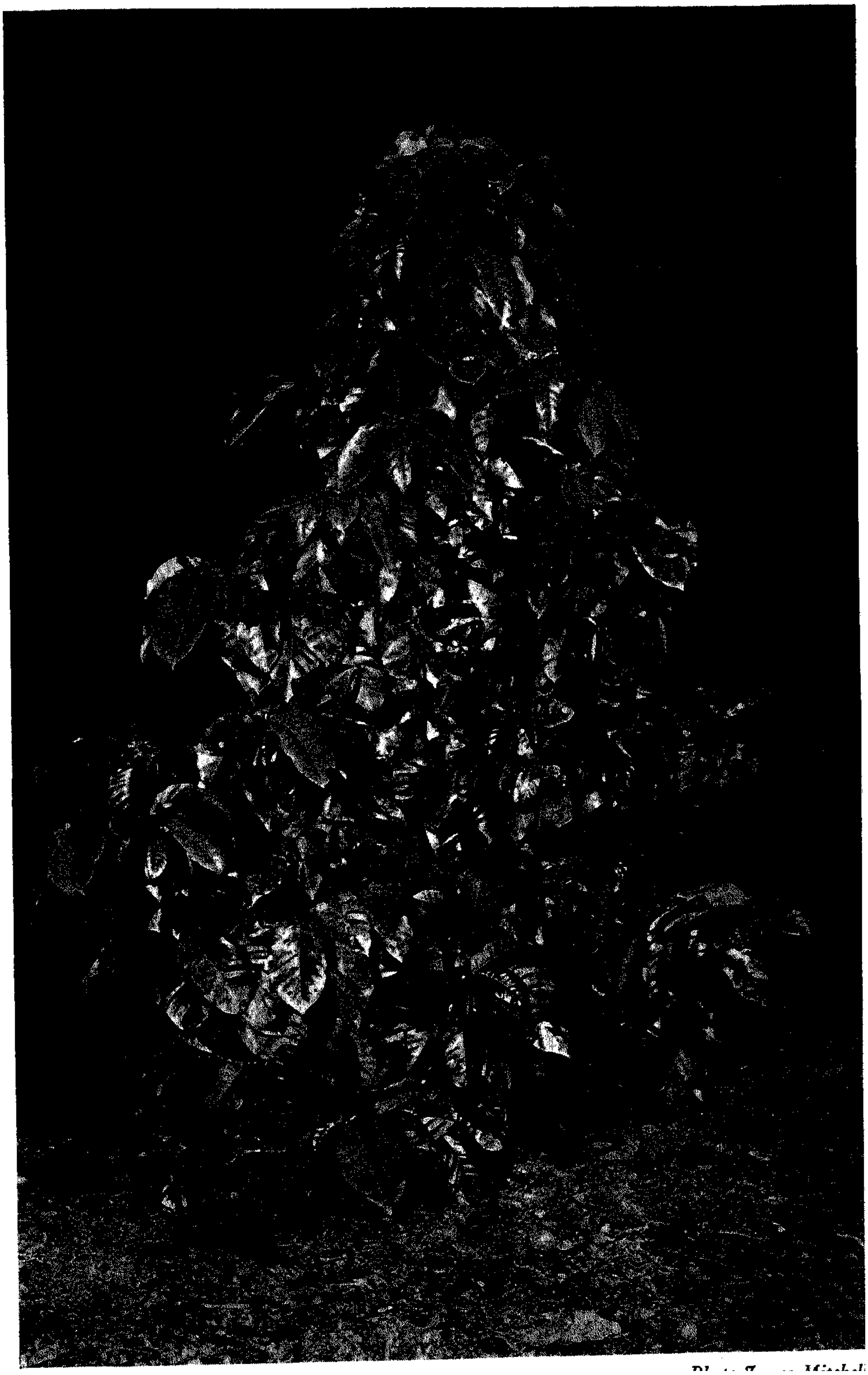


PLATE 21.-0.ie of several dwarf mutations from Arabica. In tta; case, about 2 m high i^omes from the Typica variety and is called San Ramon. It is charactered ty **«»*«.shortgemote, notably pointed over-all shape, and somewhat smaller cherries than in normal Arabica. Guatemala.

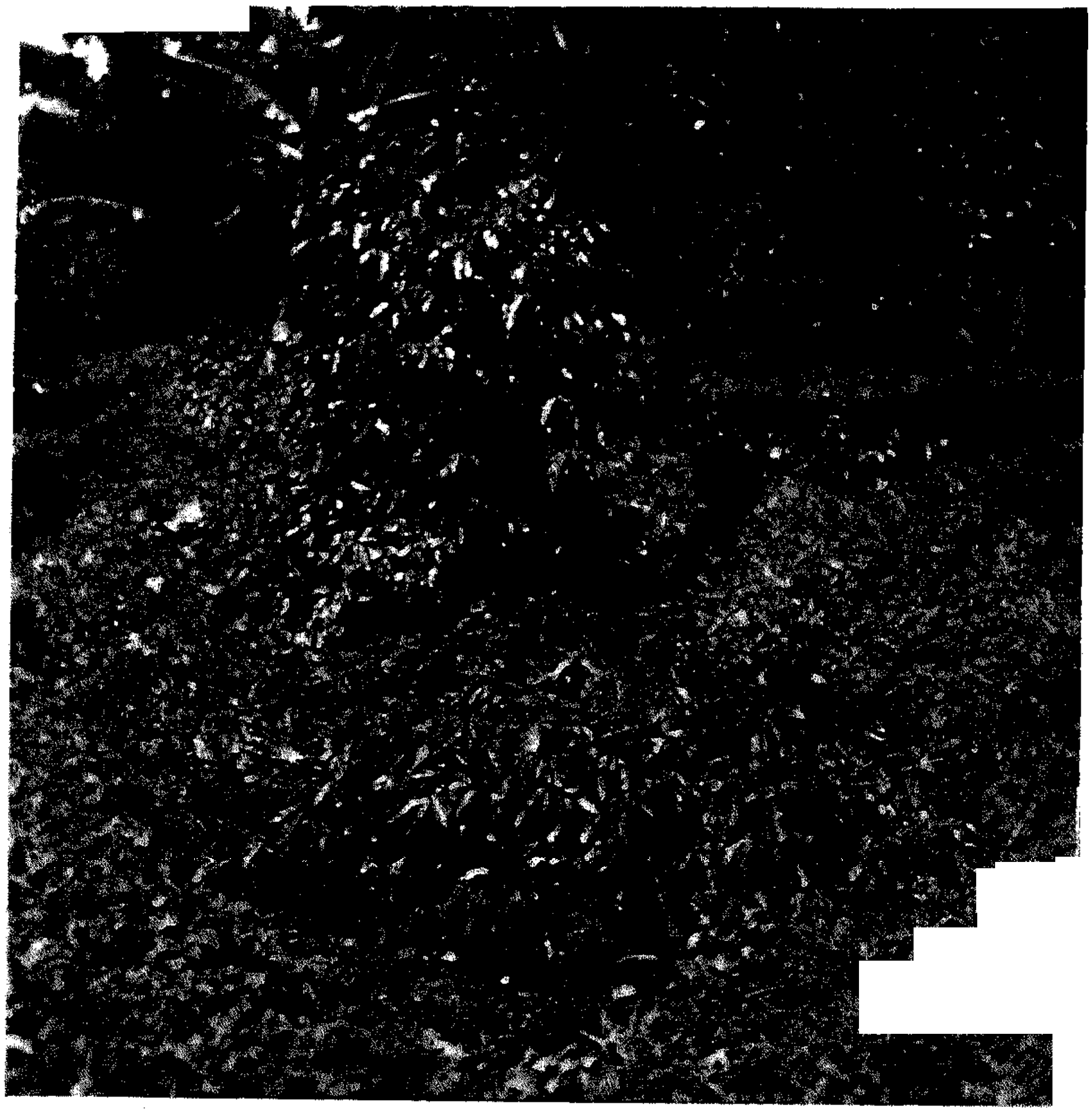
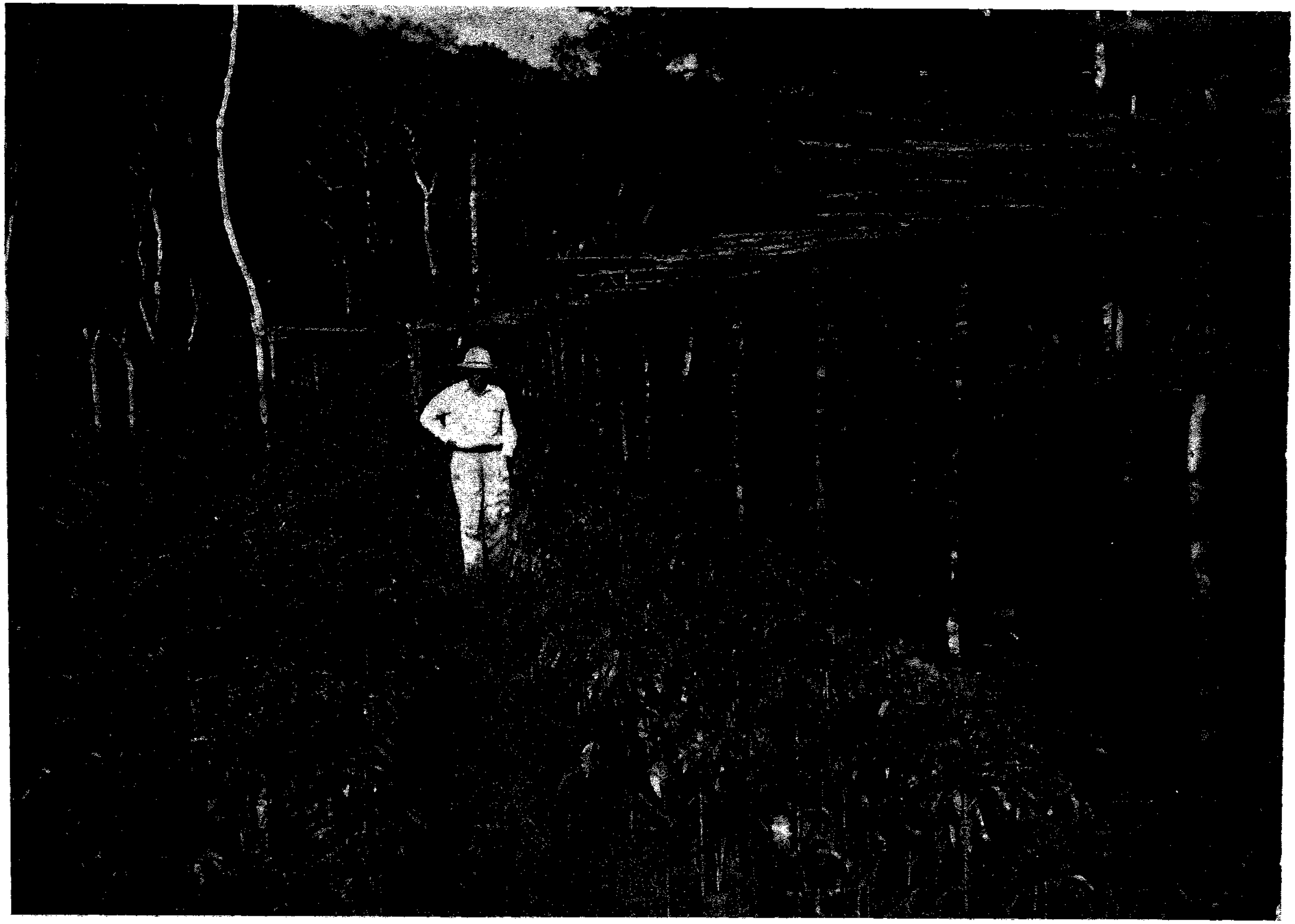


PLATE 22.—Coffees multiplied by cuttings from normal tips of orthotropic upright shoots grown as normal trees. Cuttings from plagiotropic, lateral, branches produce trees that grow flat on the ground (example in foreground). Occasionally (A. J. T. Mendes, 1938), plagiotropic trees may develop orthotropic buds and upright stems (example in background). I.A.I.A.S., Cost Rica.

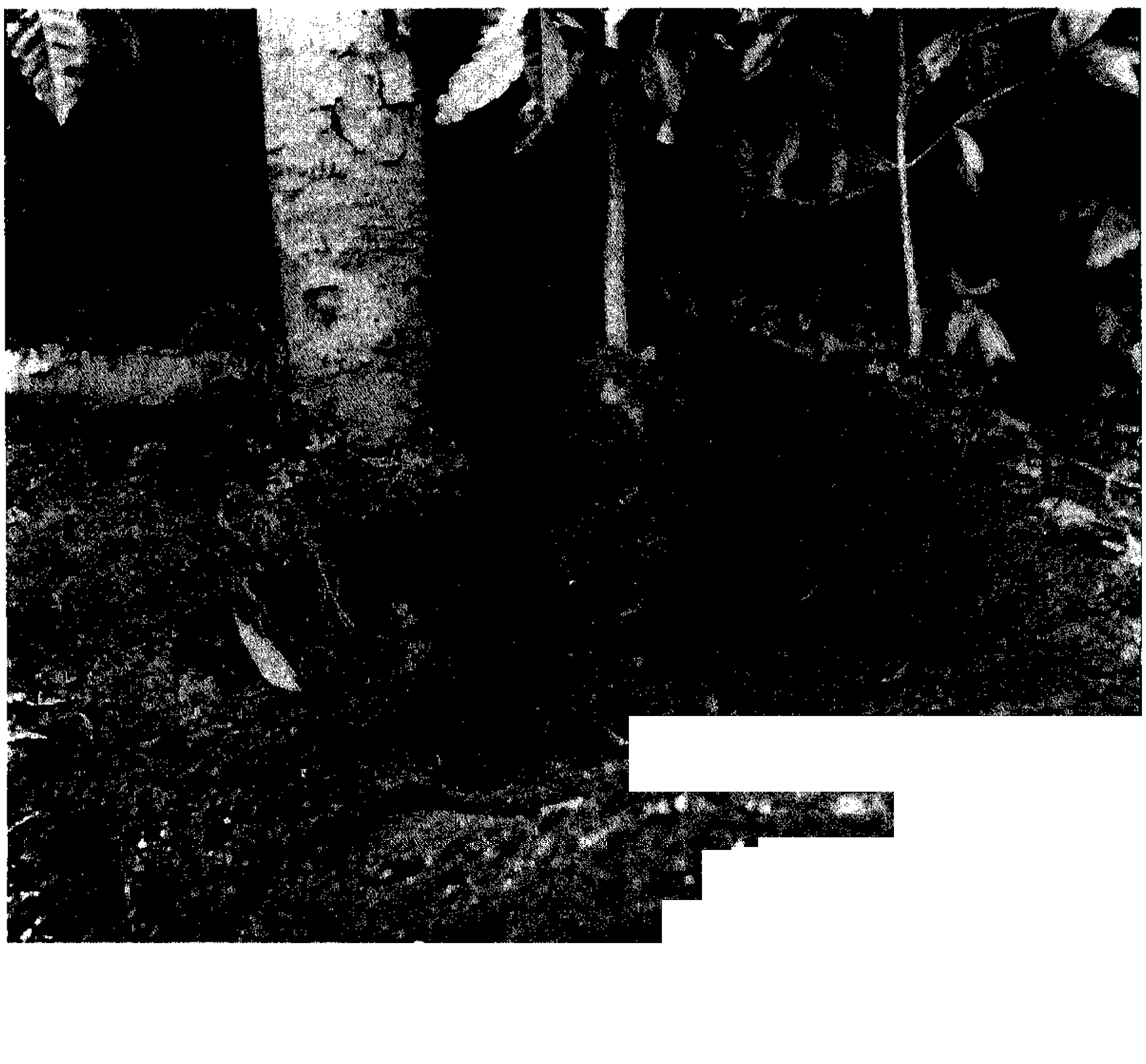


(a)

PLATE 24.—*(a)* Type of medium-light shade used for most coffee nurseries on the slopes of Central America, in this case in Guatemala.

(b) Bail of earth left around roots of shade-grown nursery seedling prepared for transplanting. Santa Ana, El Salvador,

(b)



BREEDING IN C. *canephora*

It has been clearly demonstrated by Krug & Carvalho (1951) that the tetraploid C. *arabica* has heavy pollen and has to be largely self-pollinated. Even where conditions are windy and dry, and good for natural cross-fertilization, crossing in C. *arabica* rarely reaches seven to nine per cent. With protected, shade-grown coffee, where conditions are moist, ^ cool, and not windy, cross-pollination is probably much less. This, in a way, can be used as an advantage in the breeding work on this species. It is different with both C. *canephora* and C. *liberies* that are habitually self-sterile, and cross-pollinated. Their pollen is light, and Ferwerda (1948) has shown that it is carried considerable distances in the air. Because of its fertilization habits, the genetic combinations and recombinations in C. *canephora* never end. The chances for many new recessives and mutants to be found in plantations are very low, practically nil, although they do occur. For example, Cramer (1957) reported a 'purpurascens' mutant. A yellow-fruited type, called 'namata' by indigenes in Uganda, is mentioned by A. S. Thomas (1947). There is growing in the coffee variety collection at the Inter-American Institute of Agricultural Sciences in Costa Rica, a Canephora tree that approaches a weak 'pendula' in character, and has the symptoms of a mutant. Mutants are very uncommon in Canephora.

At first, Canephora was not given much thought as a possible source of the coffee drink. The species had been used, at least hundreds of years, for chewing by aborigines and later by the civilized natives. However, when the rust disease swept through one country after another, and Arabica was destroyed, a 'wild coffee' was found tolerant and was given attention. Taken to Java in 1900, it was soon in the care and keeping of highly trained breeders. Breeding of it in a systematic manner (Ferwerda, 1936, 1948; van Hall, 1939; Thirion, 1952; Cramer, 1948, 1957; Hille Ris Lambers, 1932) started there in 1907. The first work was on seedlings from selected mother trees. Productions of such seedlings from selections are represented in Table XL There was some improvement but the heterozygous nature of the seedlings introduced such difficulty that, in the long run, they were unsatisfactory. In 1912, the first artificial pollinations were made, but it was not until 1916, when Cramer introduced grafting, that the Dutch could breed and select for clones. There were no longer the irregularities of seedling progenies. From that time on, real progress began to be felt. Clonal selections had much greater promise, but even seedling families from selected crosses gave 25 to 50 per cent greater yields than their mother trees.

In Uganda, A. S. Thomas (1947) reported that, from the beginning, Canephoras that gave the best results came from mother trees in native bush gardens and stockades. These had been native-selected for a long time and were far better than forest mother trees. He used trees that were over ten years old, for assurance that they withstood Uganda conditions. The mother trees were divisible into 'erect" and 'spreading* in habit, and the seedlings of erect inheritance were planted about 12 by 12 ft. apart, with the spreading ones at 15 by 15 ft. Some spreading trees bore

TART F XT

PRODUCTION OF CERTAIN G. *canephora* SEEDLINGS IN TEST PLOTS, ILLUSTRATING VARIATIONS BETWEEN MATERIALS AND RELATIVE "VIP*![1] V\ **TAHTf T*|*Y

m. m • M% im^ fe JP m S I R J* • ifc JLiJ • ft •

Name of selection	Year planted	Total number of trees	Pounds of market coffee per tree, 1916	1937	uyitt	1929	1930	years 1931	from eleven years
5 Sankoer Congo Import	19x4	456	17-90	29*56	a 1*02	26*a8	11*08	9*58	19*08
6 Robuata Ngredjo	1914	99	18*51	30*93	27*15	33-36	5*50	8*67	a 1*05
44 Btikobensis No. 1	19x4/13	100	6*09	18*96	to*6a	15*69	3*36	9*55	9*65
47 Bukobenaia No. 4	1913/13	35	9*48	33-04	25*26	12*07	**'93	iH'20	L^'^l
48 Bukobenaia Soember TjoeUng	19x3/13	7a	6*89	31*75	m*^	10*73	479	*4*a8	17*57
57 Robuata Soember Aain No, i	1918	56	3*06	0*31	36*40	7*34	4*36	1*33	7*14
60 Robuata C Soember Tjoe-llng	1913/13	38	2*51	170	35*70	36*59	577	13*33	18*17
90 Robuata Soember Kerto	1907/08	308	6*33	13*48	15*16	7*64	5*36	i*oo	15*33
94 Uganda Buitenxorg	1910/xi	440	11*35	*T%3*	*5'63	^'53	^*4^	3*a*	**"48
95Qj1iU0uBangeknN0.il	1910/11	60	16*04	I3'3°	>5*37	16*07	19*36	7*30	30*39
150 Robuata Soember Aain No, 3	1916/17	698	1*28	18*02	23*45	7*21	4*48	4*64	9*93
16a Robuata Soember Asin No. 5	1916/17	495	2*55	23*53	30*33	9*93	6*99	6*31	12*86
163 Laurentii No. 3 C. T. Buitemorg	19x6/17	126	5*28	19-81	36*79	8*40	4*26	4*54	12*49
166 Robusta Soember Tjoeling No. 2	1916/17	54	9*96	21*87	43*4*	9,JE7	3'°4	""°7	1773
168 Canephora Limburg	1916/17	315	3*44	20*86	28*19	9*12	8*71	8*34	13*16
169 Laurentii C. T. Buitenzorg	1916/17	81	9*59	25*37	29*11	22*86	7*85	9*41	12*87
178 Robusta Ngredjo No. 2	1916/17	198	6*02	23*53	27*18	14*56	7*05	7*86	15*29
182 Canephora Limburg No. 9	1916/17	136	3-85	21*12	27*17	12*33	6*85	7*76	16*70

[#] A portion of Table 8 from report by Hille Rig Lumbers (1932).

annually as much as 25 to 30 lb* of clean market coffee. The progenies from selected mother trees ordinarily gave better crops than the mother trees. Selection was on the basis of: 1, vigour, including resistance to disease; 2, a good root system, that was found to be superior in spreading-tree seedlings; 3, the spreading habit, as it seemed more adaptable and produced more; 4, s c co n dar v**' pnmarivS, *j, &inau anci rounGeo. leaves, 0, nowcx cnaractcribtics, as fruit colour, size, and proportion of cherry to bean. It was found that the diversity of the trees in the forest was enormous, and the best cultivated individuals showed a marked heterozygous condition. However, cross-pollination was not much practised in Uganda.

DEVELOPMENT OF CLONES IN CANEPHORAS

Controlled pollination was carried on to a high degree in Java. Effects of inbreeding were found to be harmful, but clones from selected crosses out-yielded the best seedlings 63 to 100 per cent. Inter-sterility was studied (Ferwerda, 1936) and it was soon learned that inter-sterility between clones of Robusta was infrequent and, where found, was generally

TABLE XII

COMPARATIVE PRODUCTION OF C. *canephora* CLONES AND THEIR OUTSTANDING MOTHER TREES, SHOWING THE MUCH LOWER CLONE PRODUCTIVITY *

Designation	Production in kati rood f	
	Mother tree %	Clone ||
MB95S.A.	8*50	"75
MB50S.A.	3375	4"Oo
MB75bS.A.	9-25	5*14
MB109S.A.	19-00	7"9°
MB13S.A.	29-50	5-68
MB66S.A.	11-25	5*14
MB60S.A.	1375	4*79

* From the report of Hille Ris Lambers (1932), adaptation of his Table 6.
t Kati rood, measurement of quantity used in Indonesia.
J Average production of 6 years, except for M.B.13 which was 5 years.
|| Production average for 3 years.

N.B. It must be taken into consideration that the mother trees were matured when production data were secured. The clones were physiologically at a different age and on different roots from the mothers.

not reciprocal. Mother trees were chosen on the basis of a productivity index. They were never selected unless they produced over three times as much as the average of the plantings around them, or PI 300. Trees were also analysed for regularity of bearing, size of bean, out-turn, habit of tree, vigour, and resistance to diseases and insects. Numerous planned crosses were made, and the first generation progenies planted in test gardens. At least 100 trees were grown from each Fi generation, and were arranged in three to five replications, planted next to well-known strains for comparisons. It has been found that C. *canephora* shows a strong tendency to dominance of mother-tree characters. After some years of both observation and harvest weighing, if a specially good cross seemed evident, mother trees were re-selected and crosses made again. On proof that they were of exceptional merit for crossing, these clones were planted together for crossing to produce legitimate seedlings for planting. But clones were not always of the value that might be expected. This is illustrated in Tables XII and XIII. However, it can be seen that

0

occasionally, phenomenally superior clones art* fomuh It *in* for such as these that thousands of tests are made. PI 18 shows an exceptional *canephora* tree, variety Robusta.

I, / V 15 I * 1 *i* ,/\ 1 1 I

COMPARISONS # IN PRODUCTION 01*' THE MOtllE! THEE WITH THE CLONK FROM IT f, IN C *CttMplwTtl*

Destination	Percentage of product wit Mother tree	Clone
kft(\» I ,	i«)	JO'6
	too	**pA C#**
S.A.toc)	i %,}tf	fio'j
i i i # \ $ *i*	# %#w	6«f *
n«*t* \»it	**i f/0**	
S«A*24	I ClO	***k***
HAxb		
h?& f%4/m	100	loll
		yi)»8
clones:		
Vir$t 8 yearn of selection	• ft**	af>'« 6«>*4 (44*0 avmftc)
La«t 3 years of selection	J»WV#	487- ita*5 (7J7 itvrni^r)

Compares! on the *bmh* of dw it wrap yield of tit*? mother fro;,

f Data from review of iwardt work tit Iiutonc*iia by (tamer (r«j$7).

$ Number or designations not given,

!n work with clones (Cramer, 192S), it was found that: the stock or root upon which a clone was grafted was often very important to its final success, and, therefore, might very much effect the apparent success *1 given orvvUing* x 'or example, several clones of Robusta were poor if grown on R.59 or 1.59*0,1 roots. Large numbers might die, and those remaining grew poorly. Conversely, R. 124-01 as a stock gave almost universally satisfactory results for grafting, as did certain of the Quillous, and so R.i24*01 became the standard rootstock. As a whole, Canephora clones show fairly close coefficients of variability* Cramer (1957) mentions a few; 63, 62, 62, 69, 49, 10*4, and 27*2. It will be recalled, *see* above Table IX, that coefficients of variability in *C\ arabica* ranged from 51-54 to 154*80*

It was found in Indonesia that the obtaining of fine clones required infinite patience and long years of experience in determining the best breeding combinations- Mono-clonal plots were used for breedings and were known as 'plastic' plots as any pollen could be brought in, from anywhere, and put on with a cflif gun. When handled properly and when the pollen applied was known, the resulting cross was called legitimate*. There were several designs of breeding plots, for different purposes; and there was continuous testing of the best progenies in widely different ecological regions, in a search for 'universal' clones that would produce well under the most varied conditions. Some had much narrower adaptabilities than others, but, in their specified place, these might do excellently.

The steady and long advance, for decades, in breeding Canephoras in Indonesia and Africa, has been observed in a more or less somnolent fashion from the western hemisphere. There has never been an immediate need for Canephoras in the Americas as, through good luck (Wellman, 1953), the Hemileia rust has never gained a foothold there. A most important reason for the first work with Canephoras was because of their rust resistance, and Steyaert (1946) contends that the name 'Robusta' was specially applied to the species because of this resistance. Of late years, however, there is more interest in C. *canephora* in the American Tropics. In poorer soils, the species has a much greater vigour and productivity potential than Arabica. It is increasingly acceptable in the coffee trade. There are still some coffee associations in the American Tropics that advise against growing anything but Arabicas there; but, in the meantime, grown elsewhere, the less costly Robustas and so-called 'Africas' are taking away tne business, it is even well recognized in Latin America (Krug *et al.*, 1950), that the old coffee soils must soon require new coffees, Qiixerem. irom tne xixauicaib.

The Robusta breeding programmes in the Congo (Vallaeys, 1956) and in French Equatorial Africa (Maistre, 1955) have brought up-to-date and improved some of the work once carried on in Indonesia. In the Congo, the breeders use the old Java clone S.A.34 from Soember Asin, as their base for comparison. They are using planting materials and methods much like those of Java, but adapted and improved for their conditions and purposes. In a very short time, they have increased production in Robusta by 25 to 30 per cent, even over otherwise good and reasonably satisfactory material.

Two special clones, recently reported from Africa, have been L.147, for its vigour, productivity, and market acceptance, and L.125, with its good horticultural points and beans close to Axabica in dimensions. What both the French and the Belgians are breeding for are clones for use in a standard mixed planting, that will be the most fruitful and guarantee the most for the grower. This is the perfection sought in Africa. No one should think, however, that coffee breeding has ceased in Indonesia, for it is continuing there.

In Indonesia, they are building on the past fifty years of work—*see* the Indonesian coffee growers' reference book or *Vraagbaak*, put out by Indonesia (Centrale Proefstations Vereeniging, 1954). The growers still consider C. *canephora* their most important producer. Some named varieties of it are Quillou, Robusta, Bukoba, and Sankurukoffie, and sometimes there are also included the common names Canephora and Laurentii as varietal designations. One of their very best clones, of the tall varieties, still remains Quillou BGN.121. This has been crossed successfully with

Robusta BGN.124-01 and Robusta S.A.109, producing good seedling fields. To some, these are more satisfactory than clones that require grafting. Of the shorter, spreading, and smaller-leafed varieties, three Uganda clones, BGN.ia, BGN.2a, and BGN.3-02, are the best. There have been several C. *canephora* and *C. abeokutae* crosses, giving what they designate as the Q:P hybrids, that are successful for certain conditions. The workers in Java also perfected, in the past, and use now, hybrids of C. *congensis* and *C. canephora* variety Robusta. This is called Conuga or Congusta (Cramer, 1948, 1957), and, while it requires more care than certain Robustas, there are lines of it that have definite adaptabilities that make them an advantage under some conditions.

The *Vraagbaak* recommends as best the two most widely adaptable clones, B.P.42 and B.P.39. This is their first group. Their second group of clones are listed as B.P.4, B.P.25, S.A.13, S.A.56, BGN.300, BGN.371, BGN.121, and MBL.3-04. They list as their third group B.P.46, B.P.358, and B.P.447. With all their sorting out of clones, Indonesian planters once grew almost nothing but mixed fields, hundreds of thousands of acres of them, of grafted trees. Since then, more research and breeding with clones has shown that it is possible to make clone crosses that give superior seedling fields. There is now a regular programme in Indonesia for modern growers to raise seed for replanting old, or putting in new, fields. But these crossings should be from only certain selected combinations such as: B.P.4 x B.P.46, B.P.25 X B.P.46, B.P.42 X B.P.46, B.P.358 x BJP.368, B.P.369 x B.P.368, B.P.39 X BGN.83-03, and Conuga S.A.36 x B.P.42.

When examinations are made of the botanical determinations of coffee species, one of the problems appears to be the striking similarities in certain of the described species that are grouped around C. *canephora.* The species called C. *kouilouensis* Pierre, said by Chevalier to be synonymous with C. *canephora* var. *typica,* has already been mentioned (p. 81). Others of the Canephora group of coffees have been designated with such species names as *laurentii* Chev., *robusta* Chev., *gossweileri* Chev., *hinaultii* Pierre, *oka* Chev., *stuhhnanii* Chev., *maclaudii* Chev., *ugandae* Chev., *crassifblia* Laurent, and *welwitschii* Pierre. In a few cases, these might be made subspecies of C. *canephora,* but perhaps all of them are only of varietal rank. These names are different, and they indicate differences in the collections studied. The whole group is noted for its wide variability. It is no great wonder that from it have been bred and selected so many strains of such excellent adaptabilities under extremely wide conditions.

It can be seen that the art of breeding with the use of cross-pollinations has been carried on to a high degree in Canephora coffees. These have attracted workers in several countries and rapid strides are now in progress. Through breeding and selection, the Canephoras and Arabicas are no longer, altogether, only slightly removed from forest plantings, but have become specialized agricultural tree crops. While something is known about the genetics of Arabica, much is still to be learned about the facts of inheritance in Canephora. However, until the planters and boards of directors of research institutions can see something of immediate commercial importance to be gained by genetic studies in Canephora, it is not certain that the study of genetics of the species will be given attention. In any case, both Canephora and Arabica coffees are becoming better known scientifically. This is not so much the case with either Excelsa or Liberica.

For the most part, C. *liberica* Bull plantings are only crudely grown, and less intensive study has gone into the tree. So far as there has been attention given, the species appears to be composed of aggregates, varieties, or strains that have been considered by some as of specific rank. Chevalier (19290) lists varieties *vera* and *excelsa* as certainly species in the old Cramer collection growing in Java. The following species named by botanists are either closely related to or are subspecies or varieties of C. *liberica* Bull. These listed species are: *liberiensis* Sibert, *ivorensis* Sibert, *pyriformis* Fauch., *aurantiaca* Chev., *sphaerocarpa* Porteres, *hngkarpa* Porteres, *indeniensis* Chev., *macro car pa* Chev., *demvrei* de Wild., *camerunensis* Chev., *zenkeri* Chev., *aruwimiensis* Chev., *sylvatica* Chev., *dybowskii* Pierre, *tturiensis* Chev., and *neoamoldiana* Chev. This list gives some indication of the variation problem in C. *liberica*^ and, as well, of the necessity for more botanical attention to the species or the group which it composes.

IX

PLANTING SEED-BEDS, NURSERIES, AND FIELDS

THERE is little, in the technique of coffee growing, that has had less scientific attention than seed-beds. In many places, the growers still use for replanting and new fields the voluntary seedlings that result from seed dropped at harvest time. If such seedlings are from Arabica varieties, that are all self-pollinated and of fixed characters, the chances are that inheritance will be just as good in volunteers as from elaborately selected seed. It is different with the Robustas or Canephoras, the Excelsas, and the Libericas. In these three species, open pollination is a common character. Among them the unselected seedlings may be almost anything. Selection, then, is most important, and 'legitimacy' something to be guarded carefully. Apart from seeding, the other main method of propagation of coffees is by cuttings (cf. PL 22).

SEED SELECTION AND PREPARATION

Under more careful and intensive culture, seed is chosen carefully and also sown in seed-beds and given much attention *(see* McClelland, 1912&; David, 1935; Correa, 1945; Coste, 1955; Ferreira, 1944; Swynnerton *et al,* 1948; Milsum, 1931; McDonald, 1930; and others). An example of a traditional approach is found in a well-known coffee grower's manual from Colombia (Federation Nacional de Cafeteros, 1932). Here, they gave in detail several pieces of advice. Thus it was best to select a group of trees for seed source. The trees should be of about the same age. They should be of good shape. A good selection should be rapid in development and fruiting. The crops should be abundant and constant and the beans should be of good form and excellent quality. The tree selected should exhibit resistance to diseases.

Growers in some Arabica-growing countries may speak with almost religious conviction of the special influence, for good, of seed from The Middle'. For them, seed trees must be of middle age, neither very young nor very old, and have the seed branches growing well but of median type—neither too vigorous nor in any way stunted. The basal or 'skirt' branches are not used for seed and neither are those in the top or crown. Here, again, it is the middle structures that are selected. Seed fruits are picked from the middle of such branches and from neither the tip nor the base of them.

There is evidence that the middle-selected seeds are not necessarily the best seeds, even if tip or basal seed may be poorer in growth. However, in usual Arabica selection programmes, all seeds that will germinate are used, and no matter where they come from on a branch they are equally valuable genetically. In tests of my own with Arabica, I could never obtain significantly greater germination or more vigour in seedlings when comparing those from seeds from 'middle parts' with tip or base seeds or from crown or skirt branches. However, it has been found over generations that this selection is good psychologically for the peasant labourer. The principle is simple and easily explained to him, and he is more interested in, and more careful of, the trees developing from seed he has had a part in 'selecting'.

Under the usual storage conditions, coffee seeds do not retain their power of germination for very long. In common practice, they are planted within two months, or less, of the time when they were gathered. If they come from healthy trees and out of unblemished fruits, there is no special reason for seed disinfection treatments. Seeds may carry spores of *Cercospora* and *Glomerella (Colletotrichum* but they must have been very carelessly treated to be thus contaminated. Where this does seem to be a possibility, dusting can be done with several satisfactory seed disinfectants. One is Arasan, and another is Fermate. Mould contents of seed can increase in storage and during the time required for shipment. In our work at the Inter-American Institute of Agricultural Sciences, we have found dusting with Arasan a good treatment for preventing mould development.

The amount of seed required is a matter of calculation, depending on the number of seedlings needed, germination of the seed being used, and necessity of a surplus to take care of those that die from abuse and bad management at transplanting time. Authorities differ as to the numbers of seeds in a pound, but fair averages are 960 to a pound of Arabica, about the same 01 JuXceisa, 700 of Liberica, and in Canephoras variation from about 1,000 to 1,200 to the pound although, in some cases, there may be a few more than 1,200. Coffee seeds, of whatever species, vary considerably in size, depending upon the conditions under which they are produced. Each grower will need to make weighings and calculations of his own to determine the numbers of seeds he will need to plant, making allowance for what may have been determined about percentage of germination.

SEED-BEDS

In whatever way the seeds may have been obtained, they will repay attention given in the seed-bed *(see* Malaya. Department of Agriculture, 1934; McClelland, 1917; David, 1935; Correa, 1945; Colombia. Federation Nacional de Cafeteros, 1932; and there are others). Seed-beds, or germinators, need to be carefully prepared—very often according to the best judgement and empirical teachings of the grower and his employees. Seed-beds are almost invariably shaded, although, in some countries, mulch is used with little or no shade. This treatment is for moisture retention. Beds are laid out, often about 40 in." across with about 18-in. walks between them. Rocks, roots, and excess debris are removed, the beds are dug deeply, and a few inches of the top-soil from the walks is scooped off and thrown onto and worked into the beds. This is all then dug and worked over again, and carefully smoothed with a rake or other similar tool. In wet areas beds are raised, but in dry regions beds are, most generally, kept at the same level as walks.

If germinators are desired, variously sized boxes are prepared; a common suggestion is of one about 10 in. deep and 40 across, with good drainage. In this is placed a 6-in. layer of a moist and well-mixed soil combination, of equal parts of well-rotted compost, garden soil, and fine sand. This mixture may be treated to eliminate soil-borne fungus parasites or nematodes, if there are such difficulties in the region. In the germinators, seeds are planted closely, about an inch apart, and covered with an inch of the germinator soil mixture. The boxes are arranged so that they lie level, are usually under shade, and are kept

Sand boxes are also made for seed germinators. These can be about as wide as a person can reach, and 12 or 15 ft. long. They are surrounded with boards about 10 in. wide, and, in some countries, a layer of pebbles or other drainage is put in the bottom. About 4 in. of sand is placed on top, levelled, well watered, and allowed to settle for a day or two. It is then levelled again, and coffee seeds are sprinkled on top of the sand. These should not be in clumps, but can be very close together. They are then covered with about an inch of sand, watered again, and kept watered daily until the seeds germinate. This germination will be hastened if the pergamino is removed from the seed and if the sand box is located in a warm place and not too heavily shaded.

Seed-beds are always carefully levelled, and well drained. They are made just wide enough for weeding or loosening of the soil to be accomplished easily from the sidewalks. Seeds are sown at different densities, according to tradition and conditions. Rows may be 3 in. apart and seeds placed in them almost end to end where there is little danger of damping-off trouble. Where this is more serious, rows are put at a 6- or 8-in. distance, and seeds are planted about 2 in. apart in the rows. Care is exercised to keep the seeds moist, and most generally the beds are shaded. They are covered with mulch where it is possible to use it. This latter may be a dangerous practice where there is much fear of seedling diseases.

Little experimentation has been done on seed-bed mulching, and there is practically no publication on it, although it is common practice in some places—*see*, for example, Pratt (1952), Narasimhaswamy (1948), and Colaco (1952). It is carried on for empirical reasons. Some of my own observations have indicated that one of the worst of mulches is new sawdust. It seems often to have toxic or poisoning effects. However, old, decayed sawdust has considerable value. New, dried banana leaves are not especially good for mulch until they become partially decayed. The same is true of sedges, for they fail to help much in keeping the beds moist. Apparently, almost any of the pasture grasses make good seed-bed mulch, if the material secured is leafy and dried before application. In Latin America, at least, a mulch of leafless grass stems is not very satisfactory. Jute or hemp bagging has been used with success but may be expensive. In dry countries, where seed-beds must be irrigated, and where seed-bed diseases occur, mulches may be detrimental through encouragement of damping-off disease. Where this is troublesome, it is well to recommend covering the seed-beds with a thin layer of sand to allow aeration at the soil line.

The process of seed planting, of course, is entirely by hand. With seeds planted in soil, in most instances, the rule is that they are covered with this soil to about three times their own thickness and the soil is then well firmed over them. The temperatures for seed germination have already been discussed in the chapter on botany and physiology. For reasons of temperature, the best altitude for seed germination is rather low, where temperatures are warm. For Arabica, a soil temperature of 28^0 to 30°C. is excellent. This is not obtainable in seed-beds or germinators in hill regions unless they can be heated.

A planter who can furnish a warm temperature for his seed germination should secure his seedlings for transplanting to the nursery in about three weeks. When soils are cold, as in the mountain plantations of Mexico, Central America, Colombia, the Ituri of the Congo, Kenya, Tanganyika, the Coorg of India, Hawaii, and East Java, seedlings may take a month or even eight weeks to emerge. It might be suggested that germinators be set up in lowland regions to produce seedlings for transplanting into nurseries in the cool soils of the high mountain plantations.

TRANSPLANTING TO THE NURSERY

The best stage of growth at which to pull the seedling for transplanting, depends upon where the nurseries are to be located and the conditions in the particular nursery. During the process of germinating, the seed absorbs moisture and the endosperm swells inside the seed-coat. If this seed-coat, or 'pergamino', has been carefully removed, the seeds germinate somewhat faster, but it is generally not a serious detriment to leave the seed-coat intact. The germ is located at one end of the seed, wrapped in the endosperm. The primary root starts growing first, and as it elongates it pushes the pergamino aside and emerges through a rift in the seed crease. Secondary rootlets soon form as the primary one goes down into the soil.

When in rows, after emergence from the soil and before the seed-coat is cast off, the seedlings resemble toy soldiers on parade, dressed in helmets. Indeed, at that time, they are called the 'little soldier stage' * in many languages. This depends somewhat on the taste of the grower, as there are those who prefer the term 'beetle stage', as some consider that such seedlings rather resemble beetles on top of twigs stuck in the ground. This is the stage at which transplanting is easiest, and it is the best for this when seedlings are to go into unshaded nurseries. In any case, soon after this the seed-coat is pushed off, and the two cotyledons begin unfolding. They expand and are arranged as a cup around the central bud. At this time, the seedling stage is variously spoken of as 'cup' or 'butterfly' or 'cotyledonary'.[#] This second stage is used very commonly as the one for transplanting. The seedlings are easily handled then, but have a longer tap root than at the soldier stage. In a short while the first true leaves form, which is the third stage in seed-bed terminology. The stage at which they are to be taken from the seed-bed or germinator depends a great deal upon the plans for nursery planting.

In some parts of East Africa, planters use rather elaborate methods of shading their seed-beds *(see* Haarer, 1956), and this also extends to the nurseries. Posts are set low for seed-beds, usually higher in nurseries, and wires are stretched between the posts. On these wires are arranged mats. In some cases, such shaded seed-beds may be used for several years. This type of seed-bed can be found in Latin America in some dry areas. The posts may be of durable wood. Wires are strung over the posts and thin grass mats are rolled over these wires. The mats are made of grasses woven with wire, banana thread, bark string or, in some cases, agave or henequen fibre. Such mats are of grasses that are selected for their long life as dried woven material, and are woven in such a manner as to admit a considerable amount of light. They are rolled away and stacked under shelter during long rainy periods and are put on again when the rains cease. When the time for hardening comes, they are taken off nursery beds for part of each day; later, when the seedlings need every bit of sun they can absorb, the mats are completely removed.

If nurseries have been prepared in a region where no shade is to be used, seedlings are moved at the little soldier stage. They do not suffer from lack of water so quickly, and seem to show less effects of sun scorching that may occur if they are put out after reaching a much later stage. On the other hand, where seed-beds may be contaminated with either damping-off or nematodes, it is much easier to select uninfected plantlets after they have reached the cup stage. These will survive a little better if they are planted under some shading in the nursery. Where they are planted in individual baskets, bamboo cylinders, or pots (Ukers, 1922;

[#] Seedlings in the 'little soldier' and 'butterfly' stages were shown on PL 16.

Colaco, 1952; Coste, 1955; Haarer, 1956), seedlings may be allowed to grow until the first two or three pairs of true leaves can be seen. In all cases, precautions are exercised and the work is not hurried, so that the pivotal root is not bent in the process of setting the small seedlings in the nursery bed or individual container.

PL 23 shows a coffee nursery grown without shade, and typical of moist regions of Costa Rica, while PL 24,0, shows a type of medium-light shade used for most coffee nurseries on the dry Pacific slopes of Central America.

Nursery growing requires special attention, and this has been discussed in some detail by Coste (1955). In addition to particular consideration of problems in French Africa, that author cites certain of the general findings from other regions. It is well recognized that the soil should be selected for good quality, freedom from stones and undecayed pieces of wood, accessibility to water for irrigation, and nearness to the fields in which the seedlings are to be transplanted. Nursery beds are then often built about 40 in. across, with low, narrow walks between.

The beds are dug deeply and the soil mixed, debris being removed and discarded, and, if it is necessary to add a complete fertilizer or something other than nitrogen, it should be carefully incorporated before the plants are set. The soil is left slightly firm, but not tightly packed, and well smoothed. All transplanting should be done in cool and cloudy weather, if possible, when rains will follow shortly after the work is completed.

CARE IN THE NURSERY

Fertilization of the nursery bed is largely dependent upon the soil from which it is made. If the soil is known to be reasonably well furnished with natural fertility, often it is given no extra manuring. The root system of the nursery seedling needs proper fertility in the nursery. Machado (1946) showed that deeper rooting of Arabica occurred with sun-grown nursery trees. In Hawaii, the growers are careful not to use too much nitrogen for their nurseries, and give their young plants good quantities of high-phosphate fertilizer to ensure the best root development and hardened tops.

Where soil is used that has grown seedlings before, it should have a year or two of rest under a cover crop. Even then, it is good to incorporate about a half-bushel of well rotted manure, or a pound of mixed chemical fertilizer, in each 10 sq. ft. of nursery ground. This is worked in very well, to a depth of 6 or 10 in. It has to be done carefully as there must be no spots of concentrated manure in the nursery-bed soil, for these cause toxic reactions in seedlings planted in them. If a mixed chemical fertilizer is employed, some recommended formulas* are 10-10-5, 10-10-10,

[m] As a reminder for the reader, fertilizer formulas are commonly given in three numbers, as occurs in this book. Numbers are to indicate percentage amounts in the mixture of the three major plant fertilizer elements. These elements, always given in specific order (NPK), are those available for plant food: (N) nitrogen as N (P) phosphorous as P A , and (K) potassium as K_20. Formula 10-10-5 means that the mixture contains 10 per cent N, 10 per cent P, and 5 per cent K.

or 10-15-10, with the high phosphate giving increased root vigour *(see* Correa, 1945; Goto & Fttkunaga, tc^fw; anil franco & MotuUs, 1949). Where nitrogen fertilizers are all that are used around yellowed seedlings, about half a teaspoonful may be applied lo each, scattered on the soil, surface. If this yellowing comes towards the end of their lime in the nursery, no nitrogen is put on the soil. The slightly yellow* low-nitrogen plants are transplanted to new locations with every expectation that they will recover. They may make even better trees than if they had been in a high-nitrogen condition, often showing very green and lush growth. One of the good recommendations is to apply all fertilizer, well worked into the soil, before the bed is planted for nursery growth.

Seedlings are put in the soil at slightly different distances according to place and circumstance (e.g. David, 1935; Alvarado, 1935 ^l C*ormt, 1945; Coste, t<)55)» but common spacing** are 8 or to in,, both wavs, arranged in diamond formation, or quincunx. Setting stakes on the edges of beds and marking across and planting where linen come together Is a good method* In some countries, special markers are made *ti* light planks with holes bored through at the spacing** wanted. The markers are laid on the moist: bed of soil, and small stakes are stuck, or holes are made, in the ground through the borings* This makes for rapid work, A good spacing allows of economical use of the bed, It should include sufficient space if seedlings are to be removed with roots in a ball of earth (PL 24,/;). This ball is called the equivalents of ʻcheese\ loaf*, or *mould\ The quincunx arrangement allows of a minimum of waste in cutting between the plants to make the ball PI. 25,*/, shows holes dug for planting coffee seedlings close together in double rows,

When the nursery bed has been marked, the young seedlings are put into their places. This must be done carefully, using a flat spatulate type of dibber, long enough to make a good hole into which the pivotal root can be put without its being doubled at the end. The soil must always be moist, and it is carefully filled in to leave no empty space around the root This is an operation that cannot be done speedily. Extra care is necessary in it. As soon as the nursery bed is planted it should be sprinkled with water and, if shade is to be put over it, and is not in place, this is put on without delay. If mulching is to be *iUmv*, the material should be ready and piled at the side before the transplanting operation, and distributed immediately between the newly set seedlings.

Seedlings stay in the nursery for varying lengths of time, depending on the location of the nursery, the rapidity with which the seedlings have grown, and the progress of the dry and wet seasons. Weeds are pulled, especially grasses, to avoid root; competition between them and coffee. This is done at feirly frequent intervals, with much care and entirely by hand. If the timing is such that rains are on and the young trees can be moved when they are fairly small, with *$k* to eight pairs of leaves (David, 1935), they will do well in the field. Some prefer trees near to or over 18 months of age. Many years ago, McDonald (1930) determined that the best time was at about a year of age. The trees are then from 12 to 18 or more in. high. At that time they have first primary branches.

Milsum (1931) considered 4 to 6 months ample time in the nursery, while Correa (1945) advised transplanting trees after about a year in the nursery. Many different times are used. Growers in many countries prefer young trees with two to six primary branches, called 'crosses'. These growers, if buying nursery stock, will pay extra for such trees because they believe the reserve in the stem gives insurance against transplanting and supply failures.

DIRECT PLANTING IN BRAZIL

In Brazil (Spielman, 1945; Ferreira, 1944; Coste, 1955; Brasil. Ministerio da Agricultura, 1929) the growing of seedlings is, in the main, completely different from that in any other country. This is probably the only place where it is the general practice to plant seeds where they are to grow in the field, although de Ligt (1937) indicated varying degrees of success from sowing directly in the field in open jungle in Java. In those conditions, direct seeding required a great deal of expensive attention. In Brazil, it has proved more acceptable. The soils selected, if possible, are virgin and in forest, and are types of rather loose clays to sandy loams. At the proper time of the year, when rains are on hand, they can be readily worked. The rolling forest lands of these farms are surveyed and the field outlines fixed. After this, the tree growth is felled, piled to one side and burned, and the lower bush is cleared away. The more difficult stumps, which are cut low, are usually left where they stand. It is not long before places for roadways can be selected, and after that rows for coffee are made.

When the places where coffee is to be planted have been marked, in many regions of Brazil square holes are dug—about 18 in. in diameter and a little more than knee deep. Some 6 or more in. of good top-soil are thrown back into the hole, leaving its bottom about 2 ft. below ground level. This hole or basin ('cova') is left with moist, fine soil in the bottom, and firmly smoothed down. A few seeds are planted about an inch deep in each corner of the hole, and when seedlings emerge only the best ones are kept, leaving four to six to a cova. By this time, a small armload of pieces of dry wood, the thickness of a man's wrist, are brought to each hole. They are laid across it in a loose pyramid, or 'arapuca', to furnish shade, conserve the moisture, and protect from wind and frost. In some places, many of the seedlings are grown in woven palm baskets, or in baskets made from crude and tough grass-stalks pressed and tied into shape. They are planted, basket and all, in each corner of a cova, and protected with the pyramid of loose sticks. Transplanting of nursery stock to the field in other countries has also developed into quite an art.

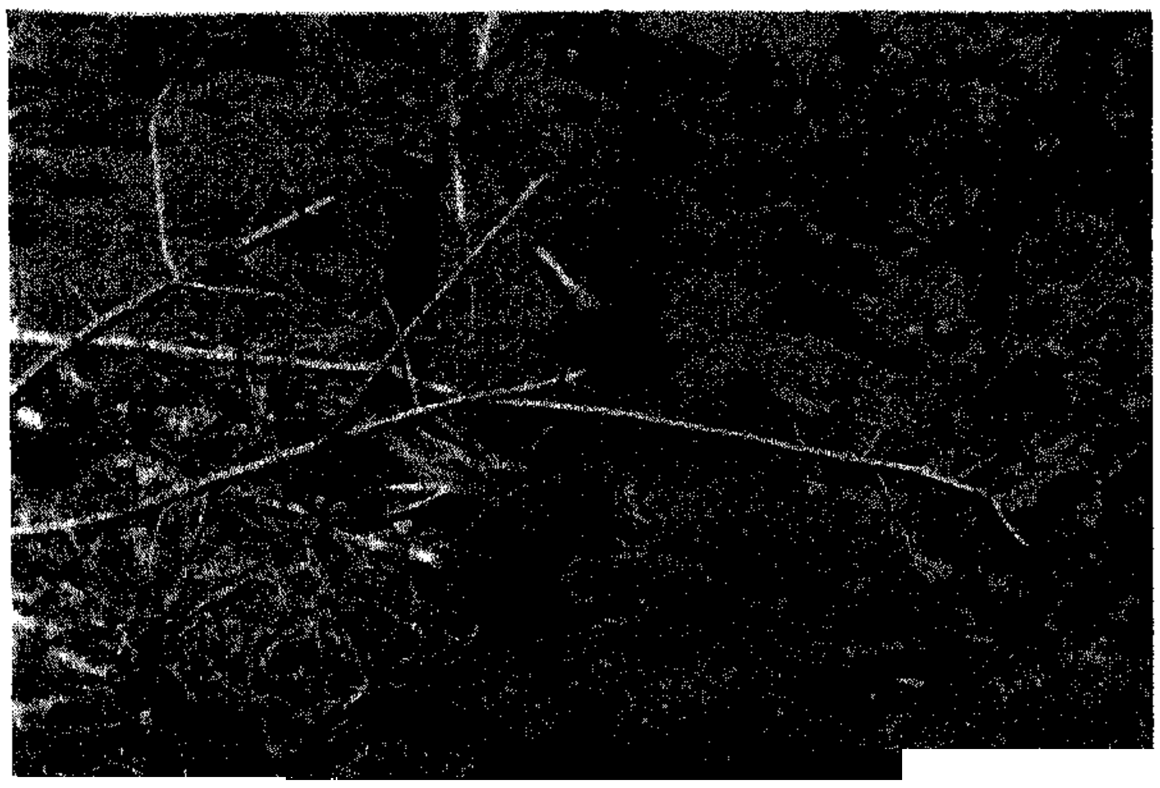
PLANTING IN THE FIELD

The moving of young coffee trees, from the nursery into the field, requires some thought and skill. It is not a simple process. There are numerous variations of the transplanting programme, and the relative success of the different methods depends upon climates and soils, and also upon the human beings connected with the work. It is to be remembered and emphasized, that the season for transplanting must be correlated with occurrence of rains. If that is not possible, a regular and unfailing sufficient supply of irrigation water must be at hand. There are four steps in transplanting. The first consists of digging the holes, the second deals with taking trees out of the nursery, the third relates to placement of tree roots and filling in the hole, and the fourth is what must be done in shading and leaf removal, where necessary, to insure the life of the tree just transplanted.

Coffee seedlings are transplanted into large holes in almost all parts of the world. Some have attempted to economize on hole sizes because digging costs money. A suggestive writing regarding hole sizes was that of David (1935) from the Philippines. He drew conclusions from wide reading and experience. His recommendation was that holes had to be of different sizes, depending on soil character. He specifically advised relatively large holes, at least 2 ft. wide, broad, and deep, in the poor or stiff and clayey soils. Where the soils were good, friable, and with adequate humus, holes could be considerably smaller—18 in. or less in all dimensions.

This was also studied in British East Africa. Jones (1949) worked in a rather dry part of Kenya, in the experimental area of the Scott Laboratories near Nairobi, with soil that had a poor humus content. He kept records for several years of the production from trees that had been planted originally in holes of the following sizes (in all dimensions): 1 ft., *i* ft:., 2 ft., 2 J ft., and 3 ft. After 8 years of harvests, he determined that trees planted in the two largest-dimension holes gave an increase, over the small-hole planted coffee, of some 200 lb. per acre of fresh coffee per year. The larger holes thus paid handsomely for the extra cost of the added digging. On the other hand, in the same country (quoted by Coste, 1955), in a soil of better humus content, smaller holes measuring 2 ft. gave results as good as much larger holes.

Such studies as those just reviewed were carried on in several other places. It was concluded from experimental results in numerous countries, such as Malaya (Malaya. Department of Agriculture, 1934), Puerto Rico (Correa, 1945), Kenya (Swynnerton *et al*$_{y}$ 1948), Tanganyika (Swynnerton *et al,* 1948), French West Africa (Coste, 1955), and a few others, that the best general recommendation for the size of planting hole was 2 ft

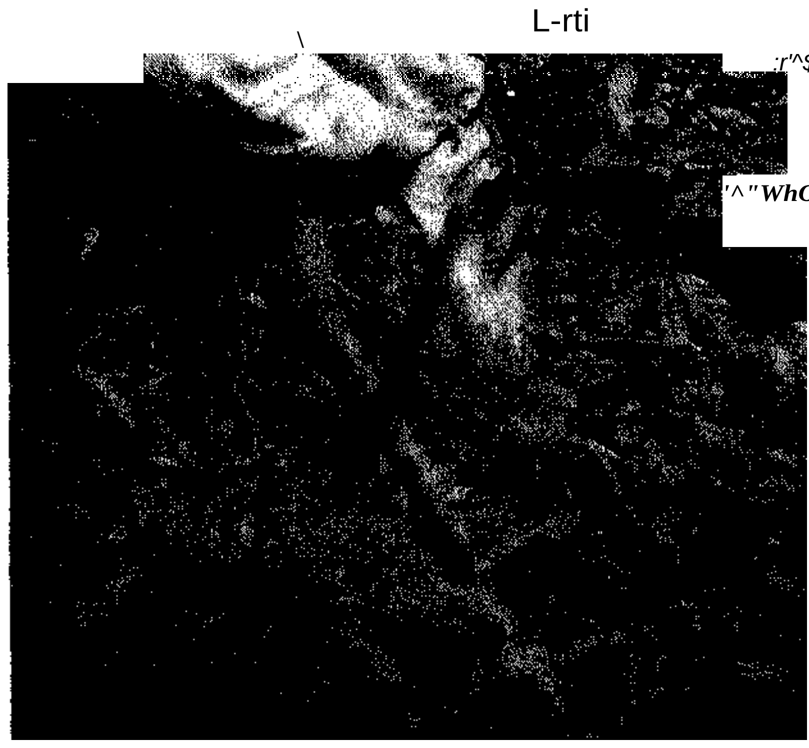


(a)

PLATE 25.—*(a)* Holes dug for planting coffee seedlings close together in double rows. J..A.J..A.O.J C/\osta JKica.

(b) Unusual depth of planting. After a volcanic eruption, two and a half to three feet of ashes had been deposited over the plantation. Some trees were killed. For replanting, holes were dug *(see* man standing in hole) and coffee trees planted in the soil beneath the ashes. Trees developed successfully. Guatemala.

(b)



long, 2 wide, and 2 deep. It has been long-accepted practice to transplant into large holes in all the countries of tropical America, except Brazil. This latter is a special case. With the others, after much private experimentation and familiarity with the results, transplanting into large holes is recognized as a valuable expedient.

After the holes have been dug, the nursery trees must be excavated for transplanting. There are two general methods of taking up seedlings from the nursery. One is careful unearthing and shaking off the soil from the roots. They are protected with moist bagging or other means, and are moved to the field as rapidly as possible to avoid drying. Sometimes this is varied by dipping in a mud bath. The other method is to cut out moulds or balls, also called cheeses, containing the roots. The nursery tree sticks up from the centre of the ball of earth (PL 24^). Both methods require considerable skill. Use of the ball of earth depends on the soil type. Where the balling system is habitually employed, nursery soil of a special consistency is specifically selected for the express purpose of being cut into the balls or moulds holding the coffee trees.

The ball is cut out deeply enough to contain about 10 to 12 in. of the main or tap root, and the cylinder of soil that contains it is diameter. The cost of cutting out the amount of soil for these moulds is considerable, as is the expense of moving the extra weight of soil. It must be understood that after the mould, with the coffee tree in it, is cut out and separated from the bed, it has to be wrapped. This is usually a neat piece of work. A few banana or sugar-cane leaves, or sometimes leaves of certain grasses or palms, may be employed. They are cut just the right length, crossed as a star, and the ball or mould is set in the centre. Wrap leaves are then brought up around the stem of the coffee seedling and tied with native jungle fibres cut for the express purpose.

SPECIAL TRANSPLANTING STUDIES

Much study has been given to avoid the expenditure of this extra manipulation in cutting the ball of earth, wrapping, and carrying it away from the nursery. While practising farmers looked on in hope, one after another of many experimenters showed, under scientific observation, that there was something more to transplanting in an earth ball than mere whim or old wives' tales. Only a few typical examples of experimental results will be given here.

It was found by McClelland (1917) in Puerto Rico *(see* the accompanying Table XIV), that much depended on what size the nursery tree was at the time of transplanting. If it had only six pairs of leaves it made some, but relatively little, difference whether it was moved as bare roots or in a ball of earth. If left until they were i| or 2 years old, which was the more normal habit, many more trees stayed alive if thfcy were taken up and moved in a ball of earth. In fact, the mould guaranteed their living if they were transplanted in the rainy season. Under identical conditions, unless very young, the bare-root planting was never completely satisfactory. Often a large percentage of the bare-root planted trees died. McClelland found that production was significantly more out of trees grown from ball-transplanting than from the bare-root system. After 2 years in the field, from the nursery, ball-transplanted trees showed 35 per cent greater height than bare-root transplants.

TABLE XIV

EFFECT ON SUBSEQUENT GROWTH OF DIFFERENT METHODS OF PREPARING ARABICA COFFEE SEEDLINGS FOR TRANSPLANTING INTO THE FIELD *

			Out of 21 trees in each row:					
			Died in field		Growth in field		Yield per tree	
ow	Seedling age	Treatment of roots	First year	Second year	First year	Second year $	Trees bearing second year	Maiden crop per tree in quarts
I	Young f	In earth block	2	4	Good	<r62	6	14*8
2	Young	Bare, cut back ‖	6	9	Poor	65	4	127
3	Young	Bare, not cut	3	3	Good	61	5	i6*9
4	Over a year §	Large earth ball	0	0	Tallest	72	5	17-0
5	Over a year	Bare, cut back ‖	1	4	Short	64	0	8-4
6	Over a year	Bare, not cut	1	2	Short	58	0	8-4

* From work of T. B. McClelland (1917).

f Seedlings with five to six pairs of mature leaves.

t Measurements in inches.

‖ Bare roots severely pruned and leaves pruned as well

§ Trees of same nursery planting as rows 1, 2, and 3, but 1 year older, of total age about 18 months.

In the work of Sanders (1950), in Tanganyika, studies were made over a period of 10 years, comparing bare-root with ball-root set trees planted at the same depth. Production was recorded on experimental plots planted in these two manners. It was found that ball planting, by itself, increased harvest over bare-root planted trees by a good hundred-weight of clean coffee per acre per year. Half-way around the world in El Salvador, it was found at the Centro Nacional de Agronomia (1953), from two-year-old trees in the nursery, that those planted in mould or ball grew much better than those from bare-root plantings. The work was very carefully done, and timed according to the best season. Yet bare-root planted trees, although all lived, also dropped all leaves from the lateral branches, and were otherwise slow in growth. Those from ball-planted trees retained almost all their leaves, were set back very little, and soon grew very well. They blossomed a year ahead of the bare-root planted trees.

In Turrialba, Costa Rica, where it is considerably more moist than in El Salvador, tests were carried out as carefully as was the case in El Salvador^ and it was found by Elgueta & Bonilla (1951) that there was no statistically significant difference between the growth of the trees from covered-root transplanting and from bare-root planting. I happened, to be present during this time and I have watched similar comparative plantings since then. My own observations, without counts, of these experiments were that the ball-root planted trees retained their leaves considerably better. There was less leaf yellowing on the covered-root planted trees. Recovery was nearly always good. However, with a short, intensively dry week coming at an unexpected time, as can happen even in Turrialba, some plant injury always occurred even in covered-root planting. Where the end product of statistical analysis showed no significant growth differences in Central America, the grower or his peon would most often select by eye, as better, the apparently more vigorous tree that comes from planting in an earth ball.

TABLE XV

DIFFERENCES IN OODUCTION FROM TREES OF ARABICA PLANTED AS SEEDLINGS AT DIFFERENT DEPTHS IN THE FIELD*

Set in field	Roots	Productions f	Percentages t
Deeper than in nursery	In ball of earth	8*82	94*8
	Planted bare roots	8*58	92*4
At nursery level	In ball of earth	9-86	106*0
	Planted bare roots	9*93	106*8

* From Gilbert (1945). Transplanted from the nursery to the fields in 1935.

f Expressed in hundredweight of clean market coffee per acre; summary of results covering harvests for 8 years, 1938 to 1945 inclusive.

J Means of productions 9-30, and of percentages ioo-o, the standard error of productions being 0*16.

The depth at which to plant nursery trees in the field has been a matter of some study. There have been occasional experiences in which the putting of trees into planting holes with inadequately firmed soil about the roots resulted in settling and deep placing of the affected seedlings. Observation has been that the tree suffered. An interpretation of this has been that the tree, when it was planted at a deep level, was not able to absorb as much soil nutrient as when put in at the nursery level This problem was given attention in several places.

It was given some detailed experimentation in Tanganyika by Gilbert (1945). Harvests were compared from trees that had been planted deeply or at nursery level. After ten years of results, it was determined *{see* Table XV) that trees which had been planted at nursery level in a ball of earth or with bare roots, gave, respectively, 9-86 and 9*93 cwt. of clean coffee per acre per year. If identical trees were planted deeply, whether in a ball of earth or in bare-root condition, they produced on an average per year only 8-82 and 8-58 cwt, respectively. In all these, the standard error was 0-16. From such information, Swynnerton *et ah* (1948) made strict recommendations respecting transplanting at nursery level.

A good many years later, under quite different conditions in El Salvador (Centro Nacional de Agronomia, 1953), they secured very little difference between trees planted in the field at nursery level or at a little below. This is a fairly common experience in several places, although I have seen bad effects of deep planting quite clearly in the Central American countries of Costa Rica and Nicaragua. In Puerto Rico, Correa (1945) strongly recommended that trees, whether used as covered- or bare-root seedlings, should be planted at the same depth at which they grew in the nursery. Sanders (1950) in Tanganyika defined, in his experiments, deep planting as occurring if the first lateral roots, that are close to the soil surface in the nursery, were plunged 6 in. below soil level. Growth studies by him showed that, apparently, adventitious roots of old trees were not developed above the point from which they originally came in nursery seedlings. What he termed 'planting at nursery level' was much the better practice for Tanganyika. To a certain extent this seems to be so in other places, but especially in the region of British East Africa.

Sanders knew he was not dealing with any accidental observation in his controlled experiments in Tanganyika. It was of interest to talk with him in Central America on a visit there after he had examined the problem in Guatemala, El Salvador, and Costa Rica (Sanders, 1954?). In Guatemala he saw trees, as many of us have, that had been buried in a few feet of volcanic ash (PL 25,^), and after one year had recovered and produced good crops for years. He knew that, after many years, some of those trees had been dug for study. It was found that there was a luxuriant growth of adventitious roots for a good distance along the tree trunks well above the original soil level

It is also known that, in vast areas of Brazil, where coffee is habitually planted in the bottoms of holes, with the first lateral roots sometimes placed as low as 2 ft. below soil level, the trees live and thrive. When the holes are gradually filled in, extra adventitious roots develop, along the base of the covered tree trunks. I myself have dug away soil from around long-filled-in, deep-planted trees in Brazil, and found abundant adventitious root growth over a foot above the region of first lateral root formation in the seedlings that produced the trees.

In this connection, preparation of the holes prior to planting seedlings in the field, appears to be of importance. It is not necessarily extremely difficult work to dig the holes, if the proper season is chosen, and if the soil is as it should be for coffee. It is common practice to dig planting holes a long time in advance of the date of planting. A workman digs a hole 2 ft. by 2 by 2 in a fairly short time. When he is put on a piece-work basis he does even more. For example, David (1935) considered forty to fifty such holes dug as a day's work in the Philippines. Coste (1955) gave thirty to fifty as an expected day's performance in French West Africa.

There appear to be good results from opening the holes and leaving them to weather for some time. The effects are apparently from soil aeration and burying of nutritious debris that otherwise would not get below the surface. The Malaya Department of Agriculture (1934) advised digging of transplant holes at least a month before planting time, and the placing of top-soil and debris in the hole bottom before the tree was planted.

In the Netherlands East Indies, a long span of years was spent in research on these lines (work reviewed by Cramer, 1957). In numerous cases, results had been obtained in the early part of this century. These were well-planned experiments, in some cases running for more than ten years in one field. It was learned that soils which had been used to fill in around tree seedling roots, still retained, at the end of more than ten years, improved structure and nitrogen content.

From an experiment covering a long period, Gilbert (19450, 1946) reported later production from planting in holes some months old, in comparison with those made at the time of transplanting, *see* Table XVI.

TART F YVT

DIFFERENCES IN WHAT WAS PRODUCED DURING EIGHT YEARS FOLLOWING VARIOUS PREPARATIONS OF HOLES FOR PLANTING ARABICA COFFEE IN THE FIELD*

Treatment	Productions †	Percentages
1. Hole dug at time of transplanting	9*49	102*0
2. Hole dug three months before, and filled one month before transplanting	10*17	109*4
3. Hole dug, subsoiled, and refilled, one month before transplanting	870	93*6
4. Same as 2 without compost	953	102*5
5. Same as 3 without compost	8*80	94*6
6. Same as *I* with compos?	9'59	103*2
7. Same as 3 with compost	8*8i	947
Mean	9-30	100*0
Standard error	0*18	1*9

* From Gilbert (1945a), work done in Moshi, Tanganyika. Trees from the nursery were planted in the field in 1935.

t Expressed in hundredweight of clean market coffee per acre; summary of results covering harvests for 8 years, being 1938 to 1945, inclusive.

After ten years of gathering harvest results from the differently treated trees, he concluded as follows. First, in trees planted in holes without any ageing before planting, the average production of clean coffee per acre per year was 9-49 cwt. In a second series, trees planted in holes made

3 months ahead of transplanting, that were then partly filled in a month before planting, produced 10-17 cwt., which was the greatest production. The trees planted obtained no advantage from holes treated exactly as those last mentioned but in which was included special subsoil digging. In other treatments, use or non-use of compost after hole ageing seemed to have no long-lasting differential effect. Many experiments elsewhere have shown the similar trends of the extra value from hole ageing effects.

Sanders (1950) has made a study of the better production from planting seedlings in aged holes, that are then partially filled a month or more ahead of actual setting of trees. He was convinced that the better development was due to the fact that not only were there good effects on the soil but, in addition, it had settled so well that the tree was held at the proper level without sinking. Deep planting, consciously done, had given poor results in his previous studies. A long time before this, Wakefield (1933) had pointed out that biennial bearing in coffee could be accentuated by deep planting, or by extreme settling of roots deeper in the hole after planting. He believed that deeply buried lateral feeding-roots could not secure a normal supply of nitrates, as these substances occurred in greatest amount in the top few inches of the field soil. This added to knowledge respecting the requirement of careful firming of soil about the trees at transplanting time but did not argue against hole ageing.

In some soils, hole ageing has to be very carefully considered. In some lateritic soils, and in certain somewhat compact and clayey soils, it is not good practice to dig holes and leave them open for any appreciable length of time before planting. Walls of the holes dug in some clays dry, tighten, and form an impervious layer. Often the layer will not soften and integrate with soil filled in the hole about seedling roots. If this case-hardening is allowed to develop, coffee roots cannot penetrate it and are kept within the confines of the old hole area. Moreover, rainwater is held in the hole, as in a buried tub. When conditions are severe, the soil in the hole is usually puddled. Such processed holes often drain with difficulty. In soils of such a character, it is preferable to have holes open only a short time between digging and planting. The moisture content of the clay has to be just right to allow of crumbling and firming about the tree roots.

After the young coffee trees are well transplanted into the field, it often becomes necessary to give them additional care to reduce somewhat the severe shock from the transplanting process. If the trees are being used for replanting in an established and shaded plantation, the rigours of exposure are not great. Usually some little attention to putting a few spare branches of brush propped over the young trees is enough. Sometimes even this is not necessary. Where the fields consist of larger, unshaded areas, the shock of transplanting is quite severe, even under the most skilful treatment. In spite of all precautions, there are times when young trees are so enfeebled from the shock of transplanting and sun injury that *Glomerella*, *Cercospora*^ and other organisms will quickly attack their leaves and branches. I have seen this counteracted by fortnightly spray applications on transplants. Some of the' best results have been obtained with organic fungicides such as Fermate, others of the Ferbam fungicides, Captan, and certain of the fixed coppers. Dithane and fungicides with an arsenic base have not been good for this.

In Brazil, the purpose of the pyramid of wood pieces, piled loosely above the seedlings growing in the cova hole, is to protect them from wind and sun injury. There are other means of providing such needed protection from the elements where seedlings are planted at ground level. Cut brush and, sometimes, palm leaves are used for this. Wherever a sufficient growth of palms is available in near-by jungle, leaves may be cut and dried, the basal part of the palm leaf rachis stripped of leaflets, and this midrib sunken in the ground with the upper part of the frond arranged to furnish shade most of the day, to reduce drying. Used in proper lengths, such frond-ends will not be badly whipped around by winds. Where there is danger from drying out, some coffee growers cut off branches or remove some of the leaves from the seedlings at transplanting. This effectively reduces evaporating surfaces (Elgueta & Bonilla, 1951; Cramer, 1957; and others).

It is noticeable throughout the tropics that an important aid in insuring the life of coffee transplants is shade. It is not uncommon in Central America, and many other coffee regions, to use annual plants for temporary shade protection in addition to the permanent shade trees. A few seeds of some tall plant may be sown around the transplanting holes at the time they are dug. These seeds may be of rapidly developing legumes, such as a high-growing crotalaria, pigeon pea, or tephrosia. In some cases, castor bean is used for temporary shade, until the coffee trees have 'struck root' and started to grow well. It may be a year before the temporary shade is unnecessary and the young trees are in a condition to withstand the severities of the less sheltered life outside the nursery.

Before leaving the subject of transplanting in the field, stump planting should be mentioned. This is sometimes done where labour is cheap, the soil is easily worked, and the trees need to be moved or thinned. The trees can be 'dehorned' to stumps 2 ft. high and the roots dug out and moved to a new hole in another location. Roots are not allowed to dry. Where it has been difficult, for some reason, to get a good stand of trees, stump planting may be successful. Stump planting, if carried on during the wet season, gives an almost guaranteed result. This method was studied considerably in the Netherlands Indies, and was used many times. When trees of unusually fine genetic characters were too closely planted, or if special clones needed to be moved in clearing the way for seedlings of another test planting, the old trees could be moved for prolongation of life by transplanting as stumped trees.

It was found by Schweizer (1934), in his physiological work dealing with transplanting stumps, that both Arabica and Robusta could be managed in the same way. It was of interest that, in wood of the same relative age, Robusta kept its food reserves much longer than Arabica. It seemed that in the more vigorous Robusta, when its reserves had been used for forming new shoots and roots, the tree began to form new reserves, and to deposit them, before the old ones were exhausted.

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PLANTATIONS AND PLANTATION PLANNING

SEVERAL species of coffee are grown in many parts of the tropical world, at many altitudes and .in many climates, by people of many different languages and with wide differences in backgrounds. There are no fixed features that are consistent in all parts of the coffee-growing world as regards planting, road arrangements, or service necessities. In a country where Arabica coffee is grown, the one characteristic that is invariable is the appearance of the low-growing trees, rather crowded in the fields. But they may be in wide- or narrow-spaced rows, in sun or in shade, well groomed or not, and varying in other ways. Where Robusta, Liberica, or Excelsa grow, the coffee trees may be larger and more studiously cut back.

WHEN A PLANTING BECOMES A PLANTATION

In a large number of coffee countries, most plantings are in ordered rows. In a few, notably some of Ethiopia, Haiti, small corners of the Sudan, of Uganda, of Angola, of French West Africa, and of the Congo, coffee trees are allowed to grow more or less from accidental seeding. Little actual planting may be done, except in cases where seeds or seedlings are stuck into crudely prepared land to fill in gaps in the fields. There are places where the indigenous populations are known to consider coffee and gather the harvests just as if these were any other forest product. They use the same kind of toil, and they pick in the same haphazard manner (Silva, 1956), as if it were wild. The coffee trees are mixed in with other trees in natural fashion. In the Americas, there are isolated places, here and there, where the peasants have grown their coffee under conditions and in a manner strongly suggestive of the way the indigenous peoples in Africa grow theirs, in forest habitats. This is now changing. There are also places, in other parts of tropical America, where coffee has been allowed to go into partial abandonment. From these, the crops are taken in haphazard fashion, mostly for local consumption. This type of treatment may be all that economics allows, and, while it is still a step away from the wild, it is not very far.

There is a second step into a true plantation, and that is where^ small growers cultivate limited areas of land. They plant in approved fashion on the basis of what a family can readily tend. These small plantings vary a great deal, depending upon conditions. In the Cameroons or Ruanda-

Urundi, for example, such properties may have 50 or, at most, 100 trees. On the slopes of Kilimanjaro, in Tanganyika, native holdings may have three or four times that many trees. These people work in co-operatives. In such countries as Hawaii, Costa Rica, and Colombia, many of the family-sized farms range in area from 5 or 10 acres to 20 or 30. When families begin having the larger plantations, they need help from outside, and a few peasant workers come in. These move into furnished quarters, or build for themselves, often picturesque but always cheap, houses beside the small farmer's buildings. They work with the owners on a part-time or other mutually acceptable basis.

One thing that may have quite an effect on the size of planting is what is done about processing. In countries with extended periods of bright sun, where the tradition consists of simple drying, all that may be necessary are an uncovered floor and a storage shed. There, sizes of farms vary from two or three to many thousands of acres. The floors may be only clean-swept beaten earth, as in parts of Angola and Brazil, or more sophisticated paved areas, also as in Brazil and Angola, and other lands. In Uganda, the small grower dries his harvest on mats. This approaches a more specialized management, and the labour required limits the number of trees that can be profitably owned.

It requires more forethought and some calculation when wet processing methods are involved. Where water is abundant, the planter owns fermentation tanks, washing and settling sluices, drying floors, and buildings for housing his mechanical devices. This is called the West Indian or wet method (Cramer, 1957). There are artificially heated driers, depulping machines that prepare the coffee for fermentation, and the machines for hulling, sorting, polishing, cleaning, sacking, and weighing. In addition, there must be buildings for storage until the product is hauled to ports of shipment. By adapting simplified measures, the wet method of field processing can be used by comparatively small owners. The most humble can be found in such places as parts of Tanganyika, Uganda, Hawaii, and Colombia. Some of the most extensive, veritable factory plants, are common in countries such as Mexico, Venezuela, El Salvador, and, to a lesser extent, in southern India.

THE PLACE FOR A PLANTATION

There is no doubt that species of the genus *Coffea* grow and produce the bean or grain under a very wide range of conditions. This is fully evident from a short review of the numerous types of ecology under which wild coffees are found in Africa, and the wide range of climate, soil, and culture that exist where coffees grow for commerce. Knowledge about these things is valuable in planning new plantations or replanting old ones. There is not always good reasoning behind large expenditures of money, and high hopes, in regions of minimum prospects.

There are certain soils that are not usually selected for coffee. These are those that have a strongly alkaline reaction, those with a very high per cent of sand, the quite heavy clays, soils with no humus, and the peat soils. It has been indicated elsewhere in this book that the better coffee soils are those that are slightly acid, that are good friable sandy loams or certain not too sticky clays—all having, wherever possible, a good content of humus. The best coffee soils should have a natural, fairly rich content of nitrogen, phosphorus, potash, and available minor elements. It is common knowledge that the best soils are recent volcanic deposits, moist but not too continuously deluged with rain, and that, before planting, they should have been covered with good vegetation to furnish a supply of humus. A good coffee soil is of such a type and, if properly managed and protected, should last for well over a hundred years. Poor soils are known to grow coffee, but they require extra work and supplementary fertilization.

The soils themselves are not all that needs attention in commercial growing. A point of primary importance is temperature. It is impossible to grow coffee for very long in a region where there occurs an annual season accompanied by regular frosts. Coffee is never completely dormant; it is a tender, broad-leafed evergreen that cannot withstand hard freezing.

are reduced progressively with distances away from the Equator and higher in the mountains. It is said that for approximately every degree removed from the Equator there is a reduction in temperature equal to what would be felt going up 270 ft. in elevation into the mountains. Plantations cannot last for a long time growing beyond the frost line. It makes no difference whether this is at low levels, extending away from the Equator, beyond the line of the tropics or in directions up mountain slopes, extending to high cold lands.

The growing of coffee in the mountains, in many parts of the tropics, is for good reasons. The purpose of hill culture is to find and use land not employed in subsistence farming, that is cheap and with a high humus content, where there is abundant moisture, and where it does not freeze but is under moderately cool temperature conditions. There is a proportional influence of temperature to altitude especially notable in the tropics. Much depends on geography and exposure for relative calculations, but with each 300 ft. of elevation up a mountain side, there is a reduction in temperature of about one degree Fahrenheit. For example, at 1,500 ft. elevation, at an average point in the tropics, it is fairly warm and often thought of as a lower limit for coffee. The temperatures there average only a little over 5°F. cooler than in a region close by but at sea level. At the same point, it is about io°F. cooler than sea level at some 3,000 ft. elevation, and that is usually a medium coffee region. At that same point, a cool coffee region would be found at 5,400 ft., with temperatures nearly 20°F. colder than at sea level. There, frosts may be of occasional occurrence and must be guarded against. The elevation of 6,200 ft. would be almost the high limit for coffee, and it would average 21 or more °F.

cooler than at sea level. Coffee would fail occasionally at this altitude. There, frosts often occur and blanket *shade* trees have to be grown for protection. A little above this, freezing would be common even with heavy tree blanketing.

Temperatures are important for coffee. These have been given more detailed attention elsewhere in this book. Review shows that, probably, the best temperature for bearing Arabica coffee is an average of 24° C, or a few degrees less. The best for flowering and fruit-set requires diurnal changes from warm days to cool nights. After fruits are set, the temperature can be quite warm or quite cold and they will progress to maturity. The optimum for seed germination is in the high temperatures, but seeds will germinate, although slowly, under quite cool conditions. It is well to keep in mind that; while Arabica coffee is a tropical tree, it is not a hot-land plant if it is to be grown for commercial purposes. Warm nights are a serious handicap as they are a mam cause of sterility.

It is on the mountain sides in the tropics that rains are precipitated. Coffee thrives where there is sufficient moisture, and under not too warm conditions. It is with high temperatures and especially rains, that there develop the great plant associations spoken of as the moist to wet, tropical rain forests* Coffee has often been planted in such regions. Where the soil is too wet, the coffee lands will *txmtl* drainage^ and there are amounts of precipitation at; which even drainage will not take away enough water to allow the planter to make money* In the same way, where lands are too dry, they can be planted to coffee if there is irrigation water, but a few of sufficient irrigation water may quickly spell the doom \ti concc lis a pcrinancniiy reinuncraitvc CUILUIC*

It is obvious, then, that the best conditions are those more intermediate m cnaraccer. z or firooo conee ffrowmK[1]* oic lantLS can oc oi iiiocivi*" ately dry forest type or even bordering on moist savanna. But by horticultural dexterity, coffee can be grown and harvested in both very wet and very dry country, though it is here not so good a commercial venture.

DEVELOPING PLANTATIONS FOR PEEMANFMCY

During the early decades of the history of coffee planting, the crop **spread** rapidly. Seed had been secured by Europeans from Ethiopia and, through successive years, the crop was quickly moved from one country to another. The first growers soon learned the potentialities of the tree for producing a product of great: popularity, through which quick fortunes could be made. It was for an adventurous exploiter to grow coffee in a semi-wild condition, make his money, and then return to civilization. There followed a period when new areas were being eagerly explored for possible fitness for growing coffee. If the combination of ecology and the nature of the tree fitted together, and if it were possible to arrange transportation, new tracts were planted. Studies of plantation management commenced and from the new regions large crops were secured. Along with proper growing conditions, there was need of a large supply of tractable labour that was not too costly. Much hand work was an essential. When that could be obtained, and with development of the crop, there followed more planting. Soon came occasional failures. Areas grew older and, with age, there developed problems of a more serious nature. An accepted method of short-term coffee plantation operation evolved. Fields were cleared and planted, a few crops harvested, and all was abandoned in about a decade. Soils, thus treated, were considered ruined. Coffee earned the reputation of being a crop that despoiled the land. Up to that time, there had been little effort given to special plans for developing the plantations as a type of permanent agriculture.

By the time agriculturists became more certain that they needed longer life in coffee plantations, science had advanced to the point at which it could be of service in this respect. The original character of coffee soils (Jacks, 1936; Mohr, 1944; Setzer, 1945) is a most important factor in the determination of whether coffee is a temporary or a stable crop. It was learned through experience (Cramer, 1957; Wilson Mayne, 1947) that the original humus content of coffee soil must be preserved as far as possible, else the maltreated land suffers early deterioration. If humus is not preserved, then its equivalent must be supplied by one of three methods: through shade trees (Cook 1901; Kirkpatrick, 1935; Machado, 1951), through mulching practices (Badcock, 1949; Reeves & Vilanova, 1948), or through additions of fertilizers (Pereira & Jones, 1950; Beaumont & Fukunaga, 1953; Beaumont, 1948).

Advances in agricultural science in the tropics have been moving rapidly as they relate to coffee growing in plantations. This has been a necessity if it were to develop steady and long-term production in given places. The problems regarding germination of seed (Ultee, 1933; El Salvador. Centra Nacional de Agronomia, 1949; Mes, 1955) have been given only a certain amount of attention, but other work is in progress. With regard to seed-bed problems, the type of work done has been based on empirical findings (Cramer, 1957; Alvarado, 1935-6), but it has served well in the development of bases for good techniques.

Meanwhile, problems have been, and are continuing to be, studied respecting nurseries and transplanting details (Colaco, 1952; Haarer, 1956; Sanders, 1950). Some of the original work on vegetative propagation in coffee was excellently carried out (Cramer, 1957), and it gave to the crop a great advantage, especially where grafting was needed because of disease or for genetical study. As it became a crop for professionals, coffee entered the stage of selection and breeding (Ferwerda, 1948; Krug & Carvalho, 1951; Vallaeys, 1954; Maistre, 1955), and the accompanying studies in genetics are developing. These have potentialities for greatly enhancing the stability of the crop.

When coffee was grown as a wild crop, or a crop for short-term attention, there was little need for trying to make the trees live longer or to assist them to escape ruinous exhaustion. One of the most interesting things in coffee research, and one of the most stimulating of studies, deals with pruning (Poskin, 1942; Thirion, 1954; Ripperton *et al.,* 1935), and shaping of the tree to conserve its life for a long time and for more economical productivity. There are certain difficulties that have to be solved if given coffee plantations are to be profitable for generations. The weed problems, some of which had very early attention (Cramer, 1957), may make or break the continuity of existence of coffee fields. Of recent years, the newer herbicides (Smith *et ai,* 1951; K. M. Thomas, 1951) have been studied and are being used more and more. Insect pests (Bredo, 1939; Coste, 1955; Pinto da Fonseca & Autuori, 1932), at one time, were thought to be mostly in the eastern hemisphere. This is now realized to be incorrect, as more serious insect pests are being reported in the Americas on coffee, although only a select number are of major importance.

With any trees that are struggling under precarious forest growth, especially in the tropics where such individuals occur at wide distances, the disease problems are not usually extreme. But as great stretches of woodland or jungle have been planted solidly to coffee, diseases have entered in intense fashion and have been a serious menace to growing coffee for long in certain fields. It is the solving of the disease problems (Hendrickx & Lefevre, 1946; Bally, 1931; Wellman, 1955) that immeasurably extends plantation age and insures plantation growth.

When it was finally realized that coffee plantations were capable of some permanency, attention was given to the planning of them. This was based, at first, on previous experience with the old haphazard systems. Common sense was added to that. Where there were differences in geography, and even differences in the people involved, plans were necessarily adjusted to the situations encountered.

ROADWAYS IN THE PLANTATION

Following a decision on the choice of soil and climate, a very important problem in plantation planning is that of roads for transportation. The most obvious observation regarding this is the need for getting the bags of coffee to market. The recent advances in the use of air for short-distance transport are known, but the need for longer hauls by water or rail and shorter ones by road is even more evident. The planter must calculate, in the cost of transportation to market, all that is needed to move his coffee from the time it leaves his outer gate to its arrival at the destination from which his payment comes.

Within the plantation itself, roadways have been one of the last things to be given their proper due. They have depended greatly upon what relative permanency had been determined for the land. In some regions, very poor roads are much more common than even moderately fair ones. Partly, this is because roads are a luxury in the tropics. They are costly to build and are expensive in upkeep. Little scientific study has been given to determine how much would be gained by changing roads from very poor to just poor, or to those of medium quality.

Roadways are the means of getting to and from the plantation, in and out of the fields, to the processing yards, to the residences, and to the living quarters of the labourers. There has grown up knowledge that inside roads should be plentiful and should reach close to the central parts of all plantings. This reduces the necessity for human beings to carry bags of harvested coffee any great distances. Nor should it ever be difficult to haul workers, sprays or sprayers, fertilizers, or other things to within a reasonably short distance of every point in the plantation. Passable roads make for more interest and more respect from the labourers. Such roads aiso increase the ease of patrolling work daily.

Roads are especially difficult to build and maintain within many of the ecological zones of best soils, where coffee grows and produces well. So long as roads are extremely poor and sparsely laid out in a plantation, the growth may easily retain a wild, inefficient character because of poor culture and rough treatment. This is the more likely as the effort required to go from field to field will not allow repeated work visits during short periods, and when they are needed most. The placement of roads and their upkeep may make the difference as to whether the planter can do planned, intensive, modern, efficient work on his crop, or whether he will be forced to manage it in a wasteful and random manner. It is upon this that there depends the longer life and increase in value of the plantation. Plantations are known to progress with good road transportation.

LABOUR ON THE PLANTATION

Coffee growing and processing depends upon such a large amount of hand labour that the human factors need special thought. Circumstances have combined to make it increasingly important for planters to understand their labourers, including some of their life habits and idiosyncrasies. These cannot be disregarded, and they have been, and are continuing to be, studied and deeply considered. Coffee is grown in some of the remote parts of the tropical world, and, for this reason, the source of hand labour for coffee has been from distant, little-known peoples. They have come from such numerous places, such various levels of living, and such different cultures, that no broad statement about them is possible.

Each plantation region has had to work out its own best pattern of labour management. This has called for intelligent attention by the landed agriculturist. He knows that, in his planning, he cannot forget that his labourers have very different backgrounds from his. If he has workmen who have become a successful part of his long-time scheme of coffee production, it is because he has given them special study. This is a matter of intelligent self-interest.

It is not necessarily true that workers have a different method of thinking from the owners, but, in their own way, they are apt to be very insistent along certain lines. These matters are well known to experienced planters. Some things that seem desirable to owners are of no interest to the labourers. Other things that they wish to secure and keep may have no meaning to a planter. It has been found that, usually, labourers as a group are more conservative than the owner. There are regions where it is practically obligatory that labourers be paid in part with food supplies. There are localities where this is still one of the best ways in which the planter can demonstrate thought for his employees. For thus the workers receive an understandable and direct good, and they are appreciative of it. They give more in return for such treatment.

In some cases, the established, permanent employees are assigned plots of land of their own. On these, they grow foods of which they are especially fond. In some cases, absences are arranged at the seasons for harvesting or planting in ancient tribal places. In some cases, special housing may be given, or time allotted, to them to construct their own habitations. With their mark set on such places, they want to settle—which is desirable in obtaining for the planter his core of skilled labourers. Where available, special living luxuries have become associated with, and included with, housing of the chosen workers. These include such things as a convenient and sanitary water supply, a good place for washing, electric lights, or oil lamps with fuel furnished free. A thoughtful planter has at hand recognized, but unmentioned, perquisites for those employed, if he is looking towards his own future good.

There are some things needed for workers that are often not given much consideration but, where planned and carried out, mean a great deal to the reputation of the plantation. Such add to the ease of securing and keeping permanent help, and assist in obtaining labourers at peak work-seasons of harvest and special field treatments. As examples, some owners are known to plant, and leave untouched, fruit trees which are expected to be visited and picked by labourers. Those trees are found in odd corners, along obscure roadways or lanes, about wood-lots, or at the backs of easily reached pastures. Fuel for home fires is also something that labourers may pick up in a coffee plantation. It may be from shade tree prunings, or from old coffee tree stumps, but it is part of the labourer's proper due under some of the best regimes.

Instances have occurred in which the owner of a plantation has encountered extreme difficulties with labourers. He may have obtained land in a heretofore hidden region, where people lived in sparse settlements with an economy based on barter. Here the planter, necessarily, will have imposed upon the population work schedules and other types of order. The labourers would be expected to work at a task a certain

Photo Pierre G. Sylvain

(a)

PLATE 26.—*(a)* Part of a great coffee fazenda in Brazil. Area of residence and workers' quarters on both sides of road, at left, are marked by shade trees. A large poultry house is seen on the brow of the hill, with one fowl for every ten covas of coffee. Covas are of Bourbon coffee and are well spaced, no weeds or grass being allowed to grow between them. State of Sao Paulo.

(b) One of the largest coffee plantations in Eritrea. Young trees in foreground, older in the rear (surrounding residences). All coffee is Arabica and, because of dry conditions, grown without shade.

(b)

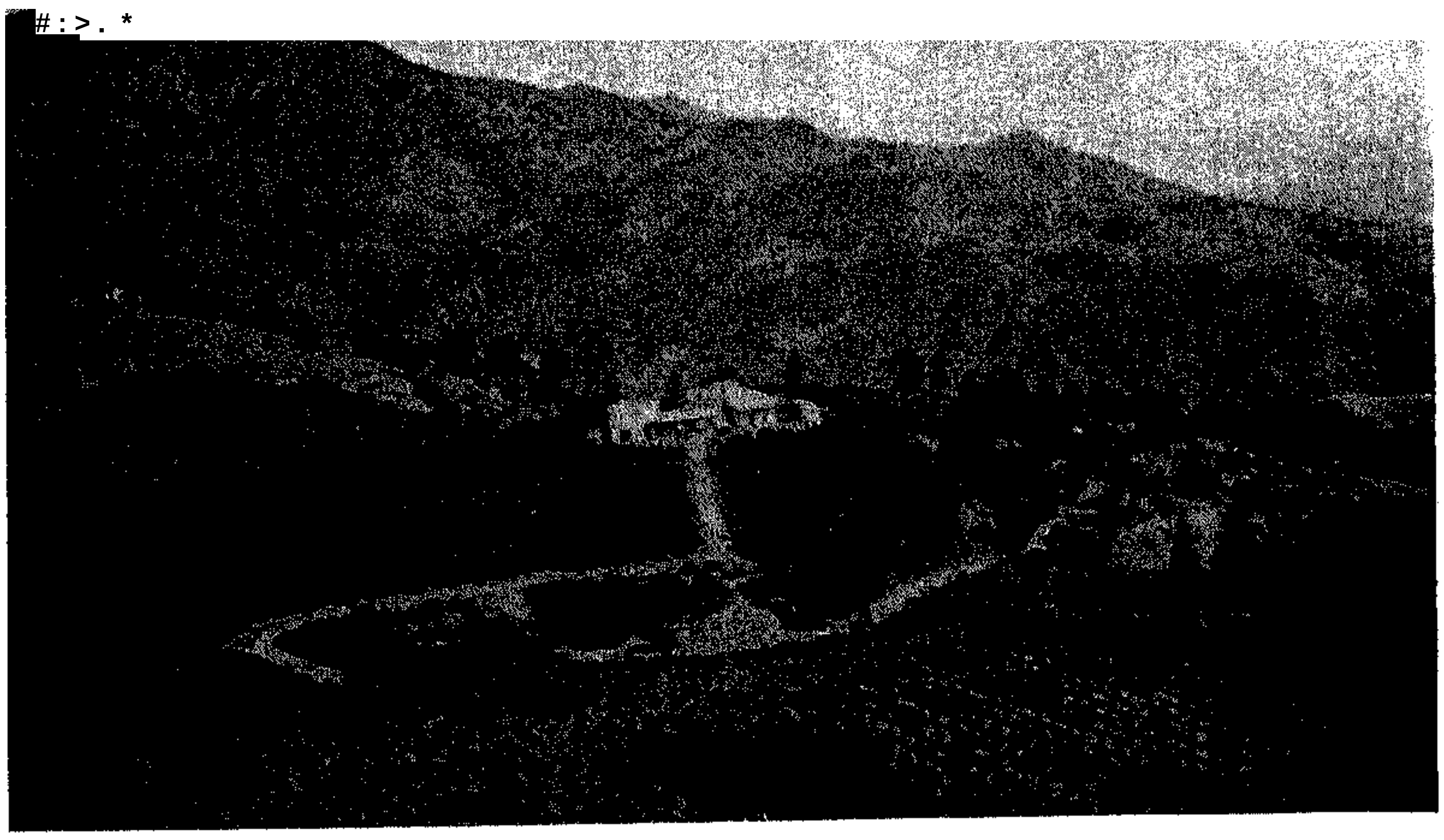
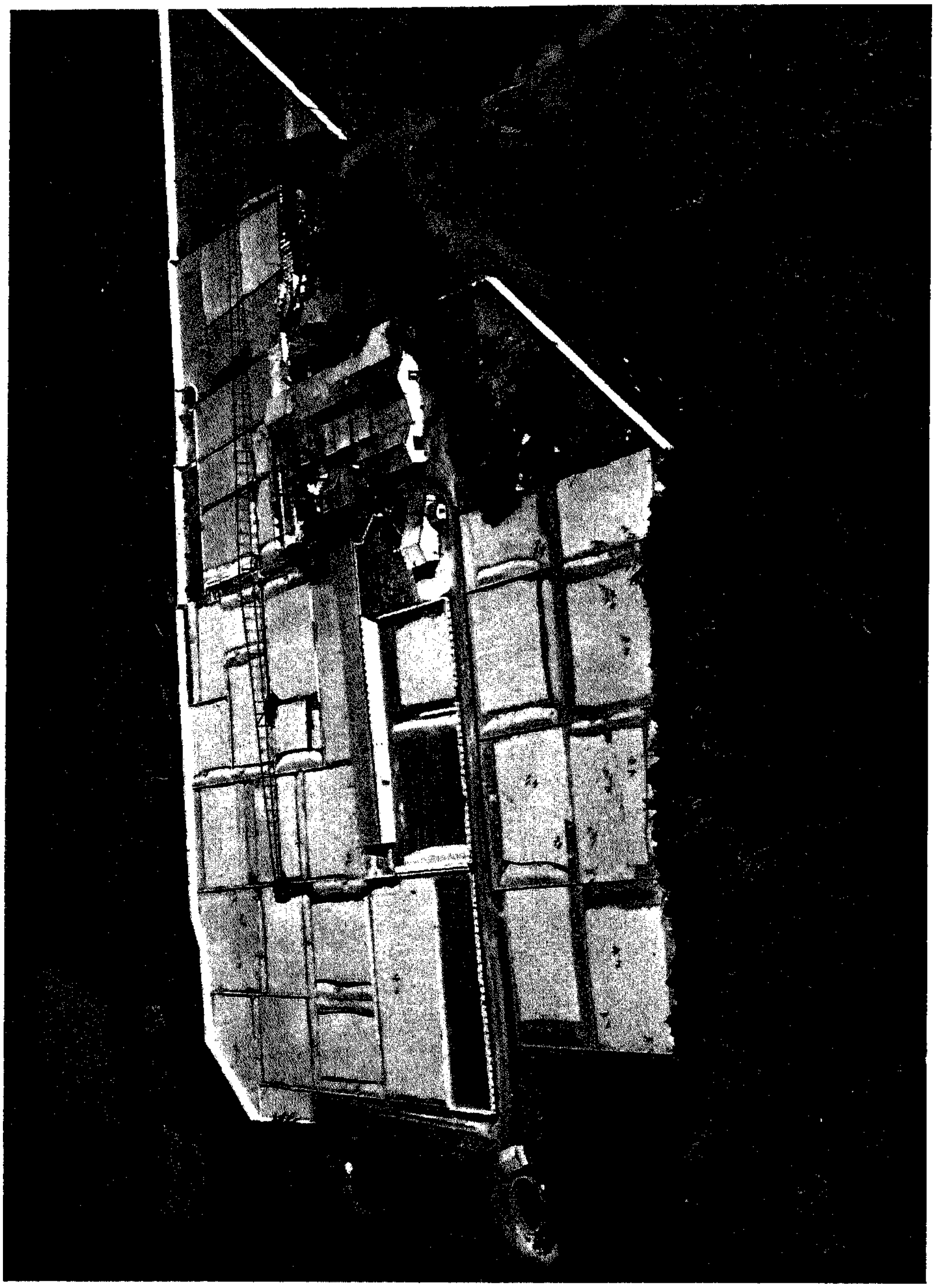


Photo Pierre G. Sylvain



amount of time every day. They would be introduced to holidays and celebrations, but the important thing was regular effort. The book-keeping, be it ever so honest and so good that, in the end, the labourers received more than they would by traditional means of livelihood, could have its limitations for the unsophisticated. Coffee, as something processed, bagged, and moved out as a dried product, may have been of less imperative worth in the eyes of workers than such crops as rice, cassava, maize, sugar cane, ground nuts, bananas, or some other edible.

An important point of misunderstanding for the fully interdependent owner and his labourers has often been religious or folk beliefs. As an example of what occurs at times, there is a period of the year when some peoples want to go back to the points of their origin. This is true in many different parts of the world. This may be for a religious pilgrimage. It may be kept as a secret reason, not told or explained to anyone outside their own people. It may coincide exactly with the time when coffee fields need some owner is hard-pressed, horticulturally, to know how much to sacrifice and what can be done to keep his fields attended without destroying the attachment of his labourers.

One of the most important problems has been housing. For the small owner it may not be so complex, but for a large plantation it is sometimes more difficult. In any case, there needs to be a good water source, a healthy building site, and availability of pleasant surroundings. Attention should be given to the location, so that it is convenient to go to work, and near to the roadways that lead to villages, churches, or temples.

It has required of planters a brand of statesmanship and sympathetic understanding to know the labourer. There are, in some regions, anthropologists and teams of researchers making investigations on these problems. From their studies, they have been able to increase understanding among all concerned, and they have developed willing participation from hitherto unco-operative workers. This enlightened policy is one bearing progressively better fruits. The rural sociologists have made, and are continuing to make, great contributions to mutual comprehension between owners and labourers. From the foregoing, it is clear that there have been serious problems. Upon his success with his employees depends the future of the grower.

PLANTATION LAYOUTS

One who has examined the layout of plantations as they exist, at least in some countries, finds certain characteristic things. A fairly common and conspicuous feature is that of placement of housing and processing factory. Usually these are so located as to have ready access to a main road. An ideal location for a main living area of a plantation is often thought of as at its centre. The owner's house is known as the main residence, with its yard and ornamental gardens. It is generally in front of, but at some distance from, the processing building or buildings. The part of the plantation where the market produce is prepared needs especially close supervision during harvest. The buildings with the machinery inside are a costly item. In some countries they lay special paved drying floors. These are the so-called barbecues, terreiros, or patios, that are open to the sun. PL 26 shows scenes in large coffee plantations in Brazil and Eritrea, and PL 27 is an aerial view of probably the largest coffee processing plant in Central America.

At a little distance from the factory is the labourers' living zone. While it is not often in full view of the main residence, roads and paths between the residence and labourers' houses make them readily reached. Often the workers will require stockades and pens for livestock, facilities for community laundry purposes, sometimes community cooking arrangements, often a medical dispensary, a commissary, and a meeting house, minor chapel, or temple. The location of housing has often been given very careful study, in relation to access to the greatest part of the plantation.

There are plantations on hillsides, or in land broken by streams, in which serious attention and calculations have resulted in placing the residence and workers' quarters far from the geographical centre of the plantation. In addition to such matters as sanitation and road accessibility, the question of which hauling is best done uphill, and which down, may have made a great difference as to where the living centre was placed most efficiently. In some cases, for such reasons as those of ventilation, view, wind protection, sun exposure, location of main roads, or for historic reasons, buildings have been located at considerable distances from where they might otherwise seem best placed for efficiency. In such cases, where a plantation is very large, permanent camps may be constructed at strategic outlying locations where mobile gangs can be taken for a week or more at a time.

The selection of the exact place upon which to construct housing has also depended on the probable length of life of the several fields of the plantation. Practice has dictated that expensive capital installations should be located where they would be of the longest use. It has recently included more expert study of soil, climate, and the life of the trees.

LIFE OF SOIL IN PLANTATION

It has been shown that the history of coffee growing goes back for some centuries, and many successes and failures point to the importance of the selection of good forest lands for planting. To know the proper moisture and seasonal changes in good coffee soils is essential, and to have a fine cover of forest shade over it is an added help in indicating long life for the plantation. Coffee is an expensively-grown tree crop and the hope is for it to be long-lived in a given planting. However, the hoped-for relative permanency is not always realized (Wilson Mayne, 1947). This can be because of poor judgement exercised at the time of land clearing—for example when, by unreasonable treatment, the soil is unnecessarily exposed.

Good lands should have a good humus content when planted (Mohr, 1944; Cramer, 1957), and this should be retained. It is known that some soils are quite short-lived, e.g. in Brazil (Laliere, 1909; Setzer, 1945; Pendleton, 1955), and in these the forest has been taken off and burned anci Liie crop grown in unshaded conditions. In some places, soils have lasted for over a hundred years, bearing coffee all that time, and are still doing well. I have had personal knowledge of this in El Salvador, Guatemala, Costa Rica, Indonesia, and South India. There are equally old fields in many other countries.

In reviewing certain aspects of coffee growing in South India, Wilson Mayne (1947) discussed the reasons why some of those century-old coffee gardens had continued for so long. They were in a relatively poor class of soils that came from gneiss as the mother rock. The soils were fairly well drained, and shaded, but the outstanding characteristic of them was that they had had their humus content protected from the very first. Those old soils had been prepared for planting by felling and clearing without burning. The large tree specimens that could not be easily dealt with for shade purposes, or that occupied too much room, were removed. But every effort was made to keep the forest trees usable for the medium-light shade needed, and at no time was the soil exposed to direct weathering by sun or the heavy tropical rains. A mixed shade canopy was maintained from the beginning, and new shade trees have been constantly brought in to keep this canopy ever young. The same kind of observations have been made by others.

An outstanding example of the method of managing the planting of coffee in jungle soils, to endure for the longest period possible, is that discussed by de Ligt (1937). In parts of Indonesia, numbers of the plantations were very old. Going back into the history of the old good soils, it was learned that farmers, in the old days, had opened untouched jungles in rather narrow bands. They cut and hauled out the trunks and main branches of large trees, and chopped the remaining brush to small pieces that were left on the ground for additional organic matter. Sufficient numbers of smaller wild trees were retained for shade, and the coffee was planted in the prepared bands between jungle zones. Excess trash was pushed over into the jungle zones, but the forest litter was most carefully retained for mulch. Above all, there was no burning.

Coffee was planted quickly among the young jungle trees kept for shade. The soil was kept well covered. The planter maintained a continuous, slow chopping of excess trash in the jungle strips. This chopped trash was easily managed and was spread between the growing coffee trees in the cultivated bands. Meanwhile, new shade trees were being planted, and, as they grew, loppings were harvested and spread on the ground between the coffee tree rows. When, according to the grower's intentions, the time had come for new planting, the jungle strips between the cultivated areas were cleaned and planted to coffee, again preserving the trash cover on the soil. Young shade trees were soon introduced, especially for loppings.

The coffee gardens, started and tended in the manner described, using care that humus was continually being returned to the soil, have lasted for generations. In contrast were the plantations close by, where there had been a sadder result. In these, the farmers were so anxious, in the fever of the venture, to complete their plantings, that they cut everything down, allowed it to dry, and then burned it during the dry season. This was called 'kaingened' land. As soon as rains came, everything was planted anew—coffee trees, temporary shade, and permanent shade. By this means they obtained quick results. Coffee started well and gave good crops for a few years. But then the growers began having troubles. It was soon learned that some of those gardens had to be abandoned because of exhaustion. This was in a short 20 years, or, at most, 30.

In the last few years, growers, because of better coffee prices, have been opening up new lands in Central America. In most cases, burning has accompanied complete removal of forest growth. It has appeared to me, at times, that this is not planning for long into the future; but all of it cannot be thoughtlessly condemned. There are extenuating circumstances for burning. It is a tool where machinery may tail, it is an indigenous method, and has been used for centuries. It is employed on the drier slopes of some mountains, not only to make soil preparation easier, but also to free the fields from ticks, noxious insects, poisonous snakes, and similar pests. It has appeared that, if brush burning is properly employed, it does not consume all the humus in a soil. On the other hand, by improper timing of both cutting and drying and then burning, everything is consumed. I have seen burning so skilfully done that it quickly cleared the loose trash under shade trees without even scorching them greatly.

Much serious study of the problems of burning of coffee lands has long been carried on by research teams in the Congo. This is still in progress. An example of one series of the results (Thirion, 1952) were harvest figures from variously treated equal plots. In land well prepared, but not burned, the yield was 873 kg. per hectare; but where land was burned over the yield was 647. The observations included areas planted in the bush where, with a minimum of care, production was only 325. This showed that cultivation was worth while, but burning did not pay. Some eighteen years before, Gandrup (1934) had advised that coffee growers make careful plans for regular and complete replanting. This included careful field preparation plans. In them, fields were divided into sections. They were cleared but not burned. They were left fallow for one year and replanted to improved stock of both shade trees and coffee, that were continually being developed. There was a regular rotation of sections so that a farmer always had young, medium-aged, and old trees. It was felt that, in this way, all of the old mistakes could be known and plans made to rectify them gradually as replanting progressed.

Grasslands have been considered by some as fit subjects to be burned, ploughed, and then planted to coffee. Their soils, and the crop they grew, could be handled thereafter on a nearly mechanical basis. However, in considering such possibilities, special study should be made of the history of the grassland being given attention. In Ceylon, there are slopes and hill-sides that once held rich plantations which were killed by rust disease. These lands turned to grass and have become the difficult~to-handle, so-called 'patna lands' that cover great areas. They have a dense growth of a grass of that name, useless for grazing and difficult to eradicate. On the other side of the world is another example of this. In Brazil, for a long time, old coffee lands have degenerated (Setzer, 1945) owing to poor husbandry abetted by low prices and inevitable reduction of soil humus. Repeated burning was followed by grass, and the land turned into pasture. Relatively soon this became poor for grazing. This has occurred in many places, and I have watched it happen in a comparatively few years in three countries of Central America.

It is only at an almost prohibitive cost that such deteriorated lands can be brought back into coffee culture. It may be considered axiomatic, that, except in desert regions, tropical grass savannas are the result of repeated burnings (Gourou, 1953), whether set by lightning, by natives, or at the orders of planters. Consequently, grasslands of the tropics occur in ecological zones that could be supporting woodlands, or coffee, if it had not been for decades of fires across them. To return these to coffee is not like breaking the sod and broadcasting wheat. It has to follow a very careful study that would include economic methods for treatment of savanna, conversion to horticulture, replacement of lost humus and of the supply of basic nutrients, and plans for the growing of mulch in sufficient amounts to keep the land protected thereafter.

ROOT GROWTH AND PLANTING DISTANCES

Planning with respect to distances between trees of Arabica still has need of much study. Results have been variable—more so than with some other species, possibly indicating the greater sensitivity and narrower adaptability of Arabica. It also shows how important the results of regional studies might be to Arabica growers. The commercial varieties, such as the Typica, known also as Arabigo and Nacional, and the variety Bourbon, also called the Hibrido, and the Harrar, the Kent, and the Mundo Novo groups, are what might be called the standard Arabicas. It is with these that most of the studies have been made in the species.

The new short types, such as Caturra, Villalobos, San Ramon, and Pache, are in a different group. They need much continuing study on spacing, and, apparently, no one has investigated properly their root systems. Crude digging of my own with spade and trowel has convinced me that Caturra has roots commensurate with its small size, and that the circle of radiating roots covers a shorter diameter than that of the standard varieties.

Maragogipe, the giant mutation of the Arabica species, seems to fit in fairly well with the standard types as to the best planting distances. Observations show this to be true in Guatemala and El Salvador, where it is mostly grown mixed with standard kinds. I have seen it in plots in the best soils at medium elevation, planted at nearly 15 by 15 ft. where Nacional close by was planted at slightly less than 12 by 12. Such compact and tall Arabicas as Laurina and Columnaris (PL *20₉a)* do not spread their branches much laterally. It has been believed in the Cameroons and Puerto Rico, that, where used, they might be put in at lesser distances than standard types. Here again, root studies are necessary—not to mention careful comparisons of productions—with plants growing at various spacings, over several years.

It would seem that an important basis for deciding how close it is best to plant trees would be determination of lateral-root distribution. This is certainly not easy work. It was indicated by Nutman (1933), in his root-digging studies, that roots of Arabica could be injured by poor cultural practices. Arabica roots required 5 or 6 years to grow fully, and during that period developed a dense mass in the root zone occupied. He also found (19330) that well-developed lateral roots, on healthy and vigorous trees, extended in a circle with a radius of 6 ft., and possibly more, from the tree trunk. A little later, he reported (1934) that the main absorbing part of the root system was in a region at the periphery of the lateral extreme of the roots. This was confirmed by Suarez de Castro (1951). Guiscafre-Arrillaga & Gomez (1938, 1940) found that Arabica roots extended laterally to a distance of over 4 ft. in all directions. In my own studies, I have found lateral extension of roots in old trees for as far as 10 ft. Such information as these studies have given, indicates that much is still to be done, and that Arabicas need a good amount of space between trees for the healthy development of their roots.

It has been found that Arabica roots are sensitive to crowding, and secondary roots, especially, were poorly developed if the trees lacked light. This would appear to be a normal effect in crowded plantings. Sylvain has reported a considerable reduction in root growth from excess shade. I have examined roots by digging in plots in which trees were planted about a yard apart in both directions. The technique of digging was crude, and the observations were only visual but, I believe, suggestive. Roots grew vigorously the first year and met in the second. They rapidly increased in numbers of branchings into feeder roots during the second and third' years after planting. In these crowded plots, feeder roots showed no injury on trees carrying their maiden crop. Such roots extended to approximately the distance of the branch periphery, out to what might be called the 'drip ring' of the tree, which was more than a yard in radius. Although these feeders seemed to have increased many times in numbers, they remained light-coloured, turgid, solid, and vigorous in appearance. It was in close plantings of trees bearing their third crop, which happened to be heavy, that many feeder roots were found that were dark in colour. Many appeared soft, weak, and dying or dead. Close by, trees growing some 9 ft. apart did not have roots of the same darkened and weak appearance as those growing 3 ft. apart Trees in both plots were bearing heavy crops. The injurious effect could be seen especially on the roots under crowded conditions.

In addition to physical root-crowding, there must be deleterious etiects because of the limitation of available nutrients to be absorbed Irom the soil that is tightly filled with feeder roots. This has not been studied experimentally and it deserves attention. Detailed studies should be carried on respecting the basic effects in crowded root zones, compared with those that are uncrowded.

Above the soil, there are also bad effects from very close planting. Diseases find good conditions for multiplication, and thickly grown conee makes it almost impossible to spray properly against diseases, ihe parasites are protected and spread rapidly under these conditions.

When trees are crowded, pruning becomes so difficult as to be easily stopped. Ordinarily, when growing too closely, Arabicas become teller than they might be otherwise. Thus, year by year, the trees bear their crops higher on a slender, weaker stem, which readily breaks. Before this happens while the trees are young, harvest is relatively easy among closely planted trees. In the first years a picker earns good wages from a relatively small area. But, as the trees grow, workers cannot break through to prune properly. Indeed, some horticulturists have even advised against prunmgin closely planted trees. In a few years, the tangle has increased to the point where it is a serious detriment. In close, multiple-row hedge or belt plantings, picking becomes a struggle. There is^creasing physiological die-back of laterals because of root crowding, and this adds to the tangle. It is only under special conditions that extremely close planting can be much recommended.

GENERAL FIELD SPACING PRACTICES

Once the land has been selected for planting and its method of preparation decided, the next problem is the planning;of distances to set the trees in the field. The important species of commercial coffee appear _to have different root-space requirements, and general figures are often givem It is said that Arabica is quite often planted at 8 by 8 ft., 680 trees per acre.

Robusta is not uncommonly grown at 10 by 10 ft, 435 per acre; and Liberica can be quite often found at 12 by 12 ft., 302 per acre. These distances are probably a little close. Without going into monographic treatment, it is considered of value to review some of the reports on various planting distances.

The size and growth-habits of a tree make differences as to space requirements. The largest trees producing commercial coffee are the Libericas and Excelsas. Although of two species, both are grown in a very similar manner. They are coarse trees that can almost take care of themselves, once they are growing well. In the Philippines, David (1935) advised that they be planted at 13 by 15 or 15 by 18 ft, employing the latter, wider spacing in the more fertile soils. In Malaya, Milsum (1931) recommended planting at 10 by 10 ft. in the poorer, sandy and inland laterite soils. In those poorer fields, at whatever distances trees were put, they lasted only about 10 years. In better soils, such as the good coastal plain loams, they grew better and produced more at 12 by 12 ft. Moreover, they lived well under these conditions for at least 20 to 30 years. Fauch&re (1927) reported that Libericas were grown in French Africa at 13 by 13 ft., and in Dutch Guiana at 16 or more ft. between rows and 13 ft apart in the rows.

There has been a great deal of special attention given to the distances at which C. *canephora* varieties and strains grow well. These trees are intermediate in size, but are vigorous in their growth. Among these varieties and strains are the Robustas, and some reports about their spacings have been given by van Hall (1913) from Indonesia. In fertile soils these pruned trees were best grown at 8 by 8 or 8 by 9 ft. If the soils were less fertile, they were planted at 7 by 7 or, at most, 7 by 8 ft. When used as a catch-crop between Hevea rubber, and therefore short-lived, unfertilized, and to be harvested only a few times, Canephoras could be planted at 6 by 6 ft. Planting distances of these were farther apart in the Philippines (David, 1935), being put in the field at 10 by 10 or 13 by 13 ft In that country, pruning is not so closely done as in some others, and I was told there that the widest spacings were absolutely essential in better soils to prevent excessive crowding. In Uganda, I saw very old specimens of the Uganda variety of C. *canephora* spaced at 30 ft., but there were younger trees producing well with good room around them at 12 by 12 and 15 by 15 ft. There seems to be a limit to the closeness under certain conditions. For example, A. S. Thomas (1937), in British East Africa, reported that 8 by 8 ft. was much too close for Robusta to produce efficiently.

It had already been reported by Fauchere (1927) that Robusta was well adapted to various distances depending upon conditions. In some of the good areas, it was best planted at *n* by 11J ft., or sometimes 10 by 10 ft. Under situations that were not so good, it might be, at the most, 9 by 10 ft., or usually a little less. In certain more fertile soils of Madagascar, the better distance was 13 by 13 ft. Narasimhaswamy (n.d.) considered that, in southern India, common distances for Robusta were 8 by 8 or 12 by 12 ft. On inquiring about this of growers there, I learned that the greater distances were used in the better soils and at higher elevations.

In the French Cameroons, Thirion (1952) reported results of 30 years of studies of Robusta planted at three different densities. Where there were 329 trees per acre, i.e. at about 12 by 12 ft., they were not sufficiently close but produced on an average 836 lb. per acre. With 587 trees to the acre, i.e. at about 7 by 7 ft., they were much too crowded and became very-difficult to manage and inefficient in culture programmes. There was a high average annual acre production of 972 lb. at this closer spacing. A somewhat lower production, 895 lb., was obtained from an acre density of 389 trees, i.e. at a little over 10 by 10 ft., but this was much the more readily harvested and cultivated and was the more practical spacing.

Conclusions from spacing studies of Canephoras are that, in good environment and soil, the wider planting distances gave better end results—all, of course, within limits. In good soils, and in climates neither too warm nor too cold, 10- or 12-ft. distances can be given as average planting recommendations for this species. In the poorer soils, in hot dry lands or cold high fields, it would be best planted at somewhat smaller distances.

The species C. *arabica* is the smallest tree and has had much the most attention by those putting it in at different distances. Rodriguez Barrera (1925) told of accepted spacings for Arabica in a number of countries. In Brazil, the general spacing varied from 6| to 13 ft. In the state of Sao Paulo, it was usually 1*1*\ by 13 ft. He reported that, in the Blue Mountains of Jamaica, spacing was generally 6 by 6 ft. In Guadeloupe, planting was largely 6J by 6J ft., although he considered this too close as the coffee grew so luxuriantly that it was crowded and needed more space. In Java, he found distances of about 5 by 5 to 8 by 8 ft. In Arabia, the common spacing was 13 by 13 ft., and in Fernando Po it was generally 8 by 8 or 9 by 9 ft.

A few years later some slightly different spacings were given for some of the same countries by Fauchere (1927). In the state of Sao Paulo, Brazil, he had found that coffee was planted at 11| by 12 ft. In Jamaica, it was planted at 5 J by 5$ ft., and in Guadeloupe at 6| by 6| ft. He reported two main spacings in Java: in good soils at 6| by 6| ft., and in poorer soils at 5 or 5\ by 5 or 5I ft. It was noted by J. H. McDonald (1930) that, in Kenya, pruning made a difference in spacing. Single-stem trees did well at 6 by 6 ft., and better at 8 by 8 ft. With multiple stems, plantations were from 9 by 9 to 12 by 12 ft., with 10 by 10 ft. as a good average. This was in the fairly dry Arabica growing area.

In South India (Narasimhaswamy, n.d.) the regular planting distance is 6 by 6 ft,, although some is done at 5 by 5 ft. In a survey of coffee from farm practices in Puerto Rico, it was learned by Guiscafre-Arrillaga & Gomez (1939) that over 33 per cent of the farmers of that island favoured 8 by 8 ft.? while 26 per cent planted at 9 by 9 ft. Over 11 per cent planted at

10 by 10 ft., although nearly *14* per cent used 12 by 12 ft. This, more or less, coincides with Haarer\s (1950) observations in Africa that, common Arabica at 6 by 6 ft. was a little too close, and that 10 by *to* ft. was heifer, Kent's Arabica* a more vigorous strain, was too close at c) by *) ft. I barer considered that with multiple-stem pruning of Arabica, an adaptation of which is used in Puerto Rico, the best distance for planting in Africa

The spacing to be allowed depends a great deal on vigour and growth habit. It was recommended by Swynnerton *et aL* (1948) to plant at 9 by 9 ft; on the slopes of Kilimanjaro, in Tanganyika, where trees are closely pruned, and mostly on the single stem. Returning to Puerto Rico, where coffee is grown as multiple stems, it was recommended by Corrca (1045) to plant at; ro by to *t*, in lowlands where it did not grow very well, and at 12 by t2 ft. higher up where it grew much better. In the Philippines (David, 1935), two distances were used; 8 by 8 ft. where the coffee did not grow very vigorously, and to by 10 ft. at higher altitudes, where it grew better.

TUt\K *SVAUKU SWDWti*

Now and then research workers have gathered together data from long-time, comparably run, sparing trials of good design. An tnMantv may be found in a report (Tremlett, 195'.) of more than to \ears of studies on Arabica in Uganda. Kqual sized plots were laid out and data taken per plot. Spacings of trees in plots in feet were; 8 by 7, 7 by 7, 6 by 6, and 4 by 4. in the beginning, plots of the 4 by 4 ft. spacing led, and retained the first place, in total production, for 12 years, due to the early advantage from larger numbers of bearing trees. However, the 6 by 6 *t*. spacing slowly caught up, and during the last 4 years it outstripped all the others.

There was also another series of such trials in which plots that had been planted at 3 by 3 ft. were treated in two different manners, I lalf were left as they were and half had the middle trees uprooted after two crops had been harvested. In this treatment the latter, leaving trees at 6 by 6 ft., gave much better production than with retention over the years at: 3 by 3 ft., at 4 by 3;/ ft., or even at a spacing of 5 by 6 ft. In other 3 by 3 *ft.* plantings, alternate rows were stumped. These sprouted and grew but developed as weak shoots because they were so crowded. Wherever there were close plantings, the coffee rust was particularly serious. A partial explanation of why the closer spacings did not do so well was that disease was more severe in their crowded and weaker growth.

At the fntcr-Amcrican Institute of Agricultural Sciences in Costa Rica, in good and moist soil, we planted Arabica at different distances: approximately 3 by 3, 6 by 6, and 9 by 9 ft. The trees were fertilized with care and judgement, cultivated, sprayed monthly, but not pruned. Considered per unit of laud, during the first two years the closest plantings produced tremendous crops, middle spacing gave medium crops, and the widest spacing gave good (but least) crops. As the third crop-year came on, difficulties in the closest spacing became evident. Spraying was almost impossible very far inside. Diseases started serious invasions. Harvesting was troublesome because of breaking and tangling. In spite of this, the curves of production had gone up rapidly—faster in the closer spacings than in the widest. But production from the closest spacing soon levelled off. By the fourth harvest the curves were taking a different turn. The farthest-distance spacing was nearly equal to the other two spacings. By the fifth harvesting the trees farthest apart were producing more per unit of land than the medium-spaced or the close-spaced. Indeed, these last plots, once the pride of the experiment, lagged well behind the other two spacings.

A different and interesting planting-distance study is that reported by Perkins (1949) from Mt. Elgon in Kenya. There, the soils are good and most growers in the vicinity plant at a 'normal' density of 550 to 600 trees to the acre. In Perkins's plots of normal density, he obtained 8*8 lb. per tree. With trees at 800 to the acre the average yield was 8-9 lb. per tree. He carried on another spacing study. In this, the trees at 9 by 9 ft. averaged 4-2 lb. each, while with trees 9 ft. between rows and in rows 4! ft. between trees, the yield was 6-6 lb. each. In a third series, Perkins started with plots of old trees that had been planted originally at 9 by 9 ft. In some plots, seedling holes were opened up half-way between trees in the row. These were then planted and harvest results taken. After 6 years of growth of the interplants, if those interplants were on both sides, the old trees averaged the best production and gave 8-8 lb. each. If the interplant was only on one side the old trees averaged a little less, 8-2 lb. each. Where there were no interplants, the old trees averaged the smallest production, which was 7-5 lb.

Many years ago, Ripperton *et al* (1935) advocated planting distances for C. *arabica* that are still followed in Hawaii. These workers pointed out that some 50 or 100 years before, when Arabica was grown without commercial fertilizers, and at altitudes of 1,500 ft. and below, it could be well accommodated at 6 by 6 or 7 by 8 ft. However, as fertilization became an accepted and valued practice, the narrow distance was superseded by wider spacing. Trees had to have more room to produce efficiently. Coffee at the closer spacings began to 'close in' and had to be replanted eventually. In more recent plantings in Hawaii at 1,500 ft., and with regular fertilizer feedings, the most successful, narrowest plantings are at 8 by 9 or 9 by 10 ft. At the higher elevations of 2,000 ft. or more, planting is at 10 by 12 ft. Only in very dry areas is it still common to plant Arabica trees as close as 7 by 8 ft.

A report by Cramer (1957) should be briefly given here. It is to be recalled that he drew upon a great deal of work in Indonesia, specializing in Robusta coffee. He reviewed carefully works of such men as Haan, Snoep, and van der Veen. After a lifetime, he did not favour thickly planted fields and, as an example, he told of a comparative study in which the densities of Robusta trees per hectare were 2,070, 1,410, 1,015, and 750. The Dutch workers found that, for the first five years, the plots with the most trees per area out-produced, per plot, the areas with the trees more widely spaced. In those first years, the plots of least density yielded only 52 per cent of those thickly planted. By the sixth year, the two more widely spaced plantings produced more than the two more narrowly spaced ones.

GENERALIZATIONS ABOUT TREE SPACING

There are some generalizations that may be drawn from observations on planting Axabica secured from widely separate places. The species grows in a wide range of conditions. Where it is possible to fertilize it, and where it does the best, it should have more space for its most efficient development and management. Where it grows poorly, it can be planted more closely together.

A certain set of recommendations can be made on planting distances in connection with planning for reasonably productive plantations over a long period of years. These recommendations are for trees with multiple-stem pruning, which takes a little more space than the close pruning and handling used in single-stem trees. With multiple stems, grown in soils rich in humus, at a reasonably cool temperature, and under good moisture conditions, the best distances are likely to be about 9 by 9 or even 10 by 10 ft: In those soils that are at a low elevation, dry, somewhat warmer, sandy or stiff, and with less humus, planting distances can be 6 by 6 or even 5 by 5 ft.

If the grower is planning for quick returns over only a few years, and making his income from intensively run plots, on a sort of rotating basis, he may consider very close planting. There has not been enough study to determine how much dependence growers can place on use of heavy fertilization, spraying, and pruning in close plantings. It is possible that, in close planting at about 4 by 4 ft. with occasional aisles, employing adequate manuring, sanitation, some special type of spraying that has still to be developed, and other procedures, production could be quite high. This would be true especially in the first 3 years and might last a few years more. After that, there is a likelihood that such a plantation would have to be completely uprooted and put into some other kind of crop. Experimental work on this is still to be done, although there has been much talk about it.

The arrangement of coffee trees is not as simple as it might sound. The so-called 'square' planting is that in which planting lines are straight down rows and at right-angles across rows. This is good for mechanical cultivation, spraying, mulching, harvest, and other field problems. But it can be a serious detriment in soils that erode readily, especially where no shade is used. In hill land, the rows should follow contours, and, in addition, be planted on the so-called 'triangle[5] system. In this arrangement, the lines down rows are straight along the rows, but across rows the lines form 45-degree angles. This aids a great deal in holding back erosion, and it adds over 10 per cent more trees to the block of land thus planted, compared with the same block in square planting.

In connection with planning of tree planting in the plantation, occasionally fields have to be specially designed for special purposes. Such is the case where attempts have been made to increase greatly the productivity by the expedient of tree crowding, although leaving swaths for convenience of field work. Since before the beginning of this century, growers have attempted, here and there, horticultural divergences from the old, standard, row after row planting. One of the old reports on this is that by de Ligt (1936), who worked in Indonesia with Robusta coffee.

He had what he called the 'belt system', in which he crowded Robusta trees into 3 dense rows, 6 ft. apart, with 12 ft. spaces between the belts. This gave heavy productivity. He also had his avenue system. In this, the rows were 12 ft. apart and the trees 6 ft. apart in the row. In comparison wren rnese avenues* he had regular 8 by 9 ft. standard planting distances. After they had been carried on for 6 years, the avenue plantings gave an average production of 17 quintals per hectare, and the standard plantings only 14. However, the closer spacing had many disadvantages of disease, culture, and harvesting, and he did not recommend it. In the end, the wider spacing was the arrangement most suitable. No one has grown any coffee at close distances in Indonesia since then.

More recent versions of this are the so-called 'hedge[5] plantings (Guiscafre-Arrillaga *et al*$_y$ 1955; Cowgill, 1955) that have been advocated for Arabica in Central America. Variations of these have been published and recommended in parts of South America, also. The plan (and it is now being tested in several localities) is based on a three-row 'hedge', like the 'belt' of de Ligt of some 30 years before. The recommendations are rows 1 m. apart and 1 m. between trees in the row, with 4 m. between hedges. The ideal was to prune the outer two rows to a topped, single-stem tree, and to leave the central row unpruned. It was believed that this soon could reach maximum production, and after 15 to 20 years new hedges planted between could replace the old. As this is written, there are partisans for and against the system. Some things are very-evident to those who have been studying it. The spacing between 'hedges', to be sufficiently wide to allow of replanting for rotation purposes, will need to be much wider than that now recommended. Diseases are very serious when they once gain entrance to a hedge, and being in full sun does not control these troubles. The trees handled in this fashion are very susceptible to minor-element deficiencies and quickly show lack of potash and nitrogen. Judging from the past, this may not become a standard practice, although it might have some special adaptability. Certain varieties may do well if used in this way. It may be studied further with development of newer varieties and more knowledge of disease and pest control. There would be required better minor-element and fertilizing practices, intensive disease control, use of insecticides, methods of arresting soil degradation, and much better information on everything, including the pruning measures to be used.

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TILLAGE, WEEDS, AND MULCH

COFFEE plantations are kept in any number of different manners, depending upon circumstances. They may vary from intensively managed orchards or well-tilled, groomed, and carefully harvested gardens, to primitive growths resembling jungles. In travelling through old coffee-growing districts in numerous countries in which there had been abandonment of planting, I have been impressed with the fact that the old trees that were still living were the ones most often with shade or the protection of a moderate growth of broad-leafed bush or weeds about them. The parts of plantations from which living coffee first disappeared always seemed to be those where grass developed thickly.

CLEAN TILLAGE AND GRASS PROBLEMS

For the most part, sun and grasses appear to be the most serious enemies of untended coffee. For example, in Central America, the Bahama grass, also called Bermuda grass, *Cynodon dactylon* Pers., becomes serious in coffee grown in the sun, and one of the worst grass menaces to coffee fincas is the Grama, *Paspalum fasciculatum* Willd., which is found over much of the region. In Africa, workers such as Wakefield (1933), A. S. Thomas (1944), and the Kenya Coffee Board (1945) point out the danger in coffee plantings or shambas of the dreaded couch-grass, *Digitaria scalarum* (Schweinf.) Chiov. This is hated over much of Africa but is especially bad in the east and central parts of the continent.

Bad effects of grasses were given serious analytical study by Pereira & Jones (1950) who reported the drastic reduction in coffee growth that resulted from such weed competition. Pendleton (1955) has discussed how heavy growth of grass accompanied and followed degradation of coffee areas in Brazil. Numerous others have observed this. Grasses are also recognized as of serious damaging effect on coffee in India, Java, and the Philippines. In Ceylon, coffee was a vigorously growing crop for more than a century when the rust disease struck. As soon as the trees were weakened and economics were such that it was impossible to carry on proper tillage, grasses came in. They further strangled the languishing coffee and the final result is now observable as wellnigh uncultivable land, sterile for crops, with wiry grasses crowded on it. In Angola, I was told that grasses were practically death to coffee trees.