SELECTION OF ARABICA COFFEE TYPES RESISTANT TO COFFEE BERRY DISEASE IN ETHIOPIA

N. A. VAN DER GRAAFF

633.73:631.524.86:632.4(63)

N. A. VAN DER GRAAFF

SELECTION OF ARABICA COFFEE TYPES RESISTANT TO COFFEE BERRY DISEASE IN ETHIOPIA

Proefschrift
ter verkrijging van de graad
van doctor in de landbouwwetenschappen,
op gezag van de rector-magnificus,
dr. H. C. van der Plas,
hoogleraar in de organische scheikunde,
in het openbaar te verdedigen
op donderdag 11 juni 1981
des namiddags te vier uur in de aula
van de Landbouwhogeschool te Wageningen

H. VEENMAN & ZONEN B.V. – WAGENINGEN – 1981

STELLINGEN

1.

'Onbelangrijke' ziekten zijn de sleutel tot het begrip van resistentie met een langdurige gebruikswaarde (duurzaamheid).

2.

Daar er veel meer 'onbelangrijke' dan 'belangrijke' planteziekten zijn mag aangenomen worden dat duurzame resistentie regel is.

3.

Een goed voorbeeld van duurzame resistentie is de resistentie van *Coffea arabica* tegen *Cercospora coffeicola*.

Dit proefschrift.

4.

In de berekening van LUKE et al. ter bepaling van het aantal genen voor horizontale resistentie in haver ten opzichte van *Puccinia coronata* zijn de variaties veroorzaakt door genotype en door de omgeving niet additief.

LUKE, H. H., BARNETT, R. D. and PFAHLER, P. L., 1975. Inheritance of horizontal resistance to crown rust in oats. Phytopathology **65**, 631–632.

5.

Het kan niet uitgesloten worden dat de door HADLEY et al. gevonden interacties tussen isolaten van *Cylindrocladium crotalariae* en aardnoot variëteiten veroorzaakt worden door schaal-effecten.

HADLEY, B. A., BEUTE, M. K. and LEONARD, K. J., 1979. Variability of *Cylindrocladium crotalariae* response to resistant host plant selection pressure in peanut. Phytopathology **69**, 1112–1114.

6.

'Directed selection' kan geen 'overtollige' virulentiegenen uit een pathogeenpopulatie verwijderen: het succes van het door CRILL and KUSH (1979) voorgestelde rotatieschema van resistentiegenen voor de beheersing van *Pyricularia oryzae* op rijst is uitsluitend afhankelijk van de effecten van 'stabilizing selection'.

CRILL, J. P. and KUSH, G. S., 1979. Effective and stable control of rice blast with monogenic resistance. Food and Fertilizer Technology Center Taiwan, Extension Bulletin no. 128, 13 pp.

7.

Hypothenemus hampei is een belangrijke plaag in veel koffieteeltgebieden. In dit verband dienen de redenen voor de zeldzaamheid van dit insekt in Ethiopië verder onderzocht te worden.

8.

In de bepalingen van oogstverliezen door ziekte worden, ten onrechte, de ziektewaarnemingen als foutenbron verwaarloosd.

JAMES, W. C. and TENG, P. S., 1979. The quantification of production constraints associated with plant diseases. In: Coaker, T. H. (Ed.) Applied Biology, Vol. IV, 201–267, Academic Press, London.
SNEDECOR, G. W. and COCHRAN, W. G., 1967. Statistical methods. Iowa State University Press, 593 pp.

9.

Het 'horizontale' karakter van een resistentie is onbewijsbaar.

10.

De verbouw van tarwe in nieuwe teeltgebieden is eerder het gevolg van eetgewoontes veranderend onder westerse invloeden dan van landbouwkundige overwegingen.

Stellingen bij het proefschrift van N. A. VAN DER GRAAFF.
Selection of Arabica coffee types resistant to Coffee Berry Disease in Ethiopia.

Wageningen, 11 juni 1981

FREE DESCRIPTORS

/ Coffea arabica / Ethiopia / coffee research / habitus / origin /
/ cultivation / horizontal resistance / vertical resistance /
/ host-parasite interactions / Coffee Berry Disease / symptoms /
/ epidemiology / geographic distribution / origin / control / resistance /
/ selection for resistance / field observations / field inoculation tests /
/ seedling inoculation tests / berry counts / detached berry tests /
/ selection thresholds / nature of resistance / multilocation trials /
/ Reaction of coffee types to / leaf rust / leaf blight / leaf miner /
/ tracheomycosis / brown eye spot. / Yield / quality / selection thresholds /

ABSTRACT

Descriptive part. A review is given of: the importance of *Coffea arabica* to Ethiopia; coffee research; habitus, origin and cultivation of *C. arabica*; theoretical aspects of resistance and its implications for the system *C. arabica*-parasites; Coffee Berry Disease, symptoms, epidemiology, geographic distribution, origin, resistance to CBD, chemical control and control through resistance.

Experimental part. Coffee trees (mother trees) were selected that showed a low level of CBD in areas with severe disease. The resistance of these trees was appraised through field observations, field inoculation tests, and seedling inoculation tests. Correlations were determined between field observations and tests. Selection thresholds were determined and their adequacy was assessed through longer term observation of the mother trees. Progenies of mother trees were planted in a heavy CBD area; the CBD resistance of the progenies was reassessed through disease estimates and berry counts in the field, and detached berry tests. The correlations between observations and tests were determined as well as selection tresholds for seed distribution to farmers.

The nature of CBD resistance was discussed and additional experiments were made on: the rôle of the cuticle, variation in resistance within and between single-tree progenies, and interactions between host and pathogen. It was concluded that resistance was most likely horizontal. In multilocation trials, differences were found between coffee types with regard to leaf rust, leaf blight and blotch leaf miner. Disease and pest severity were related to provenance of the mother trees. Progenies were found to differ in resistance to tracheomycosis. Through field observations on differences in resistance it was possible to determine indirectly that all progenies possessed adequate resistance to brown eye spot. A final evaluation of the programme is presented.

CONTENTS

1. COFFEE IN ETHIOPIA

1.1. IMPORTANCE OF COFFEE TO ETHIOPIA

Coffee is one of the major products of Ethiopian agriculture, and coffee export is a major source of foreign currency (Fig. 1). *Coffea arabica* L. is, apart from some recently introduced robusta coffee, the only coffee species present in the country. The crop is grown in all provinces of the country but the major production areas are located in the western and southwestern highlands. A separate cultivation zone exists in Harerge administrative region (Fig. 2).

The coffee in Ethiopia is grown under four different systems (INSTITUTE OF AGRICULTURAL RESEARCH, JIMMA RESEARCH STATION, 1971):

- Forest coffee (60%), which is sometimes referred to as 'wild' coffee, but exploited for many years: self sown seedlings have been transplanted to give an irregular, but dominant understorey in the forest, which itself is secondary; the forest is sometimes thinned.
- Small holder coffee (37%): Plots of varying sizes around dwellings.
- Semi plantation coffee in the forest: Seedlings raised in nurseries and planted, more or less regularly, in thinned forest.
- Plantation coffee: Plantations established on previously cleared land: seedlings raised in nurseries and regularly planted; shade trees often planted.

The authors cited in the following paragraphs used comparable, but undefined, categories.

A coffee survey project, aiming, among other objectives, at the determination of the area under coffee and the potential production, was carried out from 1972 to 1977. Data were presented by BOEREE (1976). He stated that coffee in Ethiopia is a small holders' crop. Coffee farms are predominantly small with a national average of 1.5. ha of cultivated land per farm and 0.5 ha of coffee per farm. The number of coffee farmers was estimated at 650,000 in 1975. This picture will, however, have changed considerably following the land reform of 1975. According to BOEREE, large coffee plantations occur mostly in Kefa and Sidamo. Semi-

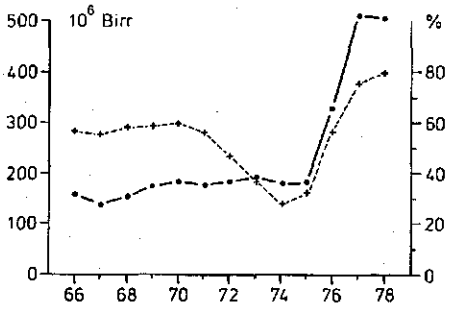


FIG. 1. Value of coffee exported by Ethiopia (solid line; left ordinate) and value of coffee export as a percentage of total export of the country (broken line; right ordinate). Sources: STATISTICAL OFFICE, 1963–1977.

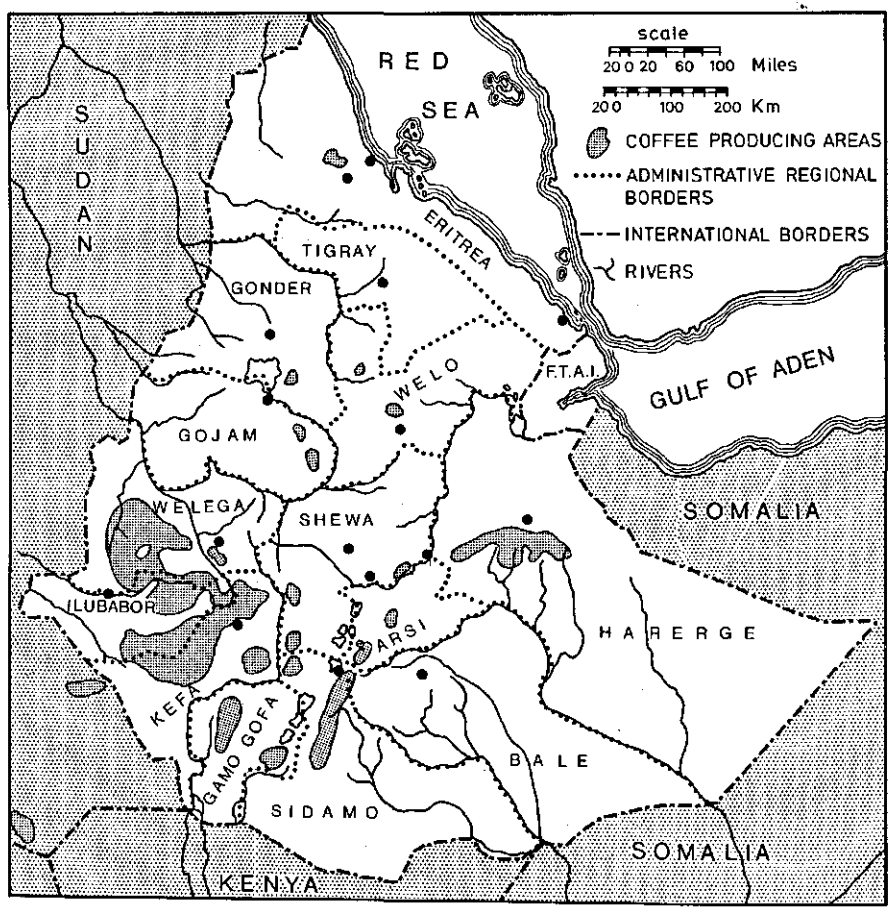


FIG. 2. Major coffee producing regions in Ethiopia. The Boma plateau, where *C. arabica* occurs, and the Imatong mountains (SE Sudan), where *C. canephora* and *C. stenophylla* are found, are also indicated.

wild 'forest' coffee mainly occurs in Kefa and Ilubabor. Large plantations became state owned after the 1974 revolution.

Estimates on area covered by coffee vary widely. The estimates presented in the yearly bulletins of the CENTRAL STATISTICS OFFICE (1963–1977) vary from 433,300 ha in 1960/61 to 626,000 ha in 1971/72; the yearly bulletins miss estimates since 1971/72. Using production estimates, CHOKKANNA (1970) calculated the area covered by large farms at 16,667 ha, and the area covered by small farms at 763,158 ha. BOEREE (1976) estimated the number of small farmers at 650,000, each with an average of 0.5 ha under coffee. This would indicate an area of ± 325,000 ha of small holders' coffee. BOEREE states in his report: 'The total area under coffee in Ethiopia may be estimated at 400,000 ha. Of this about 90 percent belongs to the household sector, 3 percent is made up of large plantations

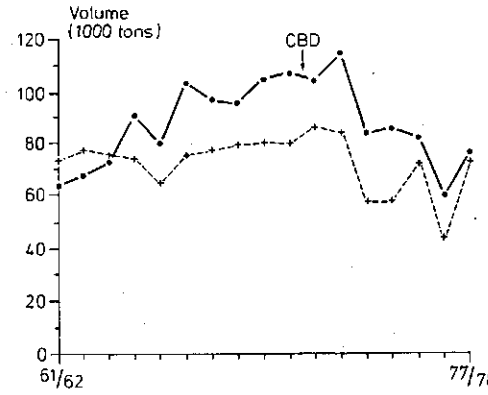


FIG. 3. Coffee arrivals at Addis Ababa and coffee exports from Ethiopia. Arrivals exclude coffee from Harerge, which is exported through Dire Dawa. Note the drop in arrivals and exports after the discovery of CBD (1971). Sources: COFFEE AND TEA DEVELOPMENT AND MARKETING AUTHORITY, 1977; INTERNATIONAL COFFEE ORGANIZATION, 1979.

(especially located in Kefa and Sidamo), and the balance (about 50,000 ha) consists of wild coffee (especially located in Ilubalor and Kefa).'

Production per hectare was reported to vary between 230 and 300 kg clean coffee in the period 1960–1972. (CENTRAL STATISTICS OFFICE, 1963–1977). BOEREE (1976), using data from the coffee survey project, mentions an average of 450 kg ha^{-1}, varying from 250 kg. ha^{-1} in Ilubator to 650 kg. ha^{-1} in Harerge. He assumes the yield of semi-wild forest coffee to be 100 kg. ha^{-1}. Estimates of total production vary widely. Production estimates published in the yearly bulletins of the CENTRAL STATISTICS OFFICE (1963–1977) gradually increased from 130,000 to 180,000 metric tons (MT) in the years 1961 through 1972. Further estimates were: 1972/73: 166,000; 1973/74: 137,000; 1974/75: not available; 1975/76: 178,600; 1976/77: 193,000 MT. According to a recalculation of BOEREE's data on area covered by coffee and on production level, the yield cannot have exceeded 165,000 MT in 1976. The only reliable production statistics available are the export figures and the data on coffee arrivals at Addis Ababa. A considerable increase of exports occurred between 1954 and 1965; this can mainly be attributed to an increase in transport facilities. For the period 1961/62 to 1977/78, exports and arrivals at Addis Ababa from the south and southwestern provinces are shown in Figure 3. The dramatic drop in arrivals after 1973 reflects the drought in 1972 and the yield reduction due to CBD afterwards. (Political changes might also have influenced the data). Data on yield reductions are further discussed in Section 1.3.2.

1.2. COFFEE RESEARCH

Some research efforts were made at the Jimma Agricultural and Technical School in the nineteen fifties and sixties. The Food and Agricultural Organization of the United Nations (FAO) provided a production expert from 1952 to 1958. However, major research efforts began only when the Institute of Agricul-

tural Research (IAR) established a research station at Jima (Kefa).

The IAR was founded with the aid of a United Nations Development Programme/Special Fund (UNDP/SF) project which became operational in February 1966. The project has been executed by FAO in close cooperation with the Ethiopian Government. The project was extended in 1971, 1974 and 1979. The Institute has as its main purposes 'the formation of a national research policy conceived within the framework of overall national development planning and the implementation of such policy through applied research programmes' and the ultimate objective is 'to help service, through proper research under local conditions, Ethiopian programmes aiming at agricultural self-sufficiency and an increased volume and variety of agricultural products.' (ANONYMOUS, 1975).

The Jimma Research Station is one of the research stations of the IAR. The Station began its operations in 1968 but most of the land was only acquired in 1970. Substations have been established in the major coffee growing areas of the country. The UNDP/SF arrangement provided for expatriate staff: a coffee processing officer from 1966 to 1971, a coffee agronomist/breeder from 1963 to date (December 1979), and part time services of an entomologist from one of the other IAR stations. The services of a plant pathologist were deemed necessary to solve the Coffee Berry Disease (CBD) problem. A plant pathologist is in post since January 1973. An associate expert was assigned to work with the plant pathologist during 1974 and from October 1975 to October 1978. The UNDP/SF also provides scholarships for counterpart staff; with respect to coffee research, a plant breeder, an agronomist and a pathologist have been trained abroad; a further agronomist is under training, and two pathologists and an entomologist will receive scholarships soon. In addition, short training courses are granted. Part of the equipment and machinery have been supplied with UNDP funds.

Funding for Ethiopian staff and operational costs are, in the case of coffee research, provided by the National Coffee Board of Ethiopia (The name changed later to Coffee and Tea Development and Marketing Authority and is at present Ministry of Coffee and Tea Development. The name CTDMA will be used throughout the study). Money is raised as part of the normal budget of the CTDMA through coffee levies and as special funding through foreign aid projects. The total budget for coffee research was probably close to 1,000,000 Birr per year (1 US $ $\approx$ 2.05 Birr) in the late nineteen seventies.

Coffee research priorities are always determined in close cooperation between CTDMA and IAR and research results are directly used by the extension service of the CTDMA. Coffee research originally aimed at the improvement of existing coffee and at the selection of new coffee types. Activities consisted of studies to define optimal management for both forest and plantation coffee, weed control, shade tree identification and observations, processing studies to improve the rather poor quality of Ethiopian coffees, and a limited amount of entomological and pathological studies. After the identification of CBD in 1971 and its subsequent spread to all major coffee areas, the emphasis of the research gradually

shifted to the control of the disease. In particular, the development of resistant cultivars gained first priority.

1.3. Coffee Berry Disease

CBD is and anthracnose of green coffee berries caused by *Colletotrichum coffeanum* Noack sensu Hindorf (Hindorf, 1973). The disease has been extensively studied in Kenya (See Chapter 3).

1.3.1. *First reports and subsequent spread in Ethiopia*

CBD was first observed in Ethiopia in 1971 (Mulinge, 1973). The disease had probably been present for some years before it was discovered. In 1971, the disease was found at Wondo Genet (Sidamo), Gore (Ilubabor), and near Agaro (Kefa). A separate outbreak occurred at Washi and Wush-Wush near Bonga (Kefa) in 1972. All of the south and southwestern coffee growing areas were probably infected about 1975, with the possible exclusion of some locations in Gamu-Gofa. In 1978, the disease was identified in the coffee growing region of Harerge.

1.3.2. *Yield reductions due to CBD*

With the spread of the disease came the recognition that it wrought disaster. Nearly total yield losses occurred in many locations. The CTDMA makes annual surveys of the reduction in yield since 1974, overall loss estimates vary between 17 and 19 % of the yield (Coffee and Tea Development and Marketing Authority, 1979). Arrivals at Addis Ababa have dropped dramatically since 1973 (Fig. 3). The low figure for 1973 might be due to the irregular and low rainfall in 1972. When the data of 1974 to 1978 are compared to the data of 1968 to 1972, an average decline of 28 % in the arrivals at Addis Ababa can be observed. The data for the individual administrative regions are: Ilubabor 37 %: Kefa 29 %; Sidamo 16 %; Welega 38 %; Shewa 29 %. The small amount of coffee that arrived from Gamu-Gofa showed an increase of 7 % over the same period. The exports declined an averaged 22 % over the period mentioned. Alarmed by this decline, the Ethiopian authorities started an action programme in 1978 to limit the domestic use of coffee and thus to increase the proportion of the crop available for export. According to well informed sources, this programme was increased in 1979.

1.3.3. *Control of CBD*

Immediate actions were considered to reduce the impact of the high yield losses encountered in the coffee areas that were attacked by the disease and the further losses that were anticipated. Chemical control trials began in 1972. In the trials, control was satisfactory. However, the cultivation system of coffee in Ethiopia and the costs of chemical control limit the possibilities for implementation (Institute of Agricultural Research, 1972, 1973, 1974, 1978).

More scope existed for the control of Coffee Berry Disease through the deployment of resistance. The Arabica coffee in Ethiopia is diverse and variations in susceptibility were obvious from the first disease outbreaks. In 1973, a major research programme was formulated to exploit the observed resistance to CBD. The immediate objective of this programme was to produce, in the shortest time possible, *C. arabica* types (For the use of the term coffee type refer to Section 2.5.2.3.), that possess an adequate level of resistance to CBD, sufficient resistance to other diseases and pests, and a reasonable yield and quality potential; the effectiveness of the respective resistances has to be durable. The long term objective was to produce a series of new coffee cultivars with known levels of disease and pest resistance, good adaptability and yield and quality potential, which could gradually replace the existing coffee population and thus permit modernization of coffee cultivation.

1.4. Scope of this publication

This publication describes the execution of the research programme to obtain coffee types which possess durable resistance to CBD, adequate resistance to other diseases and pests, and a reasonable yield and quality potential. The author joined this programme in early 1974 and was in charge of the phytopathology part from 1 January 1975 to 30 October 1978. As a consultant, he designed the research programme for 1979 and appraised its results.

1.5. Conclusions

- In recent years, coffee has been the principal source of foreign currency to Ethiopia.
- The total area under coffee in Ethiopia is not well determined; the best estimate is probably 400,000 ha.
- Production per unit area is low, and reliable data on total production are unavailable.
- Coffee Berry Disease caused a major decline in coffee production in Ethiopia. Due to the character of Ethiopian coffee production, only a very limited scope existed for immediate remedial action.

2. COFFEA ARABICA

2.1 HABITUS

Coffea arabica is a shrub or a small tree. If untended, it may reach a size of 4 to 5 metres. The plant has a dimorphic habit of branching: orthotropic branches form plagiotropic branches, which bear the flowers and fruits in clusters. The leaves are persistent. Flower buds are initiated at the end of the rainy season and during the dry season. Flowering occurs in Ethiopia some 10 days after heavy showers in January, February or early March. The berries ripen during September to December.

2.2. TAXONOMY

C. arabica is part of the section *Eucoffea* Chev., sub-section *Erythrocoffea* Chev. (CHEVALIER, 1947). Other species in this section are: *C. canephora*, *C. congensis*, and probably *C. eugenioides* (CHEVALIER, 1947).

C. canephora grows in tropical lowlands and, occasionally, up to 1,400 m. The species occurs from southern Sudan and Uganda in the north-east of Africa to Guinea in the west and to Angola in the south. *C. congensis* is a coffee species of tropical lowlands, occurring in the Nile and Congo basins, often in waterlogged areas. *C. eugenioides* occurs in East Africa from southern Sudan to Zambia. Its western limit is eastern Congo. The species occurs mainly between 1,600 and 2,400 metres.

Coffea arabica grows in Ethiopia at altitudes between 1,100 and 2,100 metres. It is also present on the Boma plateau in southern Sudan (THOMAS, 1942) and there is a report of its occurrence in the Azza forest, west of the Nile in southern Sudan (ANDREWS, undated). It is also reported to grow wild at Mount Marsabit in Northern Kenya (BERTHAUD et al., 1980). *Coffea arabica* is the only tetraploid species known in the genus *Coffea*, and is also the only representative of the genus which is self-fertile. *C. arabica* is geographically separated from its diploid relatives, a condition which is not unknown for tetraploids. The only area where overlap is reported is from Azza forest in southern Sudan, west of the Nile where *C. canephora*, *C. eugenioides* and *C. arabica* all occur (ANDREWS, undated, MEYERS cited in TOTHILL, 1954). This *C. arabica* would, however, be completely isolated from other populations; its occurrence has to be confirmed and its 'wild' nature has to be ascertained. *C. canephora* further occurs in the Imatong mountains (CHIPPS, 1929), some 250 km south-west of the Boma plateau (*C. stenophylla* also occurs at that location).

2.3. Speculations on the origin of *C. Arabica*

There have been many speculations that *Coffea arabica* was an allo-tetraploid. Doughty (undated) indicated that a cross between *C. excelsa* and *C. eugenioides* resembled *C. arabica*. Monaco and Carvalho (1964, cited by Monaco, 1968) indicated that *C. arabica* may be the result of a cross between *C. eugenioides* and *C. canephora*. Narashimhaswamy (1962, cited by Monaco, 1968) indicated that *C. arabica* might have resulted from a cross between *C. liberica* and *C. eugenioides*. Robinson (1976) speculated that *C. arabica* was formed through hybridization of *C. eugenioides* and *C. canephora* in historical times ($\pm$ 600) in Uganda and that the hybrid was taken to Ethiopia.

Monaco (1968) and Carvalho et al. (1969) stated, however, that little evidence exists on the nature of the polyploidy of *C. arabica*. Narashimhaswamy (1968) quotes the hypothesis of Hille Ris Lambers that *C. arabica*, *C. congensis* and *C. eugenioides* may have come from an original ancestor.

Based on cytological studies, Grassias and Kammacher (1975) concluded that *C. arabica* was a segmental allotetraploid. Louarn (1976) reported on crosses between *C. eugenioides* and *C. canephora*. Based on fertility rates in the F_1 and F_2, he concluded that *C. eugenioides* and *C. canephora* were not differentiated very much, the differentiation between both species being not more than between cultivated plants and their wild progenitors. He also indicated that observations on the level of differentiation between the genomes of *C. eugenioïdes*, *C. canephora* and the complex *liberico-excelsioides* contradicts the hypothesis of an allotetraploid origin of *C. arabica* as an association of the genomes of *C. eugenioides* with genomes of either *C. canephora* or *liberico-excelsioides*. The base genome present in these three taxonomic units can also be found in *C. arabica*.

The geographical distribution of the four species in the section *Erythrocoffea* might indicate a common ancestor from which a diversification occurred into a species adapted to tropical lowland and medium altitudes *(C. canephora)*, a species adapted to very special ecological conditions *(C. congensis)*, and two tropical mountain species, the tetraploid *C. arabica* in the north and the diploid *C. eugenioides* in the south. Geographical isolation between *C. arabica* and *C. eugenioides*, and between *C. canephora* and the two mountain species can easily explain species formation. The present existing overlap of species, as occurring in southern Sudan and Uganda (Thomas, 1944), might be more recent.

2.4. The occurrence of Arabica coffee in Ethiopia

Coffea arabica is the only representative of the genus *Coffea* in Ethiopia apart from some recently introduced *C. canephora* near Mizan Teferi. Practically all coffee appears to be under some form of cultivation.

Whether Arabica coffee forms a natural part of the rain forest in southwestern Ethiopia is difficult to decide. No forest exists which has not been interfered with

by man at one stage or another. The subject has been extensively discussed by CHEVALIER (1929), VON STRENGE (1956), MEYER (1965, 1968),NARASHIMHASWAMY (1968), and SYLVAIN (1955, 1958).

2.5. CULTIVATED COFFEE

2.5.1. *The origin of coffee cultivation in Ethiopia*

The origin of the coffee culture within Ethiopia might be in the old Kingdom of Kefa (CHEVALIER, 1929; SYLVAIN, 1955). However, little documentation exists and, unfortunately, in earlier centuries the area was closed to exploration. Coffee trees can be found in the present forests of the old Kingdom of Kefa together with remainders of the times when the area was much more densely populated, such as Euphorbia trees used for fencing, and grinding stones (SYLVAIN, 1955; VON STRENGE, 1956). The population dwindled considerably when the Kingdom was conquered by Emperor Menelik in 1896. The existence of this coffee indicates that it was a traditional crop in Kefa. In other areas of Ethiopia coffee culture is often fairly recent or has expanded recently, as in Welega (GILKES, 1975), Agaro (SYLVAIN, 1958), and probably Ilubabor.

2.5.2. *Present coffee cultivation*

2.5.2.1. Cultivation zone. Arabica coffee grows in many areas of Ethiopia (Fig. 2). The main cultivation is limited to the southern and southwestern zones. A separate cultivation area exists in Harerge. The coffee production there is, however, declining.

Arabica coffee grows at elevations as high as 2,100 metres and as low as 1,200 metres on the western escarpment of the highlands (Tepi). The upper limit of distribution is determined by the occurrence of frost.

Rainfall in the administrative regions of Kefa, Ilubabor, and Welega is well distributed, with a rainy season starting in March and extending to September/October. November, December, January, and February are dry months but not completely without rain. In Sidamo, the pattern differs with rainfall in October and November. In Harerge, rainfall follows the same pattern as in the south-west, but the amount of rain varies from 1291 mm/year in the west to 594 mm/year in the town of Harer. Rainfall data are presented in Table 1.

Average monthly temperatures in the cultivation zone are presented for a few selected areas in Table 2. Temperature fluctuates widely between day and night in the dry season and in the relatively higher coffee areas freezing temperatures sometimes occur in the early mornings. Temperature fluctuations are much less in the rainy season. For Jima, maximum and minimum temperatures per month are presented in Figure 4. The climates in which coffee grows vary from Thornthwaite's per-humid (Gore in Ilubabor) to humid (most locations) and sub-humid (Harerge, locations in Sidamo) (GAMACHU, 1977).

Coffee is generally grown on deep reddish-brown clay soils, which are derived from volcanic outflows and are slightly acid with Ph values from 4.5 to 6.

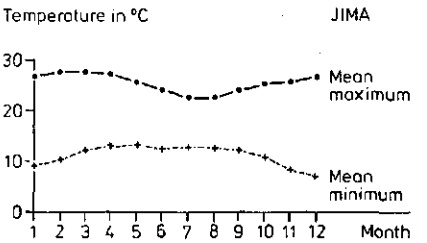
TABLE 1. Average monthly rainfall in coffee growing regions of Ethiopia. Source of data: GAMACHU (1977); INSTITUTE OF AGRICULTURAL RESEARCH, JIMMA RESEARCH STATION (1978); GOVERNMENT OF ETHIOPIA, NATIONAL COFFEE BOARD (1975).

Administrative region:	Kefa				Ilubabor		Sidamo	Harerge	
Locations:	Agaro	Jima	Bonga	Gera	Metu	Gore	Dila	Harer	Gelemso
Latitude N	7.5	7.4	7.2	7.7	8.2	8.1	6.3	9.3	8.5
Longitude E	36.4	36.5	36.2	36.2	35.4	33.2	38.2	42.1	4.4
Altitude in m	1600	1730	1730	1900	1550	2002	1635	1856	1842
Observation period	n.a.	68–77	n.a.	76–77	76–77	n.a.	n.a.	n.a.	n.a.
January	39	36	57	45	9	40	81	8	28
February	31	60	67	104	45	47	12	12	29
March	90	103	148	145	135	111	132	33	77
April	103	101	174	105	26	137	150	106	199
May	159	179	244	301	226	260	134	49	108
June	224	205	198	297	472	417	137	52	129
July	234	234	176	253	330	334	92	75	234
August	274	230	182	282	109	333	145	157	164
September	209	193	189	206	269	227	184	79	184
October	123	110	143	136	176	192	207	20	69
November	33	55	56	77	39	97	45	4	51
December	32	24	47	43	62	75	34	1	19
Total	1551	1528	1690	2007	1899	2369	1353	594	1291

TABLE 2. Average monthly temperatures of some locations in coffee growing regions. Source: GAMACHU (1977).

Administrative region:	Kefa			Ilubabor	Sidamo	Harerge
Location:	Agaro	Jima	Bonga	Gore	Dila	Harer
January	20.2	18.2	20.3	19.1	21.3	18.5
February	21.3	19.4	21.9	20.0	20.9	19.8
March	21.7	20.2	21.7	20.1	21.5	20.5
April	22.2	20.0	21.5	19.2	20.7	20.0
May	22.3	19.5	20.8	18.3	18.6	20.2
June	22.1	18.7	20.0	17.0	17.9	18.9
July	19.8	17.4	19.3	16.3	17.8	18.2
August	19.5	17.5	17.6	16.6	17.3	18.0
September	20.4	18.1	20.5	17.0	17.9	18.4
October	19.3	18.0	20.6	17.7	17.4	18.6
November	19.0	16.9	20.8	18.4	17.4	18.6
December	18.5	17.2	20.2	18.5	18.3	18.1

FIG. 4. Monthly maximum (solid line) and monthly minimum temperature (broken line) at Jimma Research Station over the period 1969–1977.
Sources: INSTITUTE OF AGRICULTURAL RESEARCH, JIMMA RESEARCH STATION, 1978.



2.5.2.2. Cultivation methods. Forest and plantation coffee (see Section 1.1.) is grown under heavy shade. This type of coffee predominates in the western administrative regions. In Sidamo, shade is often absent or provided by the false banana *(Ensete ventriculosa)*. Coffee in Harerge is mostly unshaded. The coffee in Harerge and Sidamo can chiefly be classified as garden coffee.

Planting, if needed, was formerly done with spontaneous seedlings which were pulled out and planted in a hole made with a stick. Seedlings were also bought from traders who carried them bare-rooted by donkey.

Tree density varies considerably. BOEREE (1976) mentions 2,000 trees per ha for Harerge, 2,000 to 3,000 for Sidamo, and 6,000 to 8,000 trees per ha for Kefa and southwestern Welega, while in Ilubabor densities often exceed 8,000 trees per ha. Spacing in the southwestern areas is irregular. In Harerge and parts of Sidamo, terracing is practiced and trees are often regularly spaced.

Coffee in Ethiopia is never pruned. In the western areas, it is normal to weed only at the start of the picking season. Intercropping is often practised in Sidamo. Intercrops used are the false banana (*Ensete ventriculosa*); banana; annuals such as sorghum, beans, barley, maize, and rootcrops like taro. Practices in Harer are not familiar to the author. The crop is often picked only once and green, ripe, and overripe cherries are stripped off. The berries are sun dried, often on the ground. Improved practices such as drying on concrete and 'wet processing' are being gradually adopted.

2.5.2.3. Within-species diversity. In contrast to Arabica coffee in other countries, a high level of genetical variability is present in Ethiopia. Variability exists within locations but also between regions. For example, it can be concluded from RAMA MURTHY's data (1968) that the ratios of trees with different leaf tip colour varies between locations. The coffee from Harerge is relatively uniform and it is distinct from the types from Sidamo and the southwestern provinces. SYLVAIN (1958) stated that the Harerge coffee is probably a reintroduction from Yemen. Whatever the case may be, a fair level of variability is found within the Harerge population.

Classification of Ethiopian coffee in any of the subdivisions made in *C. arabica* is difficult and has little practical value. Fairly homogeneous and identifiable populations are indicated by the neutral term 'coffee type' in this publication. The high level of variability in the *C. arabica* population designates Ethiopia as

the gene centre and probably the centre of origin for the species (ZEVEN and ZUKOVSKY, 1975).

2.6. THE RELATION BETWEEN *C. ARABICA* AND ITS PARASITES BEFORE THE INTRODUCTION OF CBD

To describe the relation between *C. arabica* and its parasites, it is necessary to devote a section to theoretical considerations on plant-parasite systems. In Section 2.6.2., the practical implications for *C. arabica* are described.

2.6.1. *Theoretical considerations*

In the plant-parasite relationship, different types of resistance may play a rôle and, therefore, they are briefly described. The definitions are based on ROBINSON (1976) and VAN DER PLANK (1963, 1968, 1975). In the definitions, resistance is considered to be a genetical characteristic that gives a certain level of protection against a component of a parasitic species. As such, it is a permanent trait. Its effectiveness to control disease or injury is determined by the viability of genotypes of the parasite that can compensate for the resistance.

2.6.1.1. Vertical resistance – prevents or reduces disease or injury caused by certain components of a parasite population but does not protect against others. This type of resistance is always governed by a gene-for-gene relationship. The action of a gene for resistance in the host is matched by the action of a gene for parasitic ability in the parasite which nullifies the operation of the resistance. Qualitative or complete vertical resistance, when operative, gives full protection while quantitative or incomplete vertical resistance gives incomplete protection.

2.6.1.2. Horizontal resistance – is quantitative and protects against the whole spectrum of genotypes of a parasite. Certain genotypes of the parasite may cause more disease or injury than others. If host genotypes with different levels of horizontal resistance are studied, the afore mentioned genotypes of the parasite cause a higher disease or injury level to all host genotypes. Thus, the ranking of host genotypes according to the level of disease or injury caused by a specific genotype of the parasite will not change if tested with another genotype of the same parasite ('constant ranking'). The inheritance of horizontal resistance is supposed to be oligogenic or polygenic.

2.6.1.3. Vertical parasitic ability – complements vertical resistance. Genotypes of the parasite with a specific vertical parasitic ability can cause disease or injury to a component of the host population but not or not so much to other parts. Genotypes that differ in vertical parasitic ability can attack different components of the host population.

2.6.1.4. Horizontal parasitic ability – complements horizontal resis-

tance. A genotype of the parasite with a certain level of horizontal parasitic ability can cause a certain level of disease or injury to a host genotype. On the same host genotype, a genotype of the parasite with a different horizontal parasitic ability will cause another level of disease or injury. When disease or injury levels are compared on host genotypes with different levels of horizontal resistance, the ranking of the host genotypes remains the same.

2.6.1.5. The vertical host-parasite system. In wild parasite-host systems and in primitive agriculture, vertical resistance is probably operative through the multiline effect: different vertical genotypes are present in the host and parasite populations, and non-matching between host and parasite reduces colonization of, or injury to, the host. The resistance, thus, reduces the redistribution of the parasite. In the case of diseases and parasitic weeds, the available number of infective propagules, and thus the chance of infection from plant to plant, limits the increase of the parasite population. In the case of colonizing insects (for example aphids), the available number of migratory individuals, and thus the chance on the formation of new colonies, may limit the increase of the parasite population. Such constraints occur, for example, after a 'dead season', when the parasitic population is at a minimum. For insects that migrate from plant to plant, the distance between susceptible plants probably is the limiting factor at a certain stage of development.

A multiline system can only be stable if the accumulation of genes conferring vertical resistance and that of genes giving vertical parasitic ability present a selective disadvantage through negative pleiotropic effects of these genes. Thus, the frequency of genes for vertical resistance in the host will tend to diminish in absence of the parasite while, in the absence of genes for vertical resistance, the matching genes of the parasite tend to disappear (stabilizing selection, VAN DER PLANK 1963, 1968, 1975). The selective disadvantages and the mutation rates of the 'vertical' genes and their alleles determine the allele ratios in host and parasite. The selective disadvantages of resistance genes may be ecologically determined and result in different allele ratios under varying ecological conditions.

The absence of particular vertical host genotypes and the resulting low frequency of the matching genotypes of the parasite is used in modern agriculture to protect a crop for a number of years by means of vertical resistance. The scarcity of matching genotypes of the parasite and the possibilities for compensation for negative pleitropic effects will largely determine the longevity of the resistance. In rare cases, the negative pleiotropic effects of the parasite cannot be compensated for and the resistance is then permanent. ('frozen' vertical resistance; ROBINSON, 1976).

The role of incomplete vertical resistance is less understood. ROBINSON (1976) considers it as an artefact of agriculture: under natural conditions, horizontal resistance may reinforce incomplete vertical resistance to a complete level.

2.6.1.6. The horizontal host-parasite system: resistance models.

Horizontal resistance reduces the development of the parasite population through a reduction of the effectiveness of parasitism. This, in the case of diseases, may occur through the reduction of conidial germination or penetration of the cuticle; the extension of the latent period; and the reduction of sporulation. In the case of animal pests, it may reduce the growth rate, prolong the reproduction cycle, or reduce fertility.

The efficacy of a particular level of horizontal resistance depends on the variability of the horizontal parasitic ability and on the variability of ecological conditions such as climate and cultivation practices.

A prerequisite for the operation of a horizontal host-parasite system is that pleiotropic effects of genes for increased horizontal parasitic ability will determine the upper limit of horizontal parasitic ability. Pleiotropic effects of the accumulation of resistance genes will probably reduce the fitness of the host. In agriculture, these fitness reductions might be unimportant or it might be possible to overcome them. The resistance can thus be 'domesticated'.

Changes in ecological conditions may influence the conditions for disease development and the level of maximum horizontal parasitic ability as the selective disadvantage of the pleiotropic effects might vary between environments. Relatively simple examples of changes in the importance of pleiotropic effects might, in the case of facultative pathogens, be changes in importance of saprophytic phases or, in the case of rusts, changes in importance of the phase of the alternate host.

The model used for horizontal resistance has certain theoretical and practical implications. At present the discussion centres on two models of horizontal resistance: Additive and small-interaction models. In the additive model of horizontal resistance and pathogenicity, gene effects are small, interchangeable, and additive. In the small-interaction model (PARLEVLIET and ZADOKS, 1977), a number of gene-for-gene actions with small effects produce a quantitative resistance expression. The gene actions are small, probably additive, but only interchangeable if they are not matched by specific resistance genes in the host. The stability of the resistance would depend on small multiline effects. In such a model horizontal resistance is an extreme form of quantitative vertical resistance and the earlier definition of horizontal resistance does not fully apply. Apparent conformity would be due to difficulties in observation.

Both models have some serious drawbacks. The additive model denies the specificity of gene actions, which is unlikely. The small-interaction model faces difficulties in explaining the durability of resistance in clonal crops such as sugarcane, banana and potato. The small gene actions for resistance and parasitic ability are highly specific in the small interaction model, however, MATHER and JINKS (1974) state that small gene actions may be less specific than the actions of 'major' genes. Furthermore, specificity does not have to imply a simple gene-for-gene action; recombination of small gene effects in the parasite might match specific gene actions in the host. Also, other processes such as incomplete penetration of genes and differences in segregation of heterochromatin, which carries polygenes (MATHER and JINKS, 1974), may cause small multiline effects

on clones or even on the same plant. Such processes are extremely difficult to describe and their description also is of little importance in a plant breeding or selection programme. For practical purposes, it is satisfactory to describe the horizontal host-parasite system as the effect of interacting polygenic or oligogenic systems with additive gene actions within each system and a low level of host-parasite specificity.

2.6.2. *Practical implications:* C. arabica *and its parasites.*

C. arabica in Ethiopia is, for the larger part, grown under the conditions in which it was domesticated. As a consequence a balanced system between *C. arabica* and its parasites has co-evolved and parasites are of little importance under the traditional growing conditions. The balance between *C. arabica* and its parasites and changes in that balance are described below.

2.6.2.1. Leaf rust *(Hemileia vastatrix* Berk & Br.) – is of minor importance in Ethiopia. Control measures are only considered in locations where the Harer coffee type is grown under rather wet conditions (Western Harerge). Harer coffee is reputed to be more susceptible to this disease than other coffee types (SYLVAIN, 1958; personal observations).

Altitude affects the disease. For example, rust is nearly absent at elevations above 1,700 metres in areas around Dila (Sidamo) but the disease is common at lower altitudes in the same region. The low rust incidence, which the author observed at Tepi (ca. 1,200 m.), was, however, remarkable and might indicate a high intrinsic level of resistance of the coffee population in that region.

Two conditions might keep leaf rust at a low level in Ethiopia: the genetic heterogeneity of the population and high levels of horizontal resistance. The occurrence of vertical resistance is established (for a comprehensive review see RODRIGUES et al, 1975) and the genetic heterogeneity might cause 'multiline effects'. Nevertheless, it is difficult to understand how these 'multiline effects' will operate. *C. arabica* plants are not deciduous and therefore there are no real 'dead seasons'. It could be argued, that rusted leaves are preferentially shed during the dry season, but a large proportion of infected leaves remains. It might, therefore, be speculated that the host-pathogen system is derived from a deciduous progenitor species. In this respect, *C. eugenioides*, the diploid species which resembles Arabica coffee both in habitus and in growth requirements, is the only closely related species with a marked deciduousness (CHEVALIER, 1947).

Whatever the magnitude of the 'multiline effect' might be, a very high level of horizontal resistance must also be present, as each tree becomes infected at one stage or another, and thus reinfection within the plant must be reduced. Furthermore, a fair level of heterogeneity is not sufficient to protect Harer coffee.

The situation in other countries differs greatly from that in Ethiopia. The coffee population is very homogeneous elsewhere and tree density is much lower. The absence of conidial dilution (the 'multiline effect') is partly replaced by the lower tree density. Leaf rust is often more severe outside Ethiopia and this may, in some cases, be caused by more favourable climatic conditions and a higher

yield level, which is known to cause a higher level of disease. It may also be argued that coffee outside Ethiopia has a lower level of horizontal resistance. This claim can be substantiated by the history of coffee outside Ethiopia. *C. arabica* was taken from Ethiopia to Yemen in the first half of the second millennium (CHEVALIER, 1929, 1947; SYLVAIN, 1958). Rainfall is low in Yemen and leaf rust rarely occurs (CORDEMANS, 1973). Therefore, selection pressure for resistance must have been very low whilst selection pressure for other characters, such as drought adaptability, was probably high. Thus, changes in the population occurred which probably resulted in a considerable erosion of resistance to leaf rust. Practically all coffee in the world is derived from material from Yemen (CHEVALIER, 1929, 1947) but *Hemileia* was left behind when coffee was taken to other countries. Coffee was grown in climates favourable to leaf rust and the disease reached high levels when the pathogen caught up with the host. The coffee from Harerge further illustrates this point. SYLVAIN's (1958) statement, that this is a reintroduction from Yemen, explains its susceptibility to leaf rust.

2.6.2.2. Leaf blight and stem dieback – is characterized by black lesions on young leaves and shoots and dieback of young shoots; it causes brown lesions on older leaves. The disease is mostly observed in wet, relatively high regions. The pathogen is, according to STEWART (1975), *Ascochyta tarda* Stewart (= *Phoma tarda* Boerema and Bollen). In this study, isolations yielded *Colletotrichum* sp. and *Phoma tarda*. As *Colletotrichum* spp. are saprophytic on all parts of the coffee tree, it may be assumed that the symptoms were indeed caused by *P. tarda*.

Differences in susceptibility occur and are described in Chapter 6; Harer coffee often is severely stunted when it is grown under wet conditions in the west of Ethiopia. Under normal conditions of cultivation, control of the disease is not needed. However, changes in the agricultural system increase its economic significance: rejuvenation of coffee trees by stumping is a newly proposed practice. Under this system, old bearing stems are removed and new shoots replace them. However, growth of these new shoots is often retarded by the pathogen, thus increasing the time span between rejuvenation and first new crop.

2.6.2.3. Brown eye spot and minor leaf disorders. Brown eye spot (*Cercospora coffeicola* Berk & Cke) does not cause any significant damage. Other leaf disorders occur, often of unknown etiology. They are so insignificant that they will not be mentioned here.

2.6.2.4. Brown blight on berries. It is assumed that a form of *Colletotrichum coffeanum* Noack caused a blight of ripening berries (FERNIE, 1966; LEJEUNE, 1958) before the appearance of CBD. Damage to the crop was insignificant as the seeds were not diseased.

2.6.2.5. Tracheomycosis. The pathogen (*Gibberella xylarioides* Heim & Saccas) causes a vascular wilt. The incubation time is very long, some six months in

seedlings (PIETERS and VAN DER GRAAFF, 1980) and some 9 to 10 months in young suckers (FEKADEH and MESERET, 1979, personal comm.). The system pathogen-host is a prototype of endemic disease (VAN DER PLANK, 1975). LEJEUNE (1958) indicated that the pathogen might exist in Ethiopia but its presence was confirmed only in 1973 (KRANZ and MOGK).

Differences in susceptibility have been reported (VAN DER GRAAFF and PIETERS, 1978; PIETERS and VAN DER GRAAFF, 1980). Damage is minimal in the dense stands of coffee in western Ethiopia, where spontaneous seedlings will fill in the gaps.

Changes in the relation *C. arabica/G. xylarioides* occur when modern cultivation practices are introduced. These practices comprise more weeding and digging to remove obnoxious grasses. This results in more wounding of the trees and better chances for transmission of the pathogen. At Washi (Kefa), 3,4 % of the trees in a spray trial died in approximately eight months and 93 % of the deaths was due to *G. xylarioides*. The occurrence of *G. xylarioides* on Arabica coffee has only been confirmed from Ethiopia, although LEJEUNE (1956) observed symptoms in southeastern Sudan.

The pathogen is well known from Excelsa coffee (SACCAS, 1951, 1956). Strains that are pathogenic to Arabica coffee might, however, be restricted to those areas where *C. arabica* is indigenous; foreign Arabicas often show a high level of susceptibility when grown in Ethiopia (VAN DER GRAAFF and PIETERS, 1978) indicating erosion of resistance in the host. The pathogen is a major risk to all Arabica coffee growing areas in the world.

2.6.2.6. Gibberella stilboides. Damage caused by this pathogen in Ethiopia seems to be confined to a collar rot of young seedlings. Some susceptible collections were observed at Jimma Research Station.

2.6.2.7. Rootrot – damage, in which a rôle of basidiomycetes is suspected, is rare and seems to be confined to high, relatively wet areas.

2.6.2.8. Pests. Damage generally is insignificant. Variability in susceptibility to a leaf miner is reported in this study (Chapter 6). *Hypothenemus hampei* (Ferrari), the coffee berry borer, is very rare, although it is a major coffee pest in other countries. Spraying against coffee berry disease appears to increase the occurrence of blotch leaf miners (CROWE, pers. comm.).

2.6.3. *Concluding remarks on the host-parasites system*

The system consisting of *C. arabica* and its parasites is well balanced in Ethiopia as is to be expected from an 'unimproved' crop. The species was gradually domesticated in Ethiopia and it is still cultivated under the conditions under which it was selected. The genetic heterogeneity of the population is high. Multiline effects for some and good levels of horizontal resistance for all parasites are to be expected.

A number of changes may upset such a gradually developed system: Firstly,

slight changes in cultural practices will influence the balance between the host and its parasites. Each change will affect the balance but only those changes that result in an increased level of injuries will normally be noted. The effect of rejuvenation and increased cultivation has already been shown above. The application of fertilizer will disrupt other balances. Secondly, the gradual domestication process will have created coffee types that are adapted to local conditions. The cultivation of coffee types under conditions different from those during domestication may cause outbreaks of some parasites. For example, material from high elevations may show an undue susceptibility to leaf rust at lower altitudes. Another example is the Harer coffee type which is fully satisfactory under dry conditions, but shows undue susceptibilities in wetter areas. In Chapter 6, differences in resistance of populations orginating from different locations are described. The third important threat to *C. arabica* stems from its isolation from related species. These species went through their own host-parasite co-evolution and resistance to some of their parasites will be insufficient in *C. arabica*. Coffee Berry Disease probably originated from another host-parasite system (Section 3.6.). Potential threats to Ethiopian coffee have already been observed on *C. arabica* in other areas: grey rust (*Hemileia coffeicola* Manblame & Roger) in west and central Africa; American leaf spot, *Mycaena citricolor* (Berkely and Curtis) Saccardo, in Latin America, and *Nematospora coryli* Peglion, a yeast transmitted by *Antestiopsis* spp., in Africa.

The most important disturbance of the host-parasite system has been the introduction of CBD. Smaller imbalances occur when the coffee cultivation is gradually modernized. Some imbalances due to the cultivation of unsuitable material cannot be excluded. CBD resistance was, therefore, the first priority in coffee improvement (Chapter 4). To recreate a balanced host-parasite system, adequate resistance to other diseases and pests was a second priority (Chapter 6). Various growth conditions might eventually lead to the selection of coffee types for specific conditions.

2.7. Conclusions

- *C. arabica* is geographically separated from other *Coffea* species. Speculations about its origin as a cross between diploid progenitors are inconclusive and of little importance for Ethiopia.
- Speculations about the occurrence of 'wild' *C. arabica* in Ethiopia are rather futile, as undisturbed forests do probably not exist in Ethiopia.
- *C. arabica* is predominantly grown in areas with a wel distributed rainfall but a marked dry season. In Ethiopia it grows between 1,200 and 2,000 metres.
- *C. arabica* in Ethiopia is very heterogeneous, and it can be characterized as a primitive crop with a low level of cultivation.
- The system *C. arabica*-parasites was, under traditional growth conditions, well balanced: resistance was adequate to keep disease and pest damage at an insignificant level. The system becomes unadapted when new agricultural practices are applied, and no adequate resistance in the host population as a whole exists against newly introduced diseases and pests.

3. COFFEE BERRY DISEASE

3.1. Symptoms

The disease is characterized by an anthracnose of green berries. Symptoms may also occur on flowers (Nutman and Roberts, 1960a) and ripening fruits. Symptoms on green berries begin with the development of a brown to black lesion which gradually expands and finally destroys the whole berry. Minute acervuli are formed on the lesion which produce the pinkish conidial masses of *Colletotrichum coffeanum*. The majority of diseased berries drop off but a small number remains on the tree as black mummies. Lesions become brown and inactive (scab lesions) under adverse weather conditions.

3.2. Taxonomic position of the pathogen

The taxonomic position of the pathogen is confused. McDonald (1925) considered it to be a form of *Colletotrichum coffeanum* Noack which differed from the normal strain in Kenya. Gibbs (1969) and Hindorf (1973 a, b) differentiated the various *Colletotrichum* strains from Arabica coffee in Kenya. Gibbs found four forms which he designated CBD, CCP, CCM and CCA. Hindorf described five condidial forms and a perfect form, *Glomerella cingulata*. He reserved the name *C. coffeanum* for the form that causes CBD. This nomenclature unfortunately confuses the situation because the name *C. coffeanum* was originally given to a Brazilian isolate which was not pathogenic to green coffee berries; the pathogenic strain which causes Coffee Berry Disease does not occur in Brazil (Van der Graaff, 1979).

Firman and Waller (1977) suggested that the name *C. coffeanum* may be invalid as the name was given to a Brazilian isolate which would now probably be classified as *C. gloeosporioides*. The strains occurring in Brazil probably cover the complete morphological range from *C. gloeosporioides* to *C. coffeanum*.

3.3. Occurrence of the pathogen and its related forms

The occurrence of the pathogen and its related forms has been thoroughly studied in East Africa (Gibbs, 1969; Hindorf, 1970, 1973 a, b, c; Vermeulen, 1970a, b). The pathogen occurs, as a micro-epiphyte, on the maturing bark of *C. arabica* (Nutman and Roberts, 1960a). It is capable of attacking green berries, flowers, and ripening fruits. Unter laboratory conditions very favourable to disease development, it is also capable of attacking young seedlings and growing points (Cook, 1973 b). *Colletotrichum acutatum* Simmonds, *Glomerella cingulata* (Stern) Spauld. B. Schrenk and forms of *Colletotrichum gloeosporioides* Penz

also occur on the bark of *C. arabica* in East Africa. They show a strong saprophytic ability and appear to be the first invaders of moribund tissue. Although these forms are often blamed for diseases like diebacks and leafspots, clear evidence for their parasitic ability appears to be lacking. Brown blight, a blemishing of ripening fruits, appears to be associated with the occurrence of the related forms (HOCKING, 1966; SMALL, 1926; FERNIE, 1966). When *C. coffeanum* is present, it also causes brown blight.

In Ethiopia, GASSERT (1976) isolated *Colletotrichum acutatum* and the acervulus form and mycelium form of *C. gloeosporioides* from the bark of *C. arabica.* He also obtained isolates that produced *Glomerella cingulata;* the imperfect form, which he obtained from the ascospores, was invariably a form of *C. gloeosporioides.*

3.4. DISEASE CYCLE

The epidemic of Coffee Berry Disease is initiated each year by conidia from the bark and, if present, from sporulating mummified berries formed during the previous season (GASSERT, 1976). The conidia are waterborne and splash distributed. They need 100% relative humidity and/or the presence of liquid water for germination (NUTMAN and ROBERTS, 1960 b). A conidium germinates, forms a germ tube and an appressorium after which the cuticle is penetrated. The whole process requires some five hours (NUTMAN and ROBERTS, 1960 b). Under favourable field conditions, the time between infection and appearance of the lesion is two to three weeks (Chapter 4). Either rain or equable temperatures accompanying rain are needed for symptom development and lesion expansion. Acervuli are formed on the lesion surface and conidia are formed under conditions of high air humidity. The author observed sporulation on the inside of the endocarp. This observation suggests the possibility of transmission of the pathogen by seeds. Under relatively dry conditions, lesions become inactive and a cork cambium is formed, sealing off the lesion, after which the lesions turn brown. Deep lesions, which penetrate the mesocarp, do not heal completely and berries with deep lesions often crack when they expand.

Resistance of berries to infection is known to vary with growth stage. HINDORF and MOGK (1975) and GASSERT (1976), following WORMER (1964), describe five growth stages:

A. Primary stage: (pinhead) up to 8 weeks after flowering, no change in size.
B. Expanding stage: rapid increase in volume, week 8 to 16, the size of the integument starts to increase.
C. Endosperm stage: growth of endosperm, week 17 to 24.
D. Hard green stage: solid endosperm, week 25 to 32.
E. Ripening stage: gradual coloration, softening and expansion of mesocarp, 33 to 35 weeks after flowering.

HINDORF and MOGK (1975) found in the field that the percentage of berries showing new lesions is low in stages A and D and high in B, C, and E. It must be

kept in mind that their observations partly indicate the level of infectibility some 2 to 3 weeks before the actual lesions can be observed. GASSERT (1976) found an increase in susceptibility from the 3rd to the 12th or even 14th week after flowering by means of detached berry tests. The susceptibility gradually decreased after the 14th week.

3.5. CLIMATIC CONDITIONS AND DISEASE DEVELOPMENT

A high rainfall level, a high air humidity, and relatively low temperatures favour disease development; disease is invariably severe at high altitudes where these conditions prevail and at valley bottoms in the highlands where high levels of humidity and therefore, heavy dews, prevail. NUTMAN and ROBERTS (1960 b) indicated optimum, minimum, and maximum temperatures for conidial germination and symptom development. Water saturated air and/or presence of liquid water for 4 to 5 hours are needed to secure germination of the conidia and penetration of the cuticle. WALLER (1971) performed experiments on the distribution of the conidia and on symptom development under field conditions. He found that rainfall is needed for the dispersal of conidia and subsequent infection. He also found that the minimum temperature determined by NUTMAN and ROBERTS (1960 b) was not an absolute minimum in the field. He concluded that the periods suitable for infection were so numerous that, even at low altitude and in a dry year, the attenuation of CBD in these regions cannot be explained by the lack of potential infection periods. WALLER further stated that the influence of climatic conditions on lesion growth, spore production, and host resistance was not adequately known.

GASSERT (1976) tried to relate berry susceptibility, temperature, relative air humidity, and amount of rainfall to the progress of the epidemic in Ethiopia. He could only establish a relation between berry susceptibility and percentage of diseased berries in the field. The variation in climatic conditions during the rainy season had virtually no influence on disease development. STEINER obtained, according to GASSERT, similar results in Kenya. It is tempting to conclude that during the rainy season in Ethiopia and in Kenya the weather conditions vary within the optimum for disease development, but this conclusion would negate the differences in disease level observed between locations and years. In GASSERT's study, the effects of climatic conditions on latent period and lesion growth were not taken into account. He used a fixed incubation time for the analysis of his data but the latent period probably depends on berry susceptibility, temperature, and, possibly, rainfall. The same dependence holds for lesion growth as under unfavourable conditons lesion development is arrested and the lesion develops into a scab lesion.

Finally, it should be emphasized that the conditions favouring infection as defined by NUTMAN and ROBERTS (1960 b) need confirmation as in their experiments they did not discriminate between saprophytic and parasitic *Colletotrichum* species.

3.6. Geographic distribution and origin of the disease

Coffee Berry Disease was first observed in Western Kenya (McDonald, 1924, 1925). It crossed the Rift valley in 1939 and reached upper Kiambu in 1951 (Rayner, 1952). Thereafter it spread rapidly over the other coffee growing areas in Kenya. From Kenya it was probably introduced into Tanzania in 1964 (Tapley, 1964). It spread to Ethiopia at the end of the nineteen sixties (Mulinge, 1973). First observations from Uganda date from 1959 (Butt and Butters, 1966). The disease might have been introduced from Rwanda, where it was observed in 1957 (Foucart and Brion, 1963). Early observations exist from other places: Angola ± 1930 (Mendes da Ponte, 1966), Zaire, 1937 (Hendrickx, 1939), Cameroon, 1957 (Muller, 1964) and West (British) Cameroon, 1955 or 1956 (Muller, 1964). The pathogen is still restricted to Africa. Reports suggesting its occurrence in Brazil could not be confirmed (Van der Graaff, 1979). The occurrence of the pathogen in India was reported but later disproved (Hindorf and Muthappa, 1974).

Little is known about the origin of the disease. Nutman and Roberts (1960 a) stated that the pathogen was probably formed through a mutation of one of the saprophytic forms of *Colletotrichum*. However, forms, comparable to the saprophytic ones found in Kenya, have been reported from Ethiopia (Gassert, 1976). Hence, it is difficult to explain why mutant strains were not present in Ethiopia.

Robinson (1976) hypothesized that Arabica coffee had encountered an insignificant pathogen of a diploid coffee species in western Kenya, the diploid species being one of the progenitors of the tetraploid *Coffea arabica*. *C. arabica* would subsequently have escaped the pathogenic form and a considerable erosion of host resistance would have occurred. Robinson indicated that *Colletotrichum coffeanum* was possibly a mild parasite of *Coffea eugenioides*.

It can be accepted that *Coffea arabica* recently encountered a relatively harmless parasite of a related species. *C. arabica* is geographically isolated from the related diploid species on which a separate host-parasite evolution may have occurred. When Arabica coffee finally encountered the pathogen, its resistance happened to be insufficient. Comparable cases are cited by Buddenhagen (1977). Whether *Coffea eugenioides* is the original host of *Colletotrichum coffeanum* is difficult to determine. The species occurs from northern Zambia to Sudan and from western Kenya to Kivu in Zaire: CBD was first found in western Kenya, but not in any other area with *C. eugenioides*. This would imply that within the species *Coffea eugenioides* certain parts of the population were geographically isolated and separate host-parasite systems would have developed. It might also be speculated that *Colletotrichum coffeanum* has evolved with another, possibly West African, coffee species. Possible candidates are *C. canephora* and *C. excelsa*, which occur from Uganda to respectively Guinea and Senegal in the West, and to Northern Angola in the south. This hypothesis could explain the early outbreaks of the disease in Angola, Cameroon and Kivu, but the lateness of the reports of the disease in Uganda cannot be explained. Alter-

natively, the disease may have been introduced in Angola, Cameroon and Kivu. In Zaire, coffee material was imported from Western Kenya during the late twenties (See Section 3.8.2.). MULLER (1964) stated that the disease might have been imported from Kenya into the section of Cameroon that was formerly a British protectorate. In Angola, the presence of cultivars that were developed in Zaire indicates a possible introduction of the disease.

3.7. RESISTANCE

3.7.1. *Variability in resistance*

Resistance varies among coffee cultivars. MCDONALD (1932, 1935, 1937) reported that the variety Blue Mountain possessed a higher level of resistance than French Mission coffee. He also reported variability for resistance in French Mission coffee.

FOUCART and BRION (1963), probably partly based on earlier work in Zaire (HENDRICKX and LEFEVRE, 1946), list as highly susceptible Harar, Moka, Kent, Mysore, and Bourbon, as moderately susceptible Blue Mountains Jamaica, Blue Mountains Kenya, and certain lines of Local Bronze, Kabura Kiseya, and as fairly resistant Jackson hybrid (the result of a double cross ((arabica × liberica) × arabica), Bourbon Mayagez, Mibirizi 49 and Local Bronze 8 and 12. Differences in resistance were also reported from Angola (TAG, 1966; MENDES DA PONTA, 1966): Bourbon and Caturra were reported to be susceptible; Blue Mountains, Mundo Novo, and a Campinas hybrid possessed some resistance while Sumatra and Jackson were rather resistant. FIRMAN (1964) identified the high resistance level of Rume Sudan, a coffee type obtained from the Boma Plateau in Eastern Sudan. VERMEULEN (1966) reported a high level of resistance in Hybrido de Timor. Differences in resistance were further reported by VAN DER VOSSEN et al. (1976). In Ethiopia differences in disease severity between trees were almost immediately noticed after the first appearance of CBD. The consistency of the differences was later confirmed (VAN DER GRAAFF, 1978 a, b; See also Chapter 4).

3.7.2. *The mechanism of resistance*

NUTMAN and ROBERTS (1960 b) used detached berry tests to study the mechanism of disease resistance. They found that wounding increased susceptibility in both susceptible and resistant cultivars and that there was little difference among cultivars in reaction after wounding. Varietal reaction could not be correlated with the percentage of conidial germination or with the stomatal density. They concluded that the sole cause of the difference in susceptibility between varieties lies in the ease or otherwise with which the infection peg can penetrate the cuticle. In detached berry tests, FIRMAN (1964) found that the level of susceptibility increased after wounding, but that some residual resistance remained in Rume Sudan. The other tested cultivars all attained 100% disease after wounding, thus not permitting any comparison. LAMPARD and CARTER

(1973) studied the antifungal properties of the cuticle wax. They found antifungal compounds with specificity against *Colletotrichum coffeanum*. The concentration of these compounds or their antifungal effectiveness was higher in resistant than in susceptible material. Exceptions were K7 and SL34: antifungal properties of extracts from cuticle wax from K7 were unexpectedly low whilst those from SL34 were rather high. LAMPARD and CARTER concluded that although cultivar specific compounds propably play a rôle in determining disease resistance, other dynamic post penetration mechanisms also determine resistance. Similar results were reported by STEINER (1972).

3.7.3. *The nature and inheritance of resistance*

The nature of the resistance and its mode of inheritance have not been studied extensively. The résistance is quantitative; absolute resistance has never been observed. Resistance appears to have remained stable in Blue Mountain coffee and in the lines which were selected in Zaire (See Section 3.8.2.), but in cultivars and lines with an intermediate level of resistance protection might be insufficient under adverse weather conditions. ROBINSON (1974, 1976) and PERSON (1974), considering the complete range of susceptibilities occurring in Ethiopia, concluded that resistance was probably horizontal.

The number of genes involved in the resistance is unknown. In Kenya, many crosses are made between susceptible and resistant material. Although speculations were made on the number of genes involved, data have yet to be published. (VAN DER VOSSEN, 1975, 1976, 1977: VAN DER VOSSEN and WALYARO, 1978).

3.8. CONTROL OF COFFEE BERRY DISEASE

3.8.1. *Chemical control*

MULLER (1964) developed a satisfactory control programme in Cameroon. It consisted of continued protection of the berries during the rainy season. These methods were adopted in Kenya only in 1967/1968 (GRIFFITH, 1968). Sprays are presently applied according to a fixed time schedule. Intervals of four weeks are used with Orthodifolatan, Carbendazim and Benomyl, intervals of three weeks are recommended for copper compounds. Carbendazim proved unsatisfactory as resistance of the fungus developed against it (OKIOGA, 1976). Recently, new compounds were found to be successful. Costs of chemical treatment are high but justified in advanced coffee cultivation.

In Ethiopia, spray trials were conducted immediately after the appearance of CBD to adapt Kenyan recommendations to Ethiopian conditions (1972 to date). Trials from 1974 to 1978 were made under the supervision of the author. Their results are presented elsewhere (INSTITUTE OF AGRICULTURAL RESEARCH, JIMMA RESEARCH STATION, 1972, 1973, 1974, 1978). Recommendations made for Kenya could easily be adapted. Protection is needed during the whole rainy season from March/April till early September.

Although control of CBD by chemicals is possible is Ethiopia, cultivation methods and yield levels limit its application. It is often difficult to spray as trees are unpruned and irregularly spaced. Many areas are inaccessible during the rainy season. Therefore, areas are selected which (a.) have an above average yield prospect, (b.) suffer severe losses if the disease remains unchecked, and (c.) have sprayable trees. These prerequisites limit, according to CTDMA officials, the area which might profitably be sprayed to some 50,000 ha. Presently, chemicals are heavily subsidised to make treatment attractive in the suitable areas. Spray teams are formed under the supervision of the extension service of the CTDMA. The estimates of treated areas are: 1975/76 1,150 ha; 1976/77 5,100 ha; 1977/78 13,000 ha; 1978/79 10,600 ha (COFFEE AND TEA DEVELOPMENT AND MARKETING AUTHORITY, 1979).

3.8.2. *Control through resistance in Kenya and Zaire*

As indicated in Section 3.7.1, differences in resistance were often observed. Johnson, a farmer in Kenya, raised seedlings from coffee bushes that showed a consistently low disease level as early as 1925 (MCDONALD, 1926) and MCDONALD (1929) urged farmers in Kenya to make selections for resistance. Part of a plantation was rented in Kenya in 1932 and was to be used entirely for the study of the Coffee Berry Disease, including selection for resistance. These activities unfortunately ceased in 1936 (MCDONALD, 1937) when observations for only one cropping season had become available. Coffee culture west of the Rift in Kenya declined in the 1920's and 1930's, mainly because of Coffee Berry Disease (RAYNER, 1952). Most of the commercial varieties grown in Kenya today were selected East of the Rift before CBD arrived there and some varieties therefore show an exceptionally high susceptibility. These varieties were tested in trials in many parts of Kenya in the nineteen fifties and sixties. Emphasis in those trials was on yield and not on disease or pest resistance.

Following the discovery of the resistance of Rume Sudan in 1964, a programme to breed for CBD resistance started in Kenya in 1971 (VAN DER VOSSEN, 1973). The programme is a formal breeding programme and in that respect differs very much from most coffee improvement programmes which are, or were, selection programmes only. As a consequence, the programme may have to rely on vegetative propagation for multiplication of suitable genotypes; cuttings will be distributed to the farmers.

Selection at the coffee research station at Mulungu in Zaire took resistance to Coffee Berry Disease into account. HENDRICKX and LEFEVRE (1946) reported results of five years of observations on disease severity: Mysore and Bourbon were susceptible, Blue Mountain Jamaica and Kenya and certain lines of Local Bronze and Mibirizi were moderately susceptible. Jackson Hybrid and certain lines of Local Bronze had a low susceptibility. Their results were consistent although only two years of serious infection occurred. Most of the material exhibiting resistance was, amazingly, derived from Kenya. 'Local Bronzes' were derived from the first selections for resistance in Kenya made by Johnson. Jackson hybrid and Blue Mountain coffees were also obtained from Kenya. The

Mizibiri's came through Rwanda from Guatemala, Mysore came from India, and Bourbon came from Porto Rico and Guatemala (SNOECK and PETIT, 1964). The material that was selected at Mulungu Research Station is still grown in Zaire, Rwanda, and Angola.

A comparison of the approaches in Kenya and Zaire shows that, applying a regular selection programme, the Belgians in Zaire were able to select material with a level of resistance adequate under their conditions, whereas, with the same material available, such efforts were abandoned in Kenya, thus causing serious problems later.

3.8.3. *Selection for resistance in Ethiopia*

Immediately after the appearance of CBD in Ethiopia, it was observed that large differences in the level of infection existed between individual trees. Inspired by these differences, the staff of the coffee agronomy section of Jimma Research Station made some selections in 1971 and 1972, but it was felt that a pathologist was needed to make selection more meaningful. R. A. Robinson was accordingly appointed in 1972 as an FAO coffee pathologist. He designed a programme to utilize the observed resistance within the shortest time possible.

The programme had the following form at the departure of Robinson in December 1974:

a. Indentification of mother trees: Some 500 disease-free trees were to be selected in areas with a high level of disease. The resistance was to be confirmed through inoculations in the field.

b. Observation of mother trees: Preliminary observations on yield and quality were to be made through subsequent observations of mother trees during 3 years after initial selection.

c. Multiplication: Initially it was assumed that, due to a high level of natural cross pollination, progenies of mother trees would be very heterogeneous. It was, therefore, proposed to use vegetative propagation, but after the observation of the homogeneity of single tree progenies at Jimma Research Station it was decided to employ seed propagation. Berries from selected trees were to be collected at ripening and were to be sown regardless of what future tests might show. Sufficient seedlings were to be raised to plant 1,000 seedlings per mother tree. These progenies were to be planted in a seed production garden 14 months after sowing and following a second year of mother tree testing. A progeny block was to contain a maximum of 1,000 trees per mother tree.

d. Observations on progenies: Progenies having their first crop were to be observed for CBD infection. Two types of variation were expected in the progenies: (1) discontinuous variation due to 5 to 10% cross pollination on the mother tree, and (2) continuous variation according to the level of heterozygosity of the mother tree. PERSON (1974) evaluated the programme and considered it scientifically sound.

A brief overview of the programme as it was carried out is given below before a detailed description is presented in the following chapters:

a. Selection of mother trees: A total of 639 trees was selected over 1973, 1974 and

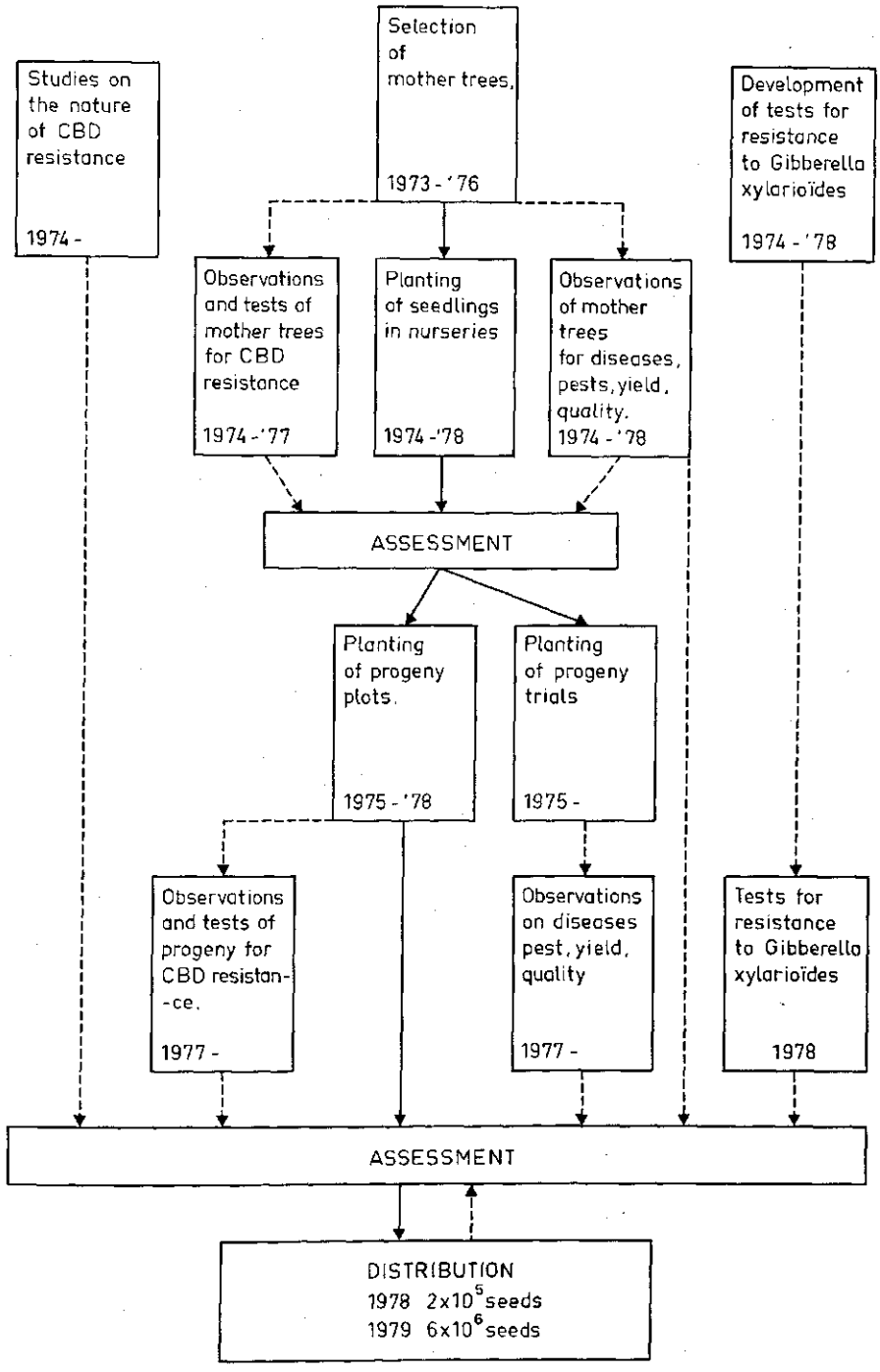


FIG. 5. A schematic representation of the selection programme to obtain coffee types resistant to CBD.

1975. The resistance of the trees was confirmed by successive inoculations in the field in the year following selection, and by inoculation tests of seedlings grown from berries of these trees. The observations on mother trees were further used for the confirmation of resistance.

b. Multiplication: A small nursery was built at Jima in early 1974 to accommodate the seeds of the 1973 selections. Land in a heavily CBD affected area at Gera (Kefa) became available at the end of 1974. Large nurseries were built immediately to receive the seeds of the 1974 selections (ca. 300,000 seeds). The seedlings of the remaining 1973 selections were planted at Gera in 1975. After June 1975, the Coffee Agronomy Section at Jimma Research Station implemented the multiplication programme which consisted of planting the 1974 selections, raising and planting the 1975 selections, and the layout and planting of various variety trials, and eventually, the assessment of progenies.

c. Observations on mother trees: Mother trees were observed for three consecutive years after selection. They were scored for yield, vigour, diseases, disorders, and pests. Quality samples were obtained whenever possible.

d. Appraisal of the resistance of progenies: The progenies were retested for CBD resistance by means of detached berry tests. Estimates of the level of disease and berry countings were made in the field to obtain accurate data on damage.

e. Resistance to other diseases and pests: Resistance to other diseases and pests was neglected in the original programme. It was therefore decided to plant progenies of the selected trees at various locations in the country to observe their susceptibility to other parasites. A separate programme was started to determine resistance to *Gibberella xylarioides*, the pathogen causing tracheomycosis.

A schematic representation of the realized programme is presented in Figure 5.

Funding for the programme came from CTDMA and UNDP/SF. CTDMA provided 100,000 Birr per year until June 1976. From June 1976 to June 1981, the programme is a research component of the Coffee Improvement Project (CIP) of the CTDMA. The CIP is financed by the European Development Fund; approximately 3,600,000 Birr was budgeted for the CBD resistance programme. The UNDP/SF provided for experts and costs for equipment.

3.9. Conclusions

- The nomenclature of the organism causing CBD has to be reviewed.
- Little evidence exists that strains of *Colletotrichum* related to the pathogen can cause disease on *C. arabica*.
- The ecological conditions favouring development of CBD after infection are poorly defined.
- CBD is a new encounter disease for *C. arabica*.
- Although variation in resistance was already observed in the 1920's, little is known on its nature, mechanism or inheritance.
- Chemical control of CBD is possible in Ethiopia, however, due to the present yield level opportunities for application are limited.

– The differences in the outcomes of the coffee selection programmes in Kenya and Zaire are remarkable; research policy decisions made in Kenya in the 1930's have negative effects until today.

4. SELECTION FOR RESISTANCE TO CBD

4.1. Introduction

The search for resistant indivduals within the coffee population, the assessment of their resistance, their multiplication, and the assessment of the resistance of their progenies is described in this chapter. The selection of individuals without CBD creates a sub-population ('mother trees') of the total Ethiopian coffee population. The selection is described in Section 4.2. The question arises whether this sub-population differs genetically from the main population or whether the differences are caused by site specific effects. This question is discussed in Section 4.3. The methods were repeated field observations, inoculations in the field, and a laboratory test on seedlings. The quantitative assessment of resistance provided further selection criteria within the sub-population of selected trees.

Multiplication of mother trees took place immediately after selection. Progenies were normally planted in the field only after the performance of the 'mother trees' had been studied during two seasons of field observations, field inoculations, and seedling tests. Progenies were planted in an area which was especially selected for its high CBD incidence. The resistance of the progenies was assessed before seeds were distributed to farmers. Field observations and detached berry tests were used to obtain information on resistance levels in the shortest time possible. Field observations also provided indications on the homogeneity of the progenies with respect to CBD resistance.

4.2. Selection of mother trees

4.2.1. *Selection methods*

Care was taken to avoid poor yielding trees or trees which were severely attacked by pests or diseases other than CBD.

4.2.1.1. Selection in 1973. In 1971 and 1972, agents of the CTDMA and the Coffee Agronomists from Jimma Research Station marked trees without CBD, or with a 'low' level of CBD in areas in which CBD was heavy. The Coffee Agronomist and the Coffee Pathologist from Jimma Research Station inspected these trees between August and December, 1973. Trees with a low level of disease were accepted as selections. Also, some new selections were made. Criteria used for selection were:

a) The area should have been infested with CBD for at least three years.
b) The selected tree should have a low level of CBD. Low was not defined, but, in practice, did not exceed 5% of the berries diseased at the time of inspection.
c) Trees to be selected should be surrounded by four heavily diseased trees.

4.2.1.2. Selection in 1974 and 1975. At Washi, a commercial estate some 30 km southwest of Bonga (Kefa), CBD was observed for the first time in 1972. The farm manager marked trees without CBD in 1973. These trees were inspected by staff members of the Coffee Pathology Section from Jimma Research Station in July 1974. Trees without CBD were retained as selections. Other areas with heavy CBD (estimated disease level over 50 %) were mostly located with the aid of CTDMA agents or local farmers. Information was collected on the origin of the coffee to judge if ample variability could be expected. The staff of the Coffee Pathology Section, mostly in collaboration with farmers and CTDMA agents, marked trees without CBD in these areas. Care was taken to avoid trees surrounded by trees without CBD.

4.2.2. *Results*

Selection areas and numbers of selections are shown in Table 3 and Figure 6. The following comments can be made for the respective selection areas:

a) Locations in the vicinity of Agaro, Kefa (locations 2, 4, 5, 17). Farmers invariably stated that their coffee originally came from Agaro.

b) Ilubabor (locations 10 to 17). It was stated that coffee originated from Goba river area, north of Metu. From Metu to the east, variation decreased and coffee was rather uniform and often young around Buna Bedele.

TABLE 3. Year, location and number of mother trees selected for CBD resistance.

			Number of mother trees		
Adm. Region	District	Location	1973	1974	1975
Kefa	Limu	1 Amboya	–	3	–
		2 Boto	–	–	31
		3 Gera	30	22	136
		4 Jachi	–	30	–
		5 Kota	–	14	–
	Jima	6 Jima	–	6	–
	Kefa	7 Bonga	–	2	–
		8 Washi	–	99	–
		9 Wushwush	–	–	25
Ilubabor	Gore	10 Gore	15	–	–
	Sor Geba	11 Supe	4	–	–
		12 Metu	5	76	2
		13 Yayu	1	1	–
		14 Hurumu	12	1	
	Buna	15 Tchora	–	5	–
	Bedele	16 Bedele	–	2	–
		17 Jachi	–	19	53
Sidamo	Gede-O	18 Wenago	–	18	–
Shewa	Hayikoch and Butajira	19 Wendo Genet	27	–	–
Total			94	298	247

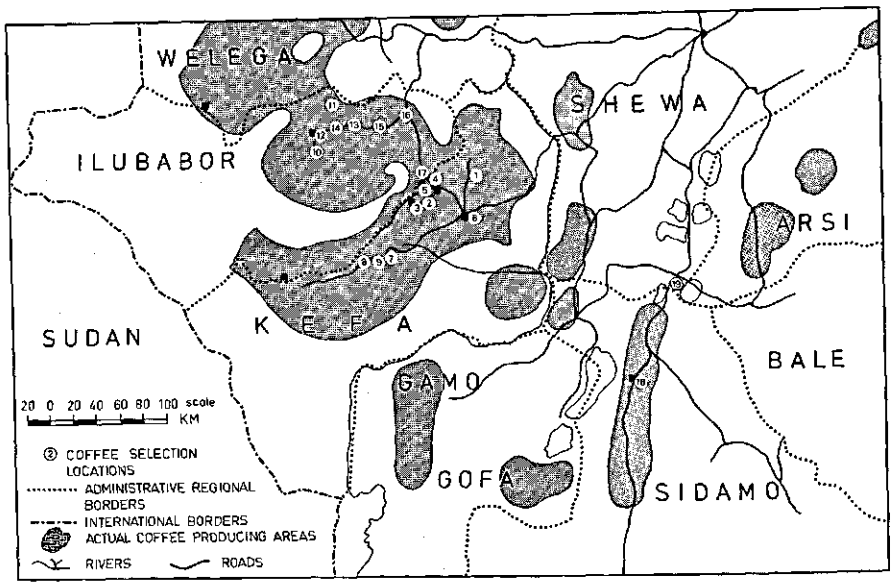


FIG. 6. South western Ethiopia. Main coffee growing areas and locations, indicated by numbers, where mother trees were selected. See also Table 3.

c) Wushwush; Kefa (location 9). Originally, the area was under secondary forest. Wushwush plantation was a relatively modern estate, established in the 1950's. Seed was mainly obtained from 'forest coffee'. These coffee bushes were probably remains from older habitation in the area (Section 2.5.1.).
d) Washi; Kefa (location 8). Washi also was a fairly recent coffee plantation. According to the former manager, seed was obtained mainly from Wushwush.
e) Gera; Kefa (location 3). The coffee was 'plantation-like'. Nevertheless, the variability between trees of the area is remarkable.
f) Other areas. All coffee was of the 'Harer type' at Wendo Genet, Shewa (location 19); and Amboya, Kefa (location 1). The population was susceptible and therefore the disease was severe. Wenago, Sidamo (location 18) was an area with 'normal' Sidamo coffee. No further information on the coffee in this area was obtained.

4.3. APPRAISAL OF THE RESISTANCE

4.3.1. *Introduction*

To ensure a sound programme, it was necessary to establish the difference in disease severity between the sub-population of selected trees and the unselected population, and to relate the difference to genetical differences. In addition, selection within the group of mother trees was desirable in order to reduce the chance that unacceptable levels of susceptibility would occur in the progenies.

The resistance was assessed through regular field observations and through tests. To remain as close to field conditions as possible, a field inoculation test was chosen. However, this test was subject to the same site specific effects as the field observations. Therefore, a seedling inoculation test performed in the laboratory was also used. The results of the tests were related to the field observations to establish selection criteria.

Apart from tests on selected trees and, in certain cases, control trees, the results of a group of widely varying accessions at Jimma Research Station are discussed. These accessions included some types which were promising with respect to characteristics other than CBD.

4.3.2. *Field Observations*

Field observations were made to check the stability of the disease level of mother trees over an extended period. Data were compared to the disease level of the unselected population in the area and to data obtained from artificial tests. Trees with more than 1 % of the berries diseased were discarded and, as a rule, no longer observed.

As indicated in Section 4.2.2., a large number of trees was selected at Gera in 1975. The number of trees and the tenancy of the farm by IAR made it possible to observe the disease levels of the group of selected trees over a number of years, to compare them with the disease level of unselected trees, and to evaluate screening techniques used to discriminate between selected trees. Results from field observations at Gera are described in this section.

4.3.2.1. Material and methods. A number of estates were established at Gera in the 1950's and 1960's. The material used for planting was extremely heterogeneous. CBD was first observed in this area in 1971 and, due to the favourable climatic conditions, disease has invariably been at a high level since. In 1975, 136 trees were selected at Gera. These mother trees were assessed for CBD in September 1976 and in August 1977 and 1978, when the berries were at the hard green or at the early ripening stage. The fraction of diseased berries was assessed by means of the seven-classed key presented in Table 4. The scale values

TABLE 4. Field observations. Seven-class key for the assessment of CBD in the field. The key was used to assess mother trees and non-selected trees around mother trees. x is the fraction of diseased berries.

Disease score	Range of x	Range of logit x	Width of range in logit units
0	$x = 0$	$-\infty$	–
1	$0 < x \leqslant 0.01$	$-\infty$ to -1.996	–
2	$0.01 < x \leqslant 0.1$	-1.995 to -0.954	1.041
3	$0.1 < x \leqslant 0.5$	-0.953 to 0	0.953
4	$0.5 < x \leqslant 0.9$	0.001 to 0.954	0.953
5	$0.9 < x \leqslant 0.99$	0.995 to 1.996	1.041
6	$0.99 < x \leqslant 1$	1.997 to ∞	–

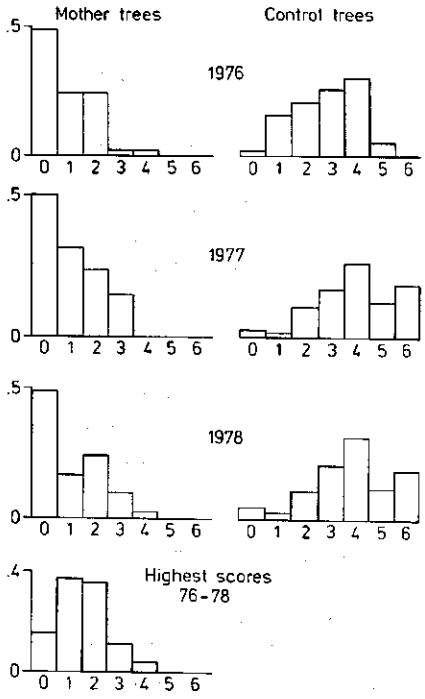


FIG. 7. Field observations. Relative frequency distribution of mother trees and control trees according to field score. Data from mother trees at Gera, 1976, 1977, and 1978; for the mother trees the highest disease score in the period is also shown. χ^2 for mother trees versus control trees was respectively 248, 274 and 218 (3 df), indicating highly significant differences between the two categories.
Abscissa: field score classes (arbitrary scale from 0 to 6, see Table 4).
Ordinate: relative frequency of trees.

are approximately equidistant after transformation of the fraction of diseased berries into logit(x) (VAN DER PLANK, 1963). For 53 trees, observations are available for all 3 years; the other trees either died, could not be found any more, or failed to bear in all three years. In 1976, disease was also estimated on trees surrounding 19 randomly chosen mother trees. In 1977 and 1978, disease was assessed on trees surrounding every fifth mother tree that was scored. In both years, 14 areas were appraised. Disease at each sampling area was assessed by estimating the disease level of 10 trees in each of four directions. 'Control area' will further be used to indicate the forty trees scored around a mother tree.

4.3.2.2. Results. The differences in disease level observed between selected and unselected trees are shown in Figure 7. The differences between both groups of trees, tested by means of a χ^2 test, are highly significant in all three years. The level of disease of each selected tree varied from year to year. Therefore, the distribution of the highest observed disease levels over the three years' period is also given in Figure 7. The consistency with which selected trees had more or less than 1% CBD is demonstrated in Table 5. The data form a three-way contingency table and were analyzed accordingly (KENDALL and STUART, 1973). The high significances indicate a strong interdependence between the observations in the consecutive years.

The results of the 1976 scoring of control trees is presented in Figure 8. For

TABLE 5a. Field observations. Frequency distribution of mother trees according to their disease level in 1976, 1977 and 1978. Two disease classes are indicated: less than 1% disease (0) and more than 1% disease (+).

Class of trees	Years			Frequency	
	76	77	78		
Never over 1% disease	0	0	0	28	
1 year over 1% disease	+	0	0	5	17
	0	+	0	3	
	0	0	+	6	
2 years over 1% disease	+	+	0	0	7
	+	0	+	4	
	0	+	+	3	
3 years over 1% disease	+	+	+	6	

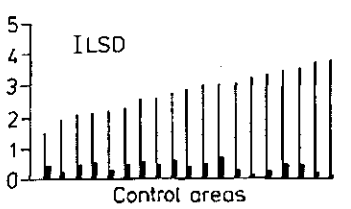
TABLE 5b. Statistical analysis of data from Table 5a. A goodness-of-fit test was made according to a 3-way table with H_0: disease classes 0 and + are randomly distributed over the trees in each year. The results show significant divergence from H_0 indicating that a + tree, in a particular year, has a higher probability being + in the other two observation years than a 0 tree.

Component	d.f.	χ^2
76	1	–
77	1	–
78	1	–
76/77	1	4.0*
76/78	1	9.4***
77/78	1	11.1***
76/77/78	1	30.9***
Total	7	55.4***

* sign. at $p \leqslant 0.05$
** sign. at $p \leqslant 0.01$
*** sign. at $p \leqslant 0.001$

each of the four directions scored at each 'control area', the average score was calculated. The 4 averages per 'control area' were treated as four replications of a disease observation. Their overall average per 'control area' and the standard error per area are shown in the Figure 8. As can be observed, standard errors did not vary grossly and, therefore, the data could be analyzed by means of a one way analysis, and it was possible to calculate the LSD between 'control areas'.

FIG. 8. Field observations. Mean field scores (thin lines) and their standard deviations (heavy lines) of 'control areas' around mother trees. Data from Gera, 1976. F (one way analysis) was 8.61 (18 and 57 df); area effect significant at $p < 0.01$.
Abcissa: control areas in order of mean field scores.
Ordinate: field score classes (arbitrary scale from 0 to 6, see Table 4).



4.3.2.3. Discussion: The population of unselected trees consistently showed much higher disease levels than the population of mother trees. The distribution of disease scores over the population of mother trees only showed small variation over the three years of observation. The population of non-selected trees, however, showed substantially fewer trees in class 6 in 1976 than in 1977 or 1978 (Figure 7). The difference might result from the difference in scoring dates. The trees were scored late in 1976 and, therefore, a large fraction of diseased berries could have been aborted at the time of scoring, thus distorting (decreasing) the value of x.

The data presented in this section demonstrate that the procedure used to select mother trees was effective for the identification of trees with a consistently low disease level. The difference between the population of mother trees and the unselected population might be due either to site specific factors, for example, small differences in microclimate caused by shade, inclination, soil fertility, or to genetical effects. Differences with regard to other characters (leaf tip colour), known to be genetically determined, were present in the total population. The hypothesis is forwarded that the difference in disease levels between selected and non-selected trees is mainly due to genetic factors.

Differences also occur between 'control areas' (Figure 8). However, inferences on genotypical versus phenotypical effects remain conjectures. The variability within the group of selected trees could again be due to either genetic or site specific factors. No convincing data can be derived from the field observations and, therefore, a threshold value for further selection can only be determined intuitively.

It is concluded that the method of field observations is quite useful for selection, but if used to the exclusion of other methods, its reliability remains questionable.

4.3.3. *Testing for resistance of mother trees*

As discussed in Section 4.3.2, continued field observations may enable us to identify the most resistant trees. Specific tests may considerably reduce the time needed for the appraisal of the resistance and they could increase the confidence in the results of the selection process. This is of particular importance as the planting op progenies of mother trees incurs considerable costs. Therefore, it is essential to reduce the number of progenies to be planted. Two tests were devised to assess the resistance level of the trees. The objectives of these tests were:

- To obtain more information on the difference between the subpopulations of mother trees and non-selected trees;
- To find differences within the population of mother trees in order to re-select within this group;
- To find indications on the nature of the resistance.

A field inoculation test and a laboratory test (seedling inoculation test) were used to achieve these objectives. Field inoculation tests were made in practically all areas where trees were selected. Their advantage is that they reflect the conditions under which the disease occurs. Their disadvantage is, of course, that

not all site-induced variability between trees can be excluded. The seedling inoculation test is a laboratory test. The advantages of this test are the absence of the site-induced variability, and the absence of the need to test fresh parts of trees. The disadvantage of the test appears to be its 'artificiality'. The original seedling inoculation test was developed bij COOK (1973, a, b) in Kenya; it is widely used in the Kenya breeding programme for CBD resistance (VAN DER VOSSEN et al., 1976). A good correlation of the seedling inoculation test with field observations has been found in Kenya, but a wide range of material such as occurs in Ethiopia has never been subjected to this test.

Although both tests were applied to material from all selection areas, the following discussion will concentrate on two locations: Gera, with a large group of mother trees, and Jimma, with trees not specifically selected for CBD resistance. Test results were compared with field observations to facilitate the establishment of threshold values.

4.3.3.1. Materials and methods. The French Collection at the Jimma Research Station consists of accessions collected by a French Coffee Mission to Ethiopia in 1966, some obtained from external sources, and some additional local material. A wide variation in CBD levels was present. A number of trees with a low level of CBD in the field were tested together with other trees to obtain a wide range of susceptibilities. Mother trees at Gera and at other locations were also tested. To compare these trees with the unselected coffee population, a control tree was chosen adjacent to each n^{th} mother tree; n varied according to the number of mother trees in a location.

The fungus can be isolated from berries: diseased berries were washed with distilled water and incubated overnight in a closed plastic box. The berries were kept damp but surface wetness was avoided to prevent fermentation. After incubation, a suspension of conidia was prepared by rinsing the berries in sterile water. The density of the suspension was determined by means of a hemocytometer. The suspension was diluted with sterile water to a density of approximately 50 conidia per ml and 1 ml of the suspension was plated out on 2% malt extract agar, to which 0.1% tetracycline was added. Thus, single conidial cultures were obtained, which were sub-cultured on 2% malt extract agar. The fungus can also be isolated from twigs (GASSERT, 1976). Fifteen branches with maturing bark were collected and cut into pieces. The pieces were rinsed with distilled water and incubated 24 hours on wet tissue paper in a closed plastic box. A condidial suspension was prepared by washing the branches in 100 ml sterile water. The suspension was diluted 1/200 with sterile water and 0.5 to 1 ml of the suspension was plated out on 0.2% malt extract agar with 0.1% tetracycline in a petri dish. Single conidial cultures were sub-cultured on 2% malt extract agar.

The cultures were maintained in the dark on 2% malt extract agar at ambient temperature. To avoid loss of pathogenicity, the fungus was regularly grown on detached green coffee berries (see detached berry test; Section 4.5.2.), re-isolated and recultured.

Inoculum was prepared from diseased berries with active lesions or from

cultures. Inoculum from berries was prepared by washing the berries with distilled water, incubating them overnight in a closed container and washing them again with distilled water. Inoculum from cultures was prepared from actively growing cultures (7 to 15 days old) by rinsing the cultures with distilled water. The densities of conidial suspensions were determined by means of a hemocytometer and adjusted through dilution with distilled water. Field inoculation tests were usually performed with inoculum from berries. Inoculum for the first field inoculation test and for the seedling inoculation tests was prepared from cultures. An isolate made from diseased material at Jimma Research Station was used in all of the seedling tests.

Field inoculations: Branches of trees to be tested were marked and the number of berries per branch was recorded. The berries were sprayed with a conidial suspension at a density of 2×10^6 conidia. ml^{-1}, using an insecticide handsprayer. Each branch was then kept overnight in a plastic 'sleeve' to retain sufficient moisture for infection. The plastic sleeve was covered with paper to avoid high temperatures due to insolation. Individual branches of a tree were used as replications. In the experiments described here, 3 replications were used at Jima and 4 at Gera. Numbers of healthy and diseased berries were recorded after three weeks. The fractions of diseased and dropped berries were analyzed after angular transformation (Arcsin $\sqrt{x}$).

Seedling inoculation test: The test was an adaptation to local requirements of the test used at Ruiru Coffee Research Station, Kenya (VAN DER VOSSEN et al., 1976). The parchment was removed from 100 seeds obtained from a single coffee tree or line. The seeds were soaked in water for two to three days and sown in heat sterilized wet sand in a plastic box. Seedlings were inoculated just before or at unfolding of the cotyledons. Prior to inoculation, the boxes were closed for 48 hours to precondition the seedlings at 100% relative humidity. After inoculation, the seedlings were sprayed with a suspension of 2×10^6 conidia $.ml^{-1}$, maintained at 100% relative humidity for 48 hours, reinoculated and then reincubated at 100% relative humidity for an additional 48 hours. Seedlings gradually developed lesions which varied in size and colour. Very small lesions were mostly greenish, larger ones were brown or black; the latter could completely girdle the plant. The small greenish and brownish lesions consisted of dead cortex cells, a newly formed cork cambium sealing off the dead tissue. Hyphae were not observed in this dead tissue after staining with anilineblue lactophenol. Sporulation of *Colletotrichum* spp. was sometimes observed on black lesions. The seedlings were scored according to size and colour of lesions by means of a 12 class scale developed by COOK (COOK, 1973 a, b, 1975; MURAKURA, 1976; VAN DER VOSSEN et al., 1976, and pers. comm.). The various classes were not equivalent as some classes were relatively empty whilst others were overfilled, thus probably creating problems of non-additivity in statistical analysis. The scale was therefore corrected on the assumption that the individual seedling scores in a test of genetically homogeneous material are binomially distributed if the various classes are 'equivalent'. Arabica coffee is an inbreeder with a low percentage of cross pollination (PERSON, 1974; VAN DER VOSSEN, 1973) and therefore

TABLE 6. Seedling inoculation tests. Classes used to score disease responses.

Score	Disease class
0	No symptoms.
1	From small greenish lesions to 1 or 2 narrow brown lesions, lesions up to 0.5 mm wide.
2	More than 2 brown lesions or brown coalescing lesions. Width of lesions exceeds 0.5 mm. Black dots, if present, are rare.
3	Wide brown lesions with numerous black dots and/or black lesions. Black lesions may completely surround the stem but the top remains alive.
4	Black lesion girdling the stem. Top killed.

genetic variation among seedlings of the same mother tree should, in most cases, be low. By trial and error the original 12 classes were reduced to 5 classes. The resulting distributions were as close to binomial distributions as possible. The new key is shown in Table 6. The binomial coefficient *(P)* of the observed distribution of each individual test was calculated, angularly transformed, and (for statistical analysis) treated as a variate with a normal distribution. Ten seedlings of each of two coffee accessions (A and B) were included in each individual box as references. The two references were used in all experimental series to permit comparison between boxes inoculated at different dates. Corrections for date of inoculation were made through the following calculations:

$$P = \frac{\sum_{i=1}^{n} x_1 + 2.\sum_{i=1}^{n} x_2 + 3.\sum_{i=1}^{n} x_3 + 4.\sum_{i=1}^{n} x_4}{4.\left(\sum_{i=1}^{n} x_0 + \ldots\ldots + \sum_{i=1}^{n} x_4\right)} \qquad (4.1),$$

where x_0 through x_4 are the responses (number of seedlings) per box for classes 0 to 4,
n is the number of boxes per inoculation date, and
P is the calculated binomial coefficient.

The correction factor CF for each inoculation date was:

$$CF = P'_A + P'_B - \frac{\sum_{i=1}^{k} P'_A + \sum_{i=1}^{k} P'_B}{2k} \qquad (4.2),$$

where P' is the angular transformation of P, and k is the number of inoculation dates.

TABLE 7a. ANOVA of field inoculation tests made at Gera on 8.06.76, 8.07.76 and 30.07.76. Fractions of diseased or dropped berries were angularly transformed before analysis.

Source of variation	df	ss	*F*
Inoculation.tree^{-1}.date^{-1}	296	519473	7.3**
Trees	98	345885	14.7**
Dates	2	37246	77.7**
Interactions	196	136342	2.9**
Error	891	213639	

TABLE 7b. Data from Table 7a, experiments analysed per inoculation date.

Source of variation	Date					
	8.06.76		8.07.76		30.07.76	
	df	*F*	df	*F*	df	*F*
Trees	98	6.7**	98	6.9**	98	6.9**
Error	297		297		297	

TABLE 8a. ANOVA of field inoculation tests made at Jima on 10.06.75 and 11.07.75. Fractions of diseased or dropped berries were angularly transformed before analysis.

Source of variation	df	ss	*F*
Inoculation.tree^{-1}.date^{-1}	63	94754	8.9**
Trees	31	79128	15.2**
Dates	1	275	1.6
Interactions	31	15352	2.9**
Error	128	21588	

TABLE 8b. Data from Table 8a, experiments analysed per inoculation date.

Source of variation	Date			
	10.06.75		11.07.75	
	df	*F*	df	*F*
Trees	31	9.6**	31	8.6**
Error	64		64	

4.3.3.2. Results. The analysis of variance for the consecutive field inoculations is shown in Tables 7 and 8. Interactions were present between inoculation dates and trees, and therefore the results of the analyses for individual inoculation

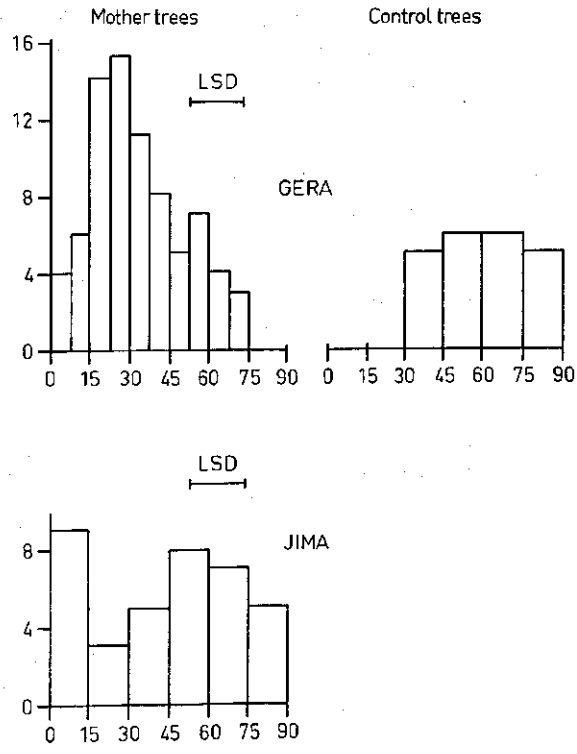


FIG. 9. Field inoculation tests. Frequency distributions of trees according to test response. Data from tests at Gera (8.06.76) and Jima (10.06.75). The frequency distribution of the test results at Jima was significantly wider (p = 0.002) than that of the mother trees at Gera.
Abscissa: fraction of diseased or dropped berries (angularly transformed).
Ordinate: number of trees.

dates are also indicated. Highly significant differences between trees were found at each specific inoculation date. The distribution of the results obtained at Gera on 8.7.1976 is shown in Figure 9. The results of the control trees show a distribution different from that of the mother trees. The distribution of results from Jima are also shown in Figure 9. In the latter distribution the lowest and highest

TABLE 9. Field inoculation tests. Mean values of tests made at three locations (between brackets number of tested trees). Trees were inoculated at three successive dates: Gera – 8.06.76, 8.07.76, 30.07.76; Jachi – 3.06.76, 30.06.76, 20.07.76; Wushwush – 1.06.76, 23.06.76, 14.07.76. According to Wilcoxon's rank sum test, differences between control trees and selected trees were highly significant ($p < 0.005$).

		Location		
Trees	Date	Gera	Jachi	Wushwush
Mother trees	1	34	36	18
	2	33 (77)	34 (28)	13 (13)
	3	22	23	18
Control trees	1	65	66	45
	2	68 (22)	68 (29)	36 (11)
	3	51	51	31

class appear to be overfilled, indicating a distribution of results that widely extends beyond the limits of 0 and 100% disease in the field. The width of the distribution of the results from mother trees at Gera and at Jima were tested through the determination of the differences $x = |\text{observed} - \text{median value}|$. This gave two new distributions which were tested by Wilcoxon's test. The mean value for Jima was significantly higher than Gera indicating a wider original distribution for the Jima data.

Differences between the average values of selected trees and control trees are shown for the various selection areas in Table 9. The correlations between results of field observations and field inoculation tests for Gera are shown in Table 10, and for Jima in Table 11. The field inoculation results were compared with the highest disease scores attained in the indicated period of observation. The rank

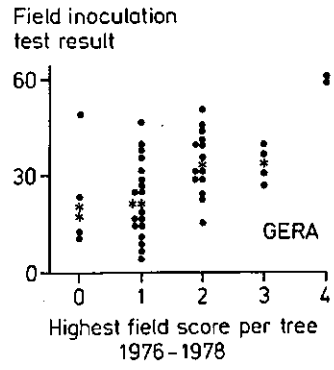
TABLE 10. Correlations between responses in field inoculation tests and in field observation scores of mother trees at Gera. For every tree, the highest field score over the indicated period was paired to the response in the field inoculation test (fractions of diseased or dropped berries were angularly transformed). Entries are Kendall's rank correlation coefficient (τ) and its significance $p(\tau = 0)$, for 48 tested trees.

Date of field inoculation	Period of field observations					
	76		76 + 77		76 + 77 + 78	
	τ	$p(\tau = 0)$	τ	$p(\tau = 0)$	τ	$p(\tau = 0)$
8.06.76	0.24	0.02	0.30	0.002	0.37	0.0004
8.07.76	0.16	0.08	0.20	0.03	0.37	0.0005
30.07.76	0.24	0.02	0.28	0.003	0.4	< 0.0001
Field inoculation response						
highest	0.19	0.05	0.23	0.01	0.39	< 0.0001
average	0.22	0.02	0.30	0.002	0.44	< 0.0001

TABLE 11. Correlations between the responses in field inoculation tests and the field observation scores of trees at Jima. For every tree, the highest field score over the indicated period was paired to the response in the field inoculation test (fractions of diseased or dropped berries, angularly transformed). Entries are Kendall's rank correlation coefficient (τ) and its significance $p(\tau = 0)$, for 33 tested trees.

Date of field inoculation	Period of field observations					
	75		76		75 + 76	
	τ	$p(\tau = 0)$	τ	$p(\tau = 0)$	τ	$p(\tau = 0)$
10.06.75	0.44	5.10^{-4}	0.30	2.10^{-2}	0.43	7.10^{-4}
11.07.75	0.60	$< 3.10^{-5}$	0.41	2.10^{-3}	0.60	3.10^{-5}
Field inoculation response						
highest	0.60	$< 3.10^{-5}$	0.36	4.10^{-3}	0.53	4.10^{-5}
average	0.58	$< 3.10^{-5}$	0.38	6.10^{-3}	0.63	$< 3.10^{-5}$

FIG. 10. Scatter diagram of the relation between field inoculation test results (mean of three successive field inoculations per tree) and field observation scores (highest observed field score per tree in the period 1976–1978) at Gera.
Abscissa: field observations, field score class (arbitrary scale from 0 to 6, see Table 4).
Ordinate: field inoculation test, fractions of diseased and dropped berries (angularly transformed).
The median value per field score class is indicated by *.

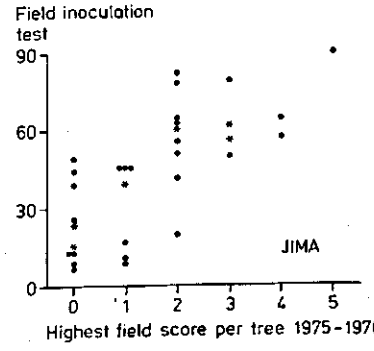


correlation coefficient was determined because a linear relation between the two variables is unlikely. The correlation improved with the number of years of field observations and the rank correlations for Jima were higher than those for Gera. In Figures 10 and 11, scatter diagrams show the relation between the average of the consecutive field inoculations and the highest field score in the observation period for Gera and Jima, respectively.

Differences among individual trees in the seedling inoculation tests were highly significant. The F value obtained from tests that were performed in 1977 and had three replications was 4.15 with 142 and 286 degrees of freedom. The distribution of the average results per tree of the seedling inoculation test are presented in Figure 12 for mother trees from Agaro, Gera, Washi, and Metu, and the tested trees from Jima. Averages and standard deviations per location are given in Table 12. The averages were compared by t-test with unequal variances: the average from trees at Metu was significantly lower than the averages for other locations. The standard deviation for the mother trees at Metu was significantly lower than the other standard deviations (F test).

The rank correlation between field observations at Gera and the results of the seedling tests made on mother trees at Gera are presented in Table 13. Only data from those trees were used which had an uninterrupted 3 years' series of field

FIG. 11. Scatter diagram of the relation between field inoculation test results (mean of two successive field inoculations) and field observation scores (highest observed field score per tree in the period 1975–1976) at Jima.
Abscissa: field observations, field score class (arbitrary units from 0 to 6, see Table 4).
Ordinate: field inoculation test, fraction of diseased and dropped berries (angularly transformed).
The median value per field score class is indicated by *.



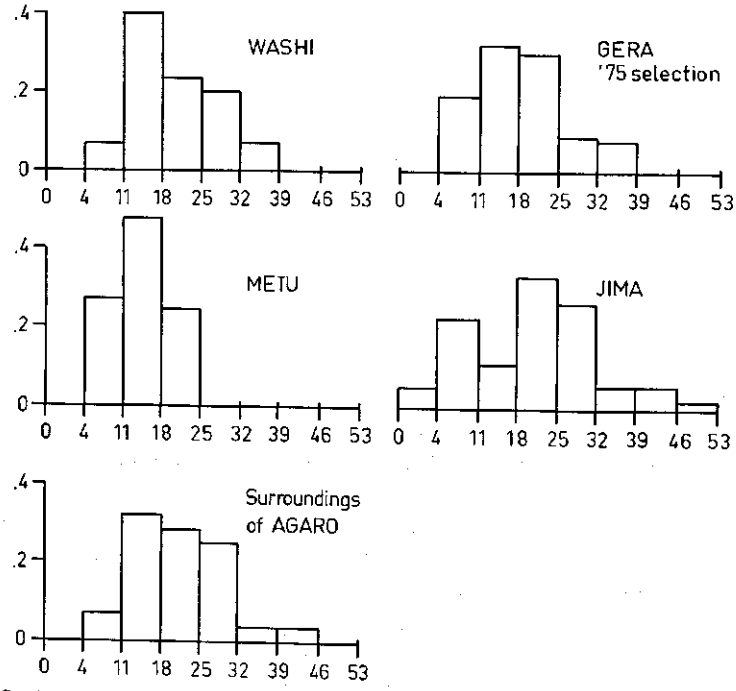


FIG. 12. Seedling inoculation tests. Relative frequency distributions of trees according to response in the test. Distributions are arranged according to the origin of the mother trees. For statistical analysis, see Table 12.
Abscissa: seedling inoculation test response (arbitrary scale from 0 to 90, see Section 4.3.3.).
Ordinate: relative frequency of trees.

observations. The highest field score observed during the indicated period was used. The correlation reaches a maximum after two years of field observations. A third year of field observations did not improve the correlation. The relation between the results of the seedling inoculation tests and three years' field observations for Gera is shown in Figure 13. The relation between the results of the seedling inoculation tests and the highest field score at Jima over 1975 and 1976 is

TABLE 12. Seedling inoculation tests. Responses arranged according to location of mother trees; mean response values $\bar{x}$ and standard deviations s per location are given. n is the number of trees, at each location, subjected to the test. In each column, values marked with the same letter do not differ at $p \leqslant 0.05$. $\bar{x}$ and s were tested by means of a t-test with unequal variances and an F-test respectively.

Location	n	$\bar{x}$	s
Metu	33	13.6 *a*	4.8 *a*
Gera 75 selection	87	18.4 *b*	8.4 *b*
Washi	30	19.8 *b*	7.7 *b*
Jima	36	20.4 *b*	11.0 *c*
Areas round Agaro	28	21.7 *b*	7.5 *b*

TABLE 13. Correlations between responses in the seedling inoculation test and field observation scores of mother trees at Gera. For every tree, the highest field score over the indicated period was paired to the response in the seedling inoculation test. Entries are Kendall's rank correlation coefficient (τ) and its significance $p(\tau = 0)$ for 34 trees.

Period of field observations	τ	$p(\tau = 0)$
1976	0.13	0.15
76 + 77	0.30	0.01
76 + 77 + 78	0.27	0.02

shown in Figure 14. Kendall's rank correlation coefficient was 0.30 and $p(\tau = 0) = 0.02$. One tree belonging to the French Collection with accession number F 58 is specially marked as it scored distinctly lower in the seedling inoculation test than could be expected from its field score. Neither for Gera nor for Jima the correlation between field inoculation tests and seedling inoculation tests was significant.

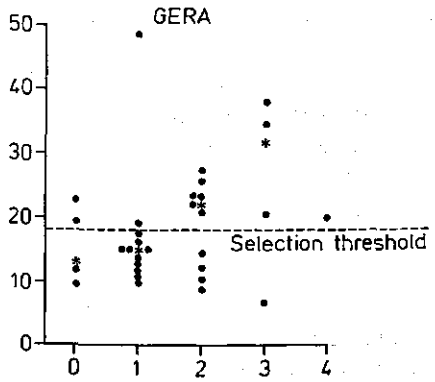


FIG. 13. Scatter diagram of the relation between responses in the seedling inoculation test (mean response of three tests per tree) and field observation scores (highest observed field score per tree in the period 1976–1978) at Gera.
Abscissa: field observations, field score class (arbitrary scale from 0 to 90, see Sec- 4).
Ordinate: seedling inoculation test response (arbitrary scale from 0 to 90, see section 4.3.3.).
The median value per field score class is indicated by *.

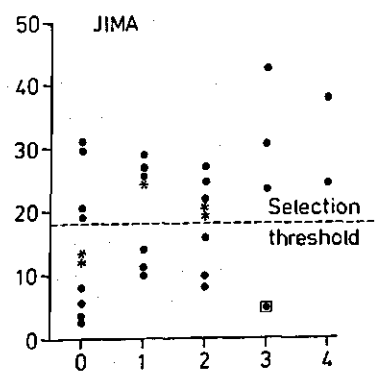


FIG. 14. Scatter diagram of the relation between responses in the seedling inoculation test (mean response of three tests per tree) and field observation scores (highest observed field score per tree in the period 1975–1976) at Jima.
Abscissa: field observations, field score class (arbitrary scale from 1 to 6, see Table 4).
Ordinate: seedling inoculation test response (arbitrary scale from 0 to 90, see Section 4.3.3.).
The median value per field score class is indicated by *.
An aberrant value in the seedling inoculation test (accession F 58) is indicated by □.

4.3.3.3. Discussion. The results of the series of field inoculation tests made at Gera showed that significant differences existed between trees both in the group of mother trees and in the group of control trees. The experiments at Jima brought into light a wide range of variation. The interaction between dates of inoculation and trees either reflects differences in growth stage of the berries or is an artefact due to a somewhat unsatisfactory transformation.

The field inoculation tests showed that large differences exist between the populations of mother trees and non-selected trees at Gera and elsewhere. This result confirms that the differences observed at selection are consistent and supports the hypothesis that these differences are mainly due to genetic factors. The possibility that extremely localized site effects caused a difference between control trees and selected trees, however remote it is, cannot be excluded.

Earlier, field inoculation reponses were compared per field score class (VAN DER GRAAFF, 1978 a). Results are reproduced in Table 14. The further data presented here show that field inoculation tests indeed give a satisfactory indication of susceptibility in the field. The finding that the rank correlation coefficient between field scores and field inoculation values for Jima exceeded that for Gera may be a reflection of two differences between these locations: (1) at Jima the range of susceptibilities tested was wider than at Gera, and (2) the microclimatological conditions at Jima were possibly more homogeneous than at Gera.

In the field inoculation test, the most interesting observation regarding the nature of the resistance was that all trees showed some disease, thus supporting the hypothesis that resistance to CBD is quantitative. In the seedling inoculation tests, obvious differences occurred between trees. The differences between the various selection areas might indicate differences in the conditions for development of CBD, and, thus, selection pressure between the locations. However, there is an alternative explanation (see below).

The correlation between field score and seedling inoculation test value was not strong. The poor correlation was partly caused by a number of trees with a poor field score but a good performance in the seedling inoculation test. A good example of this phenomenon was line F58 of the French Collection at Jima

TABLE 14. Field inoculation test responses arranged according to the field observation classes of the tested trees. Data of trees at Jima, and mother trees and control trees at Gera. Entries are number of tested trees (n) and the mean field inoculation response of the tested trees in each field observation class ($\bar{x}$). Values marked with the same letter do not differ at $p \leqslant 0.05$.

Field score	Jima		Gera	
	n	$\bar{x}$	n	$\bar{x}$
0	10	34 *a*	33	38 *a*
1	6	40 *a*	27	43 *ab*
>1	17	67 *b*	18	48 *b*
control trees			22	73 *c*

TABLE 15. Seedling inoculation test responses arranged according to the field observation classes of the tested trees. Data from trees at Jima and mother trees at Gera. Entries are number of tested trees (n) and the mean seedling test response of the tested trees ($\bar{x}$) in each field observation class. Values marked with the same letter do not differ at $p \leqslant 0.05$.

Field score	Jima		Gera	
	n	$\bar{x}$	n	$\bar{x}$
0	15	14.9 *a*	31	16.0 *a*
1	9	19.6 *ab*	28	21.0 *b*
>1	26	23.5 *b*	24	20.8 *b*

TABLE 16. Linear correlation coefficients between field inoculation and seedling inoculation test responses. Trees were arranged according to field observation score and correlation coefficients were separately calculated for trees with less than 1 % disease, for trees with more than 1 % disease, and for all trees. Data from tested trees at Jima and mother trees at Gera.

Field score	Jima		Gera	
	r	df	r	df
0 and 1	0.635**	14	0386*	44
>1	-0.155	15	-0.323	13
Total	0.256	31	0.241	59

(Figure 11). Probably due to the low correlation between field score and seedling inoculation test, the correlation between field inoculation values and seedling inoculation test values was not significant.

In an earlier publication, results obtained in the seedling inoculation test were grouped according to field score class (VAN DER GRAAFF 1978 a). Significant differences between the averages per field score class were observed (Table 15), thus indicating a relation between field scores and seedling inoculation test values. VAN DER GRAAFF (1978 a) also observed that the correlation between seedling inoculation test values and field scores became significant if trees with a field score $x > 0.01$ in 1976 were excluded from the calculations; this procedure apparently removed trees with an aberrant test response in the seedling inoculation test (Table 16).

One explanation of the erratic results in the seedling inoculation tests could be the existence of different vertical pathogenic abilities ('vertical races') within the pathogen population. The seedling inoculation tests were made with one isolate while inoculum in the field and inoculum for the field inoculation test came from many sources. This subject was discussed by VAN DER GRAAFF (1978 a) and is further treated in Chapter 5. There, the conclusion will be that in the case of accession F58 no indication for vertical resistance has been found. It must be concluded that in a number of coffee lines the resistance of young seedlings is not directly related to the resistance of berries. Such a result is not unexpected because the methodology of the seedling inoculation test is rather 'unnatural'.

The incubation phase probably induces thinness of the cuticle and possibly other reversible disorders. Differences in growth rate of seedlings may induce variation in the results of seedling inoculation tests. This could, for example, explain the low values in the seedling inoculation tests obtained with mother trees from Metu. Progenies of these mother trees have a dwarfed habitus, also suggesting a deviant growth rate of the seedling (Section 4.6.3.).

Tests comparable to the ones reported here were also made by VAN DER VOSSEN et al. (1976). They found a good correlation between the seedling inoculation test (hypocotyl test) and the corrected maximum field score, an unspecified combination of field inoculation and natural level of disease. In their work, only two cultivars showed a higher susceptibility in the field than was expected from the seedling test. As discussed earlier (VAN DER GRAAFF, 1978 a), the correlation coefficients calculated by VAN DER VOSSEN et al. (1976) might have a positive bias due to the bimodal distribution of the results of their seedling tests. They used the original scale with 12 classes. In this scale some of the middle classes are not equivalent to the classes at both ends of the scale, or, in other words, high and low values are overrepresented. Also, VAN DER VOSSEN et al. used many maximum and near-maximum values from the seedling inoculation test in their calculation. Near the end of the scale, the standard error decreases and thus also gives a positive bias to the correlation coefficient.

Summarizing, the seedling test can help to eliminate part of the susceptible coffee trees from a test population. Difficulties can be encountered if the population to be tested contains a large proportion of trees that do well in the seedling inoculation test but poor in the field because in that case no selection threshold can be established.

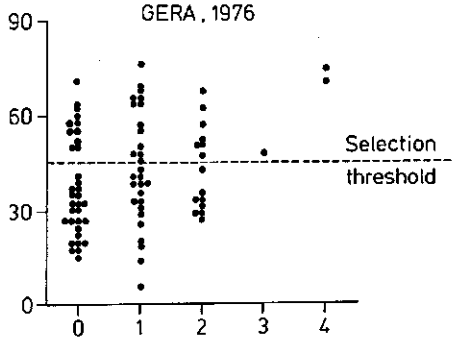
4.3.4. *The establishment of selection thresholds*

Observations of the trees selected in 1973 indicated that a disease level of $x = 0.01$ was the maximum which could be tolerated under field conditions; trees with a higher disease level invariably were unsatisfactory at a later date. Therefore, a maximum disease level of 1 % was tentatively adopted as the threshold level for reselection within the group of selected trees. The selection criteria for the various tests were based on this threshold value.

In the field inoculation test, preliminary thresholds for the 1976 planting were based on tests made at Washi and Jima in 1975. A more elaborate analysis of data was made when the results of field inoculation tests at Gera made in 1976 were available. For each tree, the test result of the inoculation date of which the mean test response was highest was paired with the field observations of 1976 at Gera (Fig. 15). The highest response of the three consecutive field inoculations was used to avoid the effects of the interaction between trees and inoculation dates, though in hindsight it may have been better to use the average (Section 4.3.3.). The selection threshold is placed at a highest field inoculation response of 45, because at higher values the number of trees with a field score over 1 increases rapidly. The threshold value of 45 was satisfactory in other selection areas also.

In the seedling inoculation test, preliminary selection criteria used in 1975 were

FIG. 15. Establishment of selection threshold. Scatter diagram of the relation between field inoculation test results (highest response of three successive field inoculations per tree) and field observation scores at Gera, in 1976.
Abscissa: field observations, field score class (arbitrary scale from 0 to 6, see Table 4).
Ordinate: field inoculation test, fraction of diseased and dropped berries (angularly transformed).



based on field observations made at Jima and Washi. The preliminary selection threshold used was close to the score attained by Rume Sudan. Later, a more elaborate study was made using the Jima and Gera field observations of 1976. Results for Gera obtained in the 1976 seedling inoculation tests are plotted against the 1976 field observation scores in Figure 16. Obviously, the group of trees with a high field score and a low response in the seedling inoculation test cannot be eliminated. A good selection threshold occurs between the values 15 and 20 in the seedling inoculation test. The response value of 18 was chosen as the selection threshold. This value was close to the test response of Rume Sudan. The selection threshold of 18 was used for the whole test series of 1976. In later years, reference material was used in the tests to reconstruct the selection threshold.

The effectiveness of the selection procedure can be ascertained by means of the field observations made at Gera in 1977 and 1978 (Table 17). Through the various tests and observations, the number of mother trees was reduced from 37 to 14. Out of these 14, only two trees showed an unacceptably high level of disease in the following years against 12 out of 23 of the rejected trees. Therefore, it can be concluded that the combination of seedling and field inoculation tests was effective in eliminating unsatisfactory mother trees.

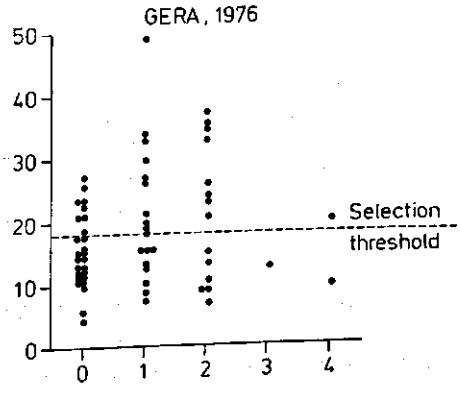


FIG. 16. Establishment of selection threshold. Scatter diagram of the relation between responses in the seedling inoculation test (mean response of three tests per tree) and field observation scores at Gera, in 1976.
Abscissa: field observations, field score class (arbitrary units from 0 to 6, see Table 4).
Ordinate: seedling inoculation test response (arbitrary units from 0 to 90, see Section 4.3.3.).

TABLE 17. Effectiveness of the various methods of selecting mother trees at Gera. The field scores obtained in 1977 and 1978 are used to evaluate the effectiveness of the methods of reselection, made in 1976, within the group of mother trees. The effectiveness of each method or combination of methods had to be evaluated by a $2 \times 2\chi^2$-test, since the number of trees was too small for a complete 4-way analysis.

Selection method: O = no extra selection of mother trees
A = extra field observation in 1976
B = field inoculation test
C = seedling inoculation test

Selection	Accepted (+)	Highest field score 77–78		χ^2	Percentage
Method	Rejected (–)	< 1	> 1		> 1
O		24	13		35
A	+	23	7	9.7**	23
	–	1	6		86
B	+	18	5	4.4*	22
	–	6	8		57
C	+	17	5	3.7	23
	–	7	8		53
AB	+	17	3	7.7**	15
	–	7	10		59
AC	+	17	3	7.7**	15
	–	7	10		59
BC	+	13	2	5.3*	13
	–	11	11		50
ABC	+	13	1	7.7*	7
	–	11	12		52

4.4. PROPAGATION

The objective of the CBD resistance programme was to produce seed of resistant coffee types in the shortest possible time. These types should also show a high yield and quality potential and a high resistance level to other diseases and pests.

C. arabica is self fertile and, in general, only shows a low percentage of cross fertilization. Recent data obtained in Kenya (VAN DER VOSSEN, 1975) show that cross pollination varies between 7 and 17% with an average of approximately 10%. *C. arabica* is normally propagated by seed. Vegetative propagation is possible, but only cuttings from orthotropic branches will produce normal trees. This fact seriously restricts the applicability of vegetative propagation for the production of new trees. A tree should be 'trained' for the production of cuttings and the maximum production from such a tree will not exceed one hundred cuttings per annum.

In an early phase of the programme, it was doubted whether low levels of cross pollination would occur under Ethiopian conditions and it was envisaged that vegetative propagation was imperative to avoid unacceptable levels of genetical

diversity. Therefore, provisions were made for large scale rooting of cuttings. However, observations made in 'single tree' progenies at Jimma Research Station showed that progenies from seed were sufficiently homogeneous (PERSON, 1974; ROBINSON, 1974). Furthermore, the mother trees are all extreme genotypes and they will, therefore, possess a higher level of homozygosity than the unselected *C. arabica* population (PERSON, 1974).

Gera, a location where CBD consistently was at a high level, was chosen for multiplication; material with a satisfactory level of resistance there will suffice everywhere. Progeny plots had to be large in view of both scientific and practical considerations. Large numbers are needed to arrive at adequate loss predictions and to obtain indications on the level of homogeneity of a progeny. The coffee replanting programme of the Ethiopian Government will also require large quantities of seed of the satisfactory progenies. If adequate numbers of seed can immediately be produced from progeny plots instead of needing an extra multiplication phase, some three years are saved. Thus, it was decided to form plots of up to 1,000 trees per progeny.

Multiplication started immediately after the selection of a mother tree in the field. Progenies remained in the nurseries for about one year and a half, thus allowing ample time for field observations and for field and seedling inoculation tests on the mother trees. Multiplication was the responsibility of the Coffee Pathology Section until June 1975, when, on arrival of Mr. R. G. WHITE, FAO Coffee Agronomist, these responsibilities were handed over to the Coffee Agronomy Section. Multiplication started in early 1974 when seeds of the mother trees selected in 1973 were sown in nurseries at Jima. Additional nurseries were constructed in early 1975, containing some 300,000 seedlings of mainly 1974 mother trees. In 1976, 250,000 seedlings were planted in pre-nurseries of which 175,000 were planted in nurseries after discarding of mother trees through seedling tests. In 1977, some remaining progenies from mother trees and some progenies from interesting accessions from Jimma Research Station were propagated.

Some 15 of the progenies present in the 1974 nurseries were planted at Gera in 1975. These plots were small to full sized (up to 1,000 trees per progeny) and the remainder of the progenies were planted at Gera as a collection in plots of up to 25 trees. The 1975 planting consisted of some 9,000 trees and covered approximately 3 ha (at 3,200 trees.ha^{-1}). The progenies planted in 1975 came from mother trees selected in 1973 and observed again in 1974, but the mother trees had not been subjected to extensive testing before planting of the progenies. Seedling inoculation tests were made in 1976, while results of field inoculation tests on some of the trees were not available until August 1975. In 1976, 77 progenies were planted from the 1975 nurseries, 72 were new and 5 progenies had also been planted in 1975. In total some 55,000 seedlings were planted. Most of the mother trees had been screened by field and seedling inoculation tests before planting the progenies. In 1977 (1976 nurseries), 58 new progenies were planted and additional seedlings were planted of 7 progenies which had been planted earlier. In total, 45,000 seedlings were planted. All mother trees had passed the

seedling inoculation test and most of them had passed the field inoculation test before the progenies were planted. In 1978, 11 new progenies were planted and new seedlings were added to 4 progenies which had been planted earlier. The progenies consisted of those 1974 and 1975 selections, which had not been tested timely or of which seed was not available in time, and of a number of promising accessions from the French Collection at Jimma Research Station. The mother trees had passed the seedling inoculation test and most of them had been subjected to the field inoculation test. Before planting, the progenies were all tested for resistance to *Gibberella xylarioides* (Section 6.2.4.).

In order to make studies on yield potential, resistance to diseases and pests, and agronomic characters, progenies were also planted in 'progeny trials'. The trials were planted at Gera and at the substations at Metu, Agaro, Wonago and, in part, at Mugi. The planting of trials at various places permitted evaluation of the progenies under different growth conditions. The lay out of the trials is given in Section 6.2.2.1.

4.5. Appraisal of the resistance of progenies

Time was an extremely important factor in the CBD programme; each year lost in one of its stages meant high and accumulating losses in revenues due to delays in replacing susceptible by resistant material. It was, therefore, considered essential to appraise the level of CBD resistance and the degree of homogeneity of this resistance among trees of individual progenies at the earliest possible time. The appraisal of the homogeneity of the progenies with regard to resistance necessitated large numbers (Person, 1974). The progenies were studied by means of extensive field observations: field estimates of the disease level and berry counts.

The large sized progeny plots rendered the use of replicated trials for CBD assessment impossible. Furthermore, a considerable variation in CBD level occurs from year to year. It was consequently necessary to use a laboratory test that is relatively free from site and year specific effects. The only meaningful test available was a test on detached berries (Bock, 1956; Firman, 1964).

4.5.1. *Field observations*

Field observations were made to obtain information on the level of resistance under field conditions. To ensure the presence of inoculum, all progenies were sprayed with a conidial suspension in the year before the first flowering was expected. The observations were made at Gera, a site chosen for its consistently high levels of CBD. Apart from an assessment of the disease level under field conditions, it was hoped that variation within progenies due to genetic factors could be separated from environmental variation. The percentage of visibly diseased berries was estimated to obtain data on disease severity, and berry counts were made to acquire accurate data on damage due to drop and disease of berries.

TABLE 18. Field assessments. Percentage scores used to assess the disease severity.

0	1	5	10	20	30	40	50	60	70	80	90	95	99	100

4.5.1.1. Materials and methods. Progenies planted in 1974 (Section 4.4) predominantly had their first crop in 1977. Most of the progenies planted in 1976 flowered for the first time in 1978. The lay-out of the plots was discussed in Section 4.4. Progenies were sprayed with a conidial suspension of *Colletotrichum coffeanum* in order to establish the fungus on the bark. Conidial suspensions were prepared from diseased berries. Berries were rinsed, incubated overnight, and conidia were washed off the next day. Conidial concentrations were not determined, but a standard amount of berries was used per sprayer tank. Sample counts indicated concentrations in the range of 10^4 conidia.ml^{-1}. The suspension was applied to the trees by means of a motorized mist blower and the trees were sprayed on overcast days when rain could be expected.

Field assessments were made by estimating the percentage of diseased berries on individual trees. To facilitate the work, a limited number of percentage scores was used (Table 18). In 1977, field assessments were made of progenies that had their first crop. Progenies were scored on 29.06.77, 26.07.77 and 20.09.77. The number of trees assessed per progeny varied from 25 to 800 according to progeny size. In 1978, field assessments were made on progenies that flowered for the first time, and some of the progenies that had already been assessed in 1977. One hundred bearing trees per progeny were scored about 11.08.1978. Progenies already scored in 1977 did not always have 100 bearing trees. Observations made before 11.08.1978 were not pursued because disease levels were extremely low.

TABLE 19. Field assessments. CBD severity in 1977 and 1978 in some progenies with a first crop in 1977. Entries are percentages of diseased berries per progeny and, within brackets, the percentages of trees with more than 1% diseased berries. The green tipped progeny 7385 contained 8% trees with bronze tipped leaves; disease severity is also indicated for green- and bronze-tipped categories.

Progeny	Date			
	29.06.77	26.07.77	20.09.77	11.08.78
7324	0.4(1)	2.6(18)	4.8(11)	
7330	0.2(0.3)	0.9(3)	1.2(5)	2.9(13)
7332	2.6(2)	2.2 (5)	2.2 (6)	0.8(11)
7352	3.0(13)	2.9(13)	11.5(10)	
7353	0.4(14)	13.9(52)	13.7(48)	7.4(51)
7395	0.1(1)	8.8(62)	28.8(89)	
741	0.1(0)	0.2 (1)	0.1(1)	0(0)
731	31.0(94)			
7385	1.5(6)	2.9(7)	12.0(21)	4.5(10)
7385 green tip	–	0.6(2)	1.9(14)	
7385 bronze tip	–	28.8(28)	57.0(81)	
old coffee in vicinity	–	59.0(4)	50.3(84)	

Berry counts were only made in 1978. For each progeny, twenty five bearing trees were selected, following the rows of planting but avoiding the two outer rows; obvious off-type trees were omitted. One bearing branch was marked on each selected tree. Per branch, the total number of berries and the number of diseased berries were recorded at three weekly intervals. Flower buds, flowers and berries formed after the first count were removed. Flowering occurred in the 6th week of 1978; counting started in the 13th week and continued until the 34th week.

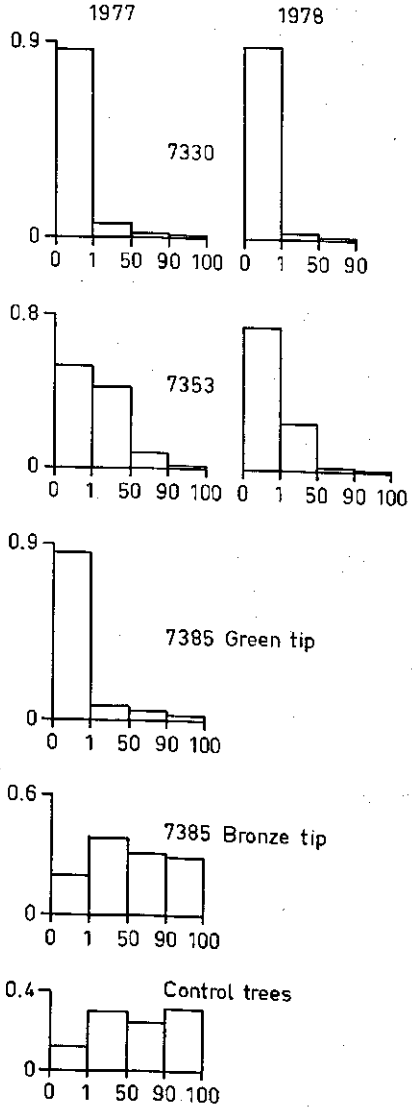
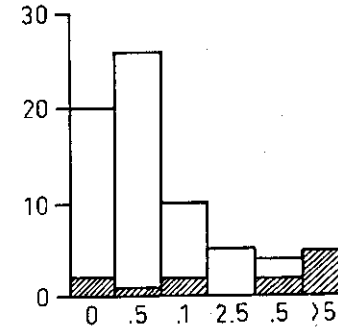


FIG. 17. Field assessments. Relative frequency distribution of trees, of some progenies, according to disease severity. Field estimates of 20.09.77 and 11.08.77.
Abscissa: percentage of diseased berries per tree.
Ordinate: relative frequency of trees.

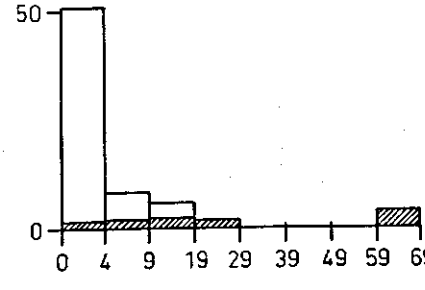
FIG. 18. Field assessments. Frequency distribution of progenies according to mean percentage of diseased berries. Field estimates made at Gera, August 1978.
Abscissa: percentage of diseased berries.
Ordinate: number of progenies.
Unshaded: progenies with their first crop in 1978.
Shaded: progenies with their second crop in 1978.



4.5.1.2. Results. The results of the 1977 field assessments are presented in Table 19. The detection level of disease probably was between 1 and 5% and, therefore, the percentage of trees with more than 1% disease is also shown in the table. Disease severity on the first observation date was low and only the susceptible 731 (a Harer coffee type from Wendo Genet) showed a high level of disease. 731 was not assessed on 26.07. and 20.09.1977. Instead, 100 old coffee trees in the vicinity of the progeny blocks were scored. Some 8% of the trees constituting progeny 7385 had bronze tipped leaves while the remainder had green tipped leaves. For both types of trees the disease severity is shown in the table. Some of the progenies were reassessed in 1978 and the results of that assessment are also shown in Table 19. The distribution of the disease severity over individual trees is presented in Figure 17 for the progenies 7353, 7330, 7385, and for old coffee in the vicinity. The level of disease in progenies that had their first crop in 1978 was low. The frequency distributions of disease severity per progeny is shown in Figure 18 and the frequency distribution of the percentage of trees with more than 1% infection per progeny is presented in Figure 19.

In berry counts, the number of berries gradually decreased over the subsequent observations. The decrease occurred both in progenies remaining free from CBD and in progenies showing disease. The reduction of the number of berries on progenies where no CBD was seen on the observed branches is probably physiological although parasites such as berry boring moth or, occasionally, CBD might cause some extra drop. This reduction is further called 'normal

FIG. 19. Field assessments. Frequency distribution of progenies according to percentage of trees with more than 1% disease. Field estimates made in August 1978 at Gera.
Abcissa: percentage of trees with 1% disease; note that disease intervals are not equal.
Ordinate: number of progenies.
Unshaded: progenies with their first crop in 1978.
Shaded: progenies with their second crop in 1978.



drop'. The percentage berries remaining at each observation date *(R)* was calculated as

$$R = \frac{100}{25} \sum_{i=1}^{25} \frac{n_{it}}{n_{i1}} \qquad (4.3),$$

where i is the branch observed on the i^{th} tree, n_{it} is the number of berries on the observed branch of the i^{th} observed tree at observation time t, and n_{i1} is the number of berries on the observed branch of the i^{th} observed tree at the first observation date. Progenies on which no CBD was observed during the successive berry countings lost an average of 21.3 % of their berries between week 13 and 34; the distribution of the losses over the progenies with their first crop in 1978 is shown in Figure 20. Significant differences occurred between progenies.

In the berry counts, the first CBD lesions were observed on the most susceptible progenies in week 19. The number of progenies with diseased berries on the observed branches gradually increased with time. In diseased progenies, the number of diseased branches gradually increased as did the number of affected berries on diseased branches. In each progeny, however, a number of branches remained without diseased berries. Figure 21 illustrates the difference between berry drop and disease of all branches and drop of disease-free branches in two progenies. Clearly, there is a 'normal drop' and a superimposed 'pathogenic' damage by CBD consisting of dropped and diseased berries. An estimate of 'normal' drop cannot be derived from disease-free progenies as there are significant differences between progenies with respect to 'normal' drop. These differences remain when only the observation period between the 19th week (in which the first CBD was observed) and the 34th week is taken into consideration. Drop is this period varies between 10 and 29.6 percent of the berries present in week 19 and F calculated for angularly transformed fraction of drop was 4.98 with 19 and 480 degrees of freedom ($p < 0.01$).

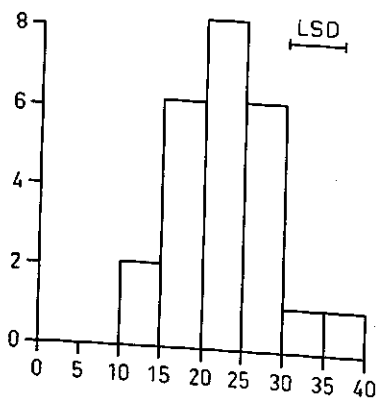


FIG. 20. Berry counts. Progenies in which all counted branches remained CBD free. Frequency distribution progenies according to 'normal drop' of berries. Berry counts made at Gera, 1978. Data from progenies producing their first crop in 1978. The percentage drop was determined over the period from week 13 through week 34. Drop differed significantly among progenies; in a one-way analysis F was 6.4 (19 and 360 df, $p < 0.01$) and F was 4.9 ($p < 0.01$) when the analysis was made with angularly transformed data.
Abscissa: percentage dropped berries.
Ordinate: number of progenies.
The LSD at $p = 0.05$ is indicated.

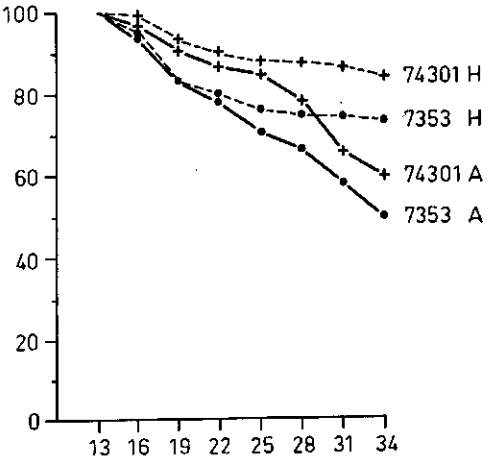


FIG. 21. Berry counts. Progenies with CBD. Percentage remaining healthy berries on branches without CBD compared with percentage remaining healthy berries on all counted branches. Data from progenies 7353 and 74103 at Gera in the period of week 13 through week 34, 1978.
Abscissa: time, in weeks.
Ordinate: percentage remaining healthy berries.
H: healthy branches.
A: all branches.

A correction for the 'normal' drop of each progeny at week t can be derived from the percentage remaining healthy berries on branches without CBD (R_h):

$$R_h = \frac{100}{25} \sum_{h=1}^{n} \frac{n_{ht}}{n_{h19}} \qquad (4.4),$$

where h is the healthy branch on the h^{th} tree, n_{19} is the number of berries on the observed branch at week 19, and n_{ht} is the number of berries on the observed branch at week t. The percentage of healthy berries on all branches (R_t) at week t is:

$$R_t = \frac{100}{25} \sum_{i=1}^{25} \frac{K_{it}}{n_{i19}} \qquad (4.5),$$

where K_{it} is the number of healthy berries on the i^{th} branch at week t, and n_{i19} is the number of berries on the i^{th} branch at week 19. The percentage of damage by disease and pathogenic drop (D_{CBD}) is then calculated:

$$D_{CBD} = \left(\frac{R_h - R_t}{R_h}\right) \times 100 \qquad (4.6).$$

The method for damage assessment proposed here may still produce uncertainties because the 'normal drop' of susceptible progenies could also include a higher number of berries that are diseased but drop off before the lesions are noticed. Therefore, losses due to 'normal' drop from disease-free progenies and those showing disease were compared. Average and median values differed only

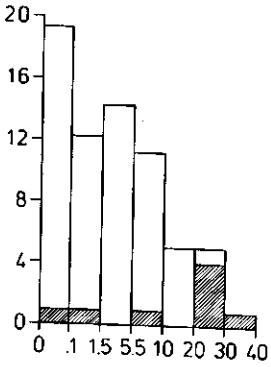


FIG. 22. Berry counts. Frequency distribution of progenies according to percentage of berries dropped or diseased due to CBD. Data from berry counts at Gera, 1978.
Abscissa: percentage of berries dropped or diseased due to CBD. Note that intervals are not equal.
Ordinate: number of progenies.
Unshaded: progenies having their first crop in 1978.
Shaded: progenies having their second crop in 1978.

slightly and significant differences could not be established; $P(H_0) = 0.18$ in Wilcoxon's rank sum test under the H_0: normal drop in disease-free progenies equals normal drop in diseased progenies. Furthermore, no higher 'normal drop' was observed in progenies with a high level of CBD.

Among progenies, damage calculated by equation (4.6.) varied between 0 and 36 percent. The frequency distribution of the damage at week 34 is shown in Figure 22. For a few progenies, damage progress is shown in Figure 23. The correlation between berry counts and field assessments was highly significant (Table 25).

4.5.1.3. Discussion. In field assessments, differences in disease severity between progenies were marked in both 1977 and 1978. Differences observed in 1977 were found again in 1978. Progenies scored for the first time in 1978 generally showed a low level of disease.

The level of homogeneity of progenies was difficult to assess by field assessments. To make such an assessment, a scale is needed on which phenotypical variability is binomially distributed. In the construction of such a scale two difficulties were encountered, one practical and one fundamental. The practical difficulty was that no material was available of which the homogeneity was confirmed.

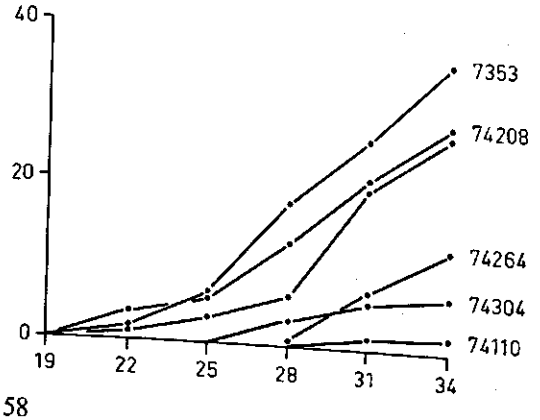


FIG. 23. Berry counts. Damage progress curves for selected progenies. Data from berry counts at Gera, 1978.
Abscissa: time, in weeks.
Ordinate: percentage of berries dropped or diseased due to CBD.

A fundamental difficulty was posed by the two stages in the CBD epidemic: condidia from the bark, from remaining mummies of last year's crop (GASSERT, 1976), or from other trees will cause the beginning of the disease development of the berries on a tree. In this initial phase, conidial densities will be low, and the chance that a berry will become diseased will be relatively low, because the chance that a berry becomes diseased is related to the conidial density (Section 4.5.2). When a berry is diseased, the esodemic (the epidemic within the tree) begins. The lesion produces many conidia and adjacent berries will easily be infected. Resistance that considerably reduces the chance of disease development resulting from the initial phase, may be insufficient to limit the esodemic, and thus large differences in disease severity may be expected in intermediately resistant material. Variation in disease severity will be much lower in progenies where resistance is too low to limit disease development in the initial phase, and in those in which resistance is so high that the progress of the esodemic is strongly reduced. The limits of the three categories are environmentally determined.

Although the level of homogeneity was difficult to assess by means of field observations, the differences observed between disease levels of bronze and green tipped trees in progeny 7385 indicate that differences in disease severity in the field reflect genotypical variability. Comparable observations were made in progeny 741 though the number of obvious 'off-types' was lower. It is likely that such two-class progenies arise from homozygous mother trees with an adequate level of resistance; if so, the susceptibles arise from cross pollination. Comparing progenies, we may expect a relation between disease incidence, disease severity being measured as the percentage of diseased berries per tree and disease incidence being expressed as percentage of trees with more than 1% infected berries (Figure 24). At the same disease incidence level, a heterogeneous progeny will show a higher disease severity than a homogeneous progeny. In resistant progenies, a relatively high disease severity level at a relatively low disease incidence will indicate a high disease severity on a few trees that probably are a result of cross pollination (see Figure 24). The progenies that have a limited number of such 'outcrossers' can easily be purified through reselection and removal of susceptibles. At the end of the season, promising progenies were surveyed for trees with CBD and trees with more than 1% disease were removed. This purification operation was successful in progeny 741; after removals in 1977

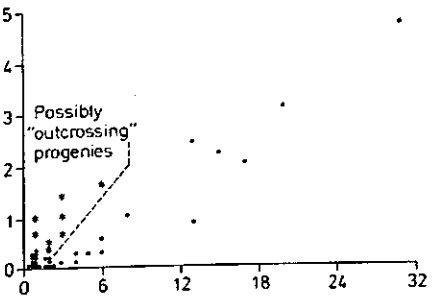


FIG. 24. Field assessments. Scatter diagram of the relation between disease severity (percentage of diseased berries per tree per progeny) and disease incidence (percentage of trees with more than 1% infection) in progenies at Gera, 1978. Only data from progenies having their first crop in 1978 were used.
Abscissa: percentage of trees with more than 1% infection.
Ordinate: percentage of diseased berries.
*: Possibly 'outcrossing' progenies.

and 1978, no further removals were needed in 1979 (FEKADE and MESERET, pers. comm.).

In 1979, the levels of disease in the field assessment correlated well with the scores of 1978 (FEKADE and MESERET, pers. comm.). Disease severity and incidence increased in susceptible progenies observed for the first time in 1978. The increase is probably caused by an increase in initial inoculum, which arose from more infected bark and the presence of mummified berries from the 1978 crop. GASSERT (1976) found that the presence of mummies significantly increased disease levels. Some disease increase may also have been due to a heavier crop in 1979, which presented better conditions for disease development.

In berry counts, the 'normal drop' was considerable after the pinhead stage. Although some of the drop may have resulted from parasitism, most of the drop represented an adjustment to the physiological status of the trees. The method used to calculate CBD damage in berry counts was the only acceptable way to correct for differences in 'normal drop' between progenies. Data on minor damage and small differences in damage may not be accurate, but low damage levels are of little importance. The progenies were tested in an area highly conducive to CBD and therefore damage in other locations will normally be less than at Gera.

The study of disease progress curves and of VAN DER PLANK's (1963) apparent infection rate r seemed rather pointless. The progenies in which this was possible were too susceptible to have practical value and as a result conclusions concerning the nature of the resistance could not be made.

Damage data obtained in 1979 correlated well with those of 1978 (FEKADE and MESERET, pers. comm.). Damage in more susceptible progenies was generally higher in 1979 than in 1978, as was the case with disease severity.

Correlations between berry counts, disease severity, and incidence are presented in Table 25. It can be observed that the various field observation methods correlated well.

4.5.2. *Detached berry tests*

A laboratory test was needed to confirm the data obtained in the field. Detached berry tests have been used in Kenya (BOCK 1956; FIRMAN, 1964) for the identification of resistance, but their relation to field observations was recently questioned (VAN DER VOSSEN et al., 1976). Preliminary tests made in 1976 showed a satisfactory reproducibility. Some of these tests were repeated in 1977 and 1978 to determine the scope of the test. The results of one comprehensive experiment are presented in the following section. The preliminary tests led to the decision to use the test at fixed intervals during the season to identify the developmental stage of the berries at which the best correlation between test responses and field observations occurred. In some tests, different berry sizes were also used and one of these is given to illustrate the relation between berry size and susceptibility.

4.5.2.1. Methods Berries were surface sterilized in laundry bleach (5.25% hypochlorite, diluted between 5 and 10 times) for 5 minutes and washed in

distilled water. Fifty berries were arranged in a plastic box on damp sand or tissue paper. Inoculum was prepared from berries with active lesions collected from the field, except in some experiments early in the season, when cultures had to be used (Section 4.3.3.1.). The berries were inoculated by placing a drop of a suspension of CBD conidia on each berry. The boxes were hermetically closed after inoculation to maintain the high relative humidity needed for infection and symptom development. The tests were normally replicated four times and the numbers of diseased berries were recorded 6 and 9 days after inoculation. For calculation, the fractions of diseased berries were angulary transformed. In 1978, some changes were made in the methods to facilitate the handling of large numbers of tests. The changes consisted of the omission of surface sterilization and the use of foam plastic with hollows as a substrate. The boxes were also lined with wet tissue paper to maintain a high level of humidity. The changes in method resulted in somewhat lower percentages of diseased berries.

An experiment on the scope of the test was laid out with conidial concentrations of $10^{6.5}$, 10^{6}, $10^{5.5}$, and $10^{4.5}$ conidia.ml^{-1}. Small, intermediate, and fully expanded berries were collected from progenies at Gera. The collection of berries from progenies was made in such a way that every picked tree had an average of one berry in each replication of that progeny. The small sized berries could, however, only be obtained from a few 'out of season' trees, so that sampling could not follow the method described. The weight of 100 berries was recorded to obtain information on berry sizes. All treatments on progeny and berry size were replicated three times.

Detached berry tests on progenies at fixed intervals were made on 17.05, 31.05, 15.06, 28.06, 12.07, 28.07, 10.08, and 24.08. 1977 and on 3.05, 23.05, 13.06, 4.07, and 26.07. 1978. In 1977, berries were more or less randomly collected. Pickers were told to collect only a few berries per tree and then to proceed to the next tree of the same progeny. The sampling method was standardized in 1978. After picking five berries per tree the pickers proceeded to the next tree of the same progeny. A total of 250 berries were collected per progeny. Pickers were instructed to pick the largest size berries and to avoid obvious 'off-types'. Hundred berry weights were recorded to see whether the berries were in the fully expanded stage. On 17.05.77 and 31.05.77 not all berries were fully expanded. In a number of experiments berries of smaller sizes were included to obtain information on the susceptibility of such berries. Often, a rot of the small sized berries appeared between the 6th and the 9th day. This rot did not occur in the experiment of 15.06.1977. The density of the inoculum was usually 2.5×10^{5} conidia.ml^{-1}. In 1978, a density of 4×10^{5} conidia.ml^{-1} was used for the tests of 13.06, 4.07 and 26.07. All tests were replicated four times.

4.5.2.2. Results. The experiment on the scope of the test is presented in Table 20. For the small berries, observations after six days are given as the disease after 9 days was heavy but difficult to distinguish from ordinary rot. For the other two berry sizes, the level of disease after 9 days is indicated. The disease level of these berries after 6 days was negligible. The analyses of variance are presented in the

TABLE 20a. Detached berry tests. Responses with varying inoculum densities, progenies, and berry sizes (1978). Small berries were scored after 6 days, intermediate and big berries after 9 days. Entries are angularly transformed fractions of diseased berries.

Progeny	Hundred berry weight	Inoculum density in log conidia.ml^{-1}					
		6.5	6.0	5.5	5.0	4.5	Mean
741	4	36	35	28	34	24	21
	79	27	24	13	20	8	18
	119	36	19	18	14	16	21
7332	10	34	28	38	27	7	27
	81	22	17	20	19	9	17
	101	22	25	24	18	15	21
74208	12	58	57	63	57	45	56
	71	39	34	39	41	26	36
	120	27	33	20	23	15	23
7422	18	57	46	42	43	26	43
	61	23	36	26	21	10	23
	119	37	48	28	12	14	32
7395	19	66	44	45	36	32	45
	63	55	62	46	33	43	48
	100	57	32	40	40	24	38

TABLE 20b. ANOVA of data from Table 20a. Data for small berries were analyzed with one missing number, and for large berries with three missing numbers, according to an unweighed analysis of cell means (SNEDECOR and COCHRAN, 1967).

Small berries (6 days) Source of variation	df	ss	F
Treatments	24	4246	6.5**
Densities	4	1178	10.8**
Progenies	4	2604	24.0**
Interactions	16	463	1.1
Error	49		

Large berries (9 days) Source of variation	df	ss	F
Treatments	49	8043	6.7**
Densities	4	4612	47.3**
Progenies	9	1793	8.2**
Interactions	36	1638	1.9**
Error	97		

table; all main effects were significant, but interactions were also significant for the two larger berry sizes. Part of the interaction may have been due to differences in regression coefficients between disease response in the test and the logarithm of the conidial concentration. The regression coefficients are given in

TABLE 21. Detached berry test of Table 20. Regression coefficients for density of inoculum (log conidia.ml^{-1}) versus test response. Entries are: regression coefficients, per berry size, for untransformed (O) and transformed (T) fractions of diseased berries in the test. Kendall's coefficients of concordance (w) between the rankings of the regression coefficients according to berry size were 0.78 (untransformed data); and 0.76 (transformed data); $p(w = 0)$ values were respectively 0.026 and 0.028.

Progeny	Berry size						Mean	
	Small		Interm.		Big			
	O	T	O	T	O	T	O	T
741	8.4	8.3	10.1	8.8	6.9	4.8	8.7	7.3
7332	4.3	5.4	4.4	4.0	10.2	7.2	6.3	5.5
74208	6.0	3.8	9.2	7.0	8.5	5.3	7.9	5.3
7422	8.9	8.1	21.9	16.5	20.5	12.8	17.1	12.5
7395	16.1	10.6	16.2	10.7	21.9	15.3	18.1	12.2
Mean	8.7	7.7	12.5	9.4	13.6	9.1		

Table 21 together with the regression coefficients that were calculated from the original data, which were not angularly transformed. The latter were calculated to prevent any unwanted effect, resulting from the transformation. The regression coefficients were considered as new variates, were ranked according to berry size, and Kendall's coefficient of concordance *(w)* between the three rankings was calculated. W was significant for regression coefficients from transformed and untransformed disease data, indicating that the regression coefficients differ among progenies.

As indicated, detached berry tests were made at fixed intervals. One of these experiments also yielded valuable data on the susceptibility of various berry sizes. The results of this experiment, made on 15.06.1978, are shown in Figure 25. Small berries show more disease than intermediate or fully expanded berries, but the difference in test response between intermediate and fully expanded berries is not significant.

Table 22 gives an ANOVA of test rest responses in the 1977 series of experiments with large sized berries. Main effects and interactions were significant, indicating that separate analyses had to be made for each inoculation date.

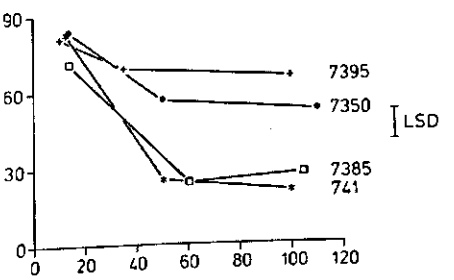


FIG. 25. Detached berry tests. Disease response versus weight of 100 berries for selected progenies at Gera. Data from experiments made in 1977.
Abscissa: weight of 100 berries, in grams.
Ordinate: fraction of diseased berries (angularly transformed).
Entries: progeny numbers.
The LSD at $p = 0.05$ is indicated.

TABLE 22. Detached berry tests. ANOVA of test responses of large berries of progenies at Gera tested on 17.05.77, 31.05.77, 15.06.77, 28.06.77, 12.07.77, 28.07.77, 10.08.77 and 24.08.77. The fractions of diseased berries were angularly transformed before analysis. The ANOVA was made according to a non-weighted analysis of variance with 4 missing numbers.

Source of variation	df	ss	*F*
Treatments	191	38781	14.8**
Inoculation dates	7	7637	79.9**
Progenies	23	14805	46.8**
Interactions	161	16280	7.4**
Error	570		

Comparable data were obtained in 1978. Responses of detached berry tests with various progenies from Gera made on 10.08.1977 and 26.07.1978 are shown in Figure 26. The progenies tested in both years are indicated in the figure. The correlation between the responses at the the two dates is low; Kendall's rank correlation coefficient ($\tau = 0.19$) was not significantly different from 0. However, if the rankings of the mean test responses over the whole test series of 1977 are compared with the rankings of the mean test responses over the last four testing dates of 1978, high levels of significance were observed: $\tau = 0.830$, p ($\tau = 0$) = 0.01. On the first testing date of 1978, some progenies were not used and therefore these data were omitted from the calculation.

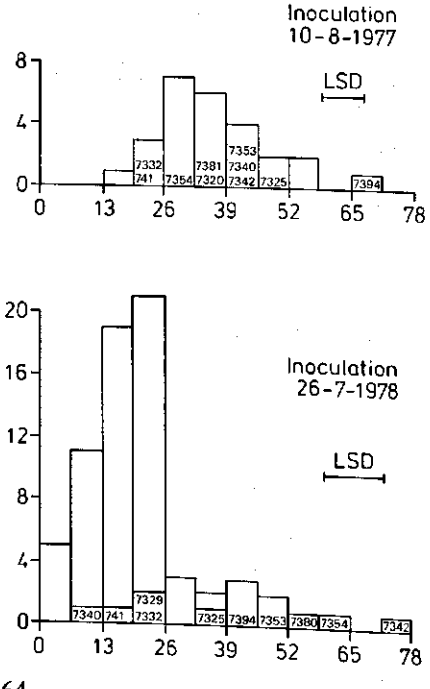


FIG. 26. Detached berry tests. Frequency distribution of progenies according to disease response in the test. Data from the 1977 and 1978 progeny testing.
Abscissa: fraction of diseased berries in the detached berry test (angularly transformed).
Ordinate: number of progenies.
Entries: progenies common to both test series.
The LSD at $p = 0.05$ is indicated.
Note that the relative change in disease response of the numbered progenies is far more than the respective LSD's indicating interaction effects between date of inoculation and progeny.

TABLE 23. Correlations between responses in the detached berry test and field assessments of progenies at Gera (1977). Disease incidence is the percentage of trees with more than 1 % diseased berries. Disease severity is the percentage of diseased berries. Fractions of disease in the detached berry tests were angularly transformed before analysis. Entries are Kendall's rank correlation coefficient (τ) and its significance $p(\tau = 0)$ for 11 progenies.

Date of detached berry test	Field observations							
	Disease incidence				Disease severity			
	26.07.77		20.09.77		26.07.77		20.09.77	
	τ	p	τ	p	τ	p	τ	p
17.05.77	0.35	0.08	0.16	0.27	0.38	0.06	0.20	0.22
31.05.77	0.46	0.03	0.45	0.03	0.53	0.02	0.38	0.06
15.06.77	0.31	0.11	0.24	0.18	0.31	0.11	0.20	0.22
28.06.77	0.53	0.02	0.38	0.06	0.60	0.006	0.13	0.32
12.07.77	0.49	0.02	0.53	0.02	0.42	0.04	0.45	0.03
28.07.77	0.49	0.02	0.09	0.38	0.46	0.03	0.13	0.32
10.08.77	0.60	0.006	0.53	0.02	0.67	0.003	0.45	0.03
24.08.77	0.49	0.02	0.16	0.27	0.42	0.04	0.16	0.27
Mean DBT	0.56	0.01	0.35	0.08	0.64	0.004	0.27	0.14

Kendall's rank correlation coefficients between the rankings of the responses in the consecutive detached berry tests made in 1977 and the rankings of incidence and of severity in the field on 26.07 and 20.09.1977 are shown in Table 23. The correlation between the mean responses in the consecutive detached berry tests and the field observations is also given. The responses in the detachted berry tests of 10.08.1977 showed the best correlation with the field observations; mean responses over the consecutive detached berry tests also correlated well with the field observations. Correlations with the field data of 26.07 were considerably better than with those of 20.09, the difference mainly being caused by the heterogeneous progeny 7385. The relation between mean response in the detached berry test and percentage disease is shown in Figure 27.

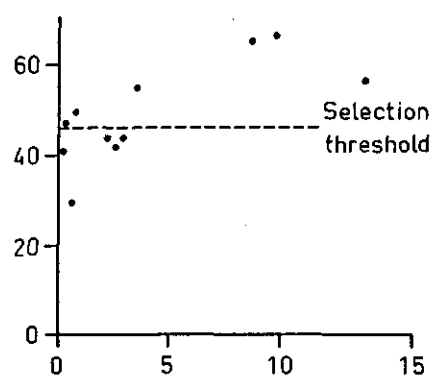


FIG. 27. Scatter diagram of the relation between the response in the detached berry test and field evaluation. Data from progenies at Gera, 1977. Progenies represented by dots.
Abscissa: field evaluation, percentage diseased berries.
Ordinate: detached berry test, fraction of diseased berries (angularly transformed).

TABLE 24. Correlations between responses in the detached berry test and the percentages of berries dropped or diseased due to CBD in berry counts. Data from progenies at Gera (1978). Fractions of disease in the detached berry tests were angularly transformed before analysis. Entries are Kendall's rank correlation coefficient (τ) and its significance $p(\tau = 0)$ for 48 progenies.

Date of detached berry test	τ	$p(\tau = 0)$
3.05.78	0.17	0.05
23.05.78	0.20	0.03
13.06.78	0.21	0.02
4.07.78	0.20	0.03
26.07.78	0.34	0.005
Mean DBT	0.35	0.003

TABLE 25. Correlations between disease incidence (field assessment), percentage drop and disease due to CBD (berry counts) and responses in the detached berry tests averaged over all testing dates (DBT). Data from progenies at Gera (1978). Entries are number of progenies (n), Kendall's rank correlation coefficient (τ) and its significance $p(\tau = 0)$.

	DBT			Incidence			Severity		
	n	τ	$p(\tau = 0)$	n	τ	$p(\tau = 0)$	n	τ	$p(\tau = 0)$
Incidence	48	0.32	10^{-3}						
Severity	48	0.36	3.10^{-4}						
Damage	48	0.35	3.10^{-4}	57	0.41	$< 10^{-4}$	57	0.42	$< 10^{-4}$

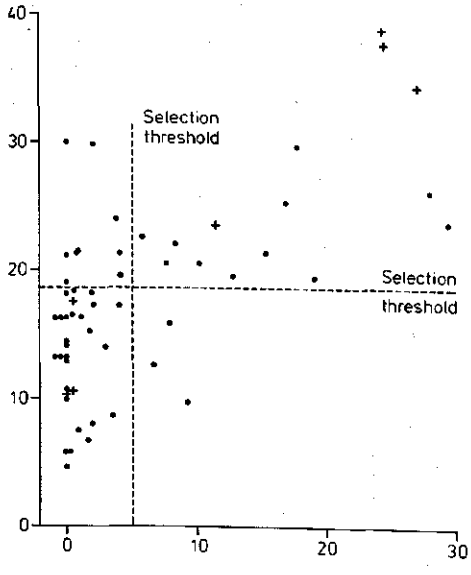


FIG. 28. Scatter diagram of the relation between response in the detached berry test and berry counts. Data from progenies at Gera, 1978. Progenies represented by dots. Progenies bearing for the second year represented by +.
Abscissa: berry counts, percentage of berries dropped or diseased.
Ordinate: detached berry test, fraction of diseased berries (angularly transformed).

Rank correlations between the results of berry counts and the results of detached berry tests made in 1978 are shown in Table 24. The detached berry tests of 26.07 and the mean responses in the detached berry tests over four testing dates gave the best correlation with the field data. The relation between damage in the field and the mean detached berry test responses is shown in Figure 28. The relation between mean responses of detached berry tests, disease incidence and disease severity is presented in Table 25.

4.5.2.3. Discussion. The percentage of diseased berries in the detached berry test depends on inoculum density, progeny, and berry size. Temperature and air humidity also affect the results. Among progenies, the regression coefficients between test responses in the detached berry test and log concentration differed, explaining a part of the interaction observed in the ANOVA of the responses of the detached berry test with various levels of inoculum density.

Berries are more susceptible at the early expanding stage than at later stages (Fig. 25). As the early expanding stage is short and resistance expression at that stage is probably not stable, berries at the early expanding stage are not suitable for resistance tests. The relatively high susceptibility of small berries of resistant progenies (741, 7385) is interesting. It is possible that small berries escape disease as they do not touch each other so that persistent water films, which facilitate spore germination, are rare.

In the experiments with fixed time intervals, the observed interactions between inoculation dates and progenies may have a number of causes, one of them being that berries of different progenies are in different growth stages. Other possible causes may be temperature differences, between inoculation dates, which may influence conidial germination and resistance mechanisms, and a not fully satisfactory transformation. The low correlation between results of individual testing dates in 1977 and 1978 might also indicate variation of growth stages, of berries, between progenies.

The correlations between responses in detached berry tests and field observations vary according to the date at which the detached berry tests were performed. Correlations were best on 10.08.77 and 27.07.78 which may indicate that the berries of most progenies were in a comparable growth stage at that time. The mean responses for the consecutive detached berry tests also showed a good relation with disease in the field, probably because differences in growth stages over the period offset each other. In 1979 again, the correlations between detached berry tests and field observations were best at the end of July and in August (FEKADE and MESERET, pers. comm.). Therefore, future detached berry tests can be limited to that period.

The findings on the correlation between field observations and detached berry tests are in contrast to the level of correlation reported by VAN DER VOSSEN et al. (1976). These authors, however, made only one test in which all berries may not have been at the same growth stage. The observed correlations between detached berry tests and field observations were satisfactory but not particularly high. It should, however, be kept in mind that the material with which the experiments

were made was preselected and the relation was, therefore, studied in a small part of the total susceptibility range. The correlation between field observations and detached berry tests indicates that both are expressions of the resistance of the berries over the whole of the observation period. The function of the detached berry test is to confirm that differences in the disease level in the field are due to differences in berry susceptibility and not to environmental differences between the progenies.

4.6. Criteria for distribution of progenies

4.6.1. *Introduction*

The choice of a selection threshold is, by necessity, somewhat arbitrary. Not all effects of environment on CBD development can be foreseen; only long term observation in different environments can guarantee that resistance will be adequate under all conditions. However, the substantial losses due to CBD in Ethiopia do not permit a long term testing programme. In view of the pressing economic needs of the country some risks must be taken. It must be remembered that, even if a progeny shows a higher level of CBD than anticipated, it will still have a lower level of disease than the coffee population it will replace.

Final decisions on the large-scale distribution of progenies can only be made on the basis of CBD levels, of levels of other diseases and pests, and of indications on yield and quality potential. In this section the criteria for CBD are discussed: in Chapter 6, other criteria are given. Note that Ethiopia has no formal organization for the testing and registration of cultivars.

4.6.2. *The 1977 testing series*

The relation between the observed disease levels and the data collected in detached berry tests for 1977 are presented in Figure 27. The selection threshold thought to be adequate, is indicated. The selection threshold in the detached berry test was placed at the response level of 45 corresponding with approximately 50 percent diseased berries.

In field observations, disease levels up to 1 percent often went undetected. Since CBD resistance is considered to be a quantitative character, low levels of disease are to be expected and accepted as normal. Therefore, only trees with more than 1 percent were regarded as unacceptable. Such trees were removed from progenies that were intended for distribution and seed from neighbouring trees was withheld in the first year of distribution. Additional trees with over 1 % disease were often found the second year of observation: these trees had either escaped infection in the first year or had had no crop. As indicated in Section 4.5.2, progeny 741 was the only progeny which was carefully screened in both 1977 and 1978, and no further removals were needed in 1979.

4.6.3. *The 1978 test series*

In Figure 28 the relation was shown between berry counts and detached berry

TABLE 26. Numbers of progenies accepted or rejected in 1978 according to their provenance. H_o: acceptance levels were equal for all locations, was rejected ($\chi^2 = 10.0$, $p(H = H_o) < 0.01$).

Provenance	Accepted	Rejected
Washi	10	0
Metu	9	4
Yachi and Kota	2	5

tests (both made in 1978). Selection thresholds were 5% for the level of damage and 18.5 in the detached berry test; damage levels over 10% occurred at DBT responses of 19. With regard to the percentage of trees with more than 1% disease, the comment for 1977 applies also to 1978.

It is interesting to note the provenance of the progenies accepted in 1978. The number of progenies tested and their origin is indicated in Table 26. In the table only those progenies are entered that passed the seedling inoculation test. Two progenies of which the mother tree was at Gera were omitted. The significant differences which exist between the locations may reflect the difference in disease pressure at the selection locations (Washi versus Yachi Kota) or morphological differences between coffee populations (Washi versus Metu). The second type of differences may be expressed by a different level of disease in the seedling inoculation test at an identical level of disease in the detached berry test. The existence of such differences, already indicated in Section 4.3.3, is supported by the existence of morphological differences between trees from Metu and from other locations: Trees from Metu are small, dense and slender, have short internodes, long leaves, small berries, and a persistent 'skirt' of lower lateral branches, which cover the soil around the trunk.

4.7. CONCLUSIONS

- In the field observations made after the selection of mother trees, large differences were observed between the population of mother trees and the unselected coffee population.
- In the group of mother trees at Gera, certain trees had consistently more disease than others.
- Field observations are quite useful for the selection of mother trees, but if used at the exclusion of other methods, their reliability to reselect within the group of mother trees is questionable.
- Field inoculation tests showed considerable differences between the population of mother trees and the unselected population and smaller, but statistically significant, differences among mother trees. The correlation of field inoculation tests with field observations was satisfactory.
- In seedling inoculation tests, statistically significant differences among mo-

ther trees were found, but the test results did not always give a good indication of the susceptibility in the field.

- The combination of one year's field observation after selection, field inoculation test, and seedling inoculation test was very effective to eliminate unsatisfactory mother trees.
- From field observations on progenies, it was possible to conclude that differences in CBD severity were related to the genotype of the host.
- The progenies, which were established from seed, showed a satisfactory within progeny homogeneity. Off-types in progenies could easily be removed.
- The level of non-pathogenic berry drop appears to vary among progenies. Regular berry counts offer the only reliable means to determine the percentage of berries dropped and diseased due to CBD.
- Detached Berry Tests on berries in the hard green stage, repeated during the season, offer the best correlation with field observations. Tests made at the end of July and in early August correlate better with field observations than those made earlier in the season.
- The combination of field assessments, berry counts, and Detached Berry Tests permits the establishment of selection thresholds that allow early distribution of progenies.

5. CONSIDERATIONS ON THE NATURE OF THE RESISTANCE

5.1. INTRODUCTION

Resistance has to present a lasting solution to the CBD problem. Vertical resistance is, in most cases, only effective during a limited period. Horizontal resistance is supposed to have a long lasting effect. Therefore, it is important to identify those characteristics which differentiate horizontal and vertical resistance (ROBINSON, 1976, 1979; VAN DER PLANK, 1965, 1968, 1975).

Horizontal resistance is:
quantitative – its expression depends on the conditions for disease development;
polygenic or oligogenic – a rather continuous variation occurs in the host population between full susceptibility and complete resistance;
non-specific - differential interaction between components of the host and of the pathogen populations is at a low level or absent.

Vertical resistance is:
mostly qualitative – quantitative resistance does occur but it is rare;
monogenic or oligogenic – variability in the host population is discontinuous;
specific – interaction between elements of the host and of the pathogen populations is differential, being due to a gene-for-gene relationship.

Quantitative results were obtained in all observations and tests reported in Chapter 4. Practically all mother trees showed some CBD at one or more of the consecutive field observations. For example, out of 55 trees selected at Gera in 1975 and observed until 1978, only 8 trees never showed disease in the field. Field inoculations invariably produced disease, though the lesions obtained on highly resistant trees often relapsed into inactive scab lesions. Seedling inoculation tests showed a gradation of disease. Detached berry tests always gave quantitative results and the disease level in the test depended on inoculum density. The relation between berry size and susceptibility (Section 4.5.2.) indicated that resistance is not equally effective at all growth stages of the berry, but in no stage complete resistance occurs. It might be argued that in detached berry tests of progenies some berries from off-trees are collected occasionally. Such berries would show susceptibility in the detached berry tests and might thus give a false picture of quantitativeness. However, this is unlikely because, for example, the mother tree of progeny 741 was extensively tested in 1977, and the tree did not show complete resistance. Another explanation for quantitative results may be found in cuticle intactness or in cuticle-characteristic resistance to penetration. NUTMAN and ROBERTS (1960 a) stated that all resistance disappeared after wounding and indicated that cuticular resistance was the only resistance mechanism. FIRMAN (1964), however, found residual resistance in Rume Sudan after wounding. Therefore, in the following sections of this chapter, an experiment is described in which detached berry tests on wounded and intact berries were compared.

Continuity of variation was difficult to prove as a complete separation between phenotypic and genotypic variation was impossible. In field observations, a continuous variation was observed between fully diseased and practically disease free and in field inoculations or detached berry tests no indications for discontinuous variation were observed. In field observations made on progenies, it was difficult to make sure whether the variation observed between and within progenies was continuous (Section 4.5). In seedling inoculation tests, problems of scaling (Section 4.3.3) made it difficult to decide on the continuity of the variation. To elucidate the variation in the seedling test, an experiment is presented in the next sections in which variability between single-tree progenies is compared with that within progenies.

Specific interaction between components of the host and pathogen population may be suspected because the results of seedling inoculation tests did not always correspond with field observations; certain coffee types showed a low response level in the seedling inoculation test and a high disease level in the field (Section 4.3.3). Furthermore, progenies of mother trees from Metu showed a higher level of disease at Gera than expected from the seedling inoculation tests (Section 4.6). Such findings could be interpreted as indications of a specific host-pathogen interaction: certain vertical genes are not matched by the monospore isolate used in the seedling inoculation test but the matching genotypes of the pathogen are present in the field. To study this possibility, two experiments were made: By means of seedling inoculation tests, an accession of the French Collection at Jima, which showed such a discrepancy between seedling inoculation test and field observations, was tested with natural inoculum, a monospore isolate obtained from the accession F58, and the isolate that was used in the seedling inoculation tests reported in the Section 4.3.3. Other accessions and individual trees were included in the experiment to detect possible specific interactions. Tests were made on both seedlings and detached berries. In a comparable experiment, three inocula were tested on detached berries of progenies having their first crop in 1978. The results of these experiments are reported in the following sections.

5.2. Methods

5.2.1. *The rôle of the cuticle*

S 952 (an accession from India), 741 (cuttings from the mother tree) and F 58 (an accession from the French collection) were used. S 952 and 741 have a high level of resistance to CBD while F 58 is susceptible; the berries were fully expanded. The experiment was made with a monospore isolate from Sidamo and with natural, supposedly heterogeneous, inoculum from diseased berries from Jimma Research Station. The inoculum density was 4×10^5 conidia.ml^{-1} and the methods were according to Section 4.5.2 with the variations used in 1978. The treatments were replicated eight times. After inoculation, the berries of 4 replications were wounded by puncturing the berries through the inoculation droplet with a preparation needle.

5.2.2. *Variation between and within single-tree progenies*

Seedling inoculation tests were made on accessions from the 'National' and 'French' Collections at Jima. The accessions were all progenies of single trees and originated from Ethiopia. Several trees of each progeny were tested. The tests were part of the experimental series described in Section 4.3.3.

5.2.3. *Specific differential interactions*

Seedling tests: Coffee trees from the 'French Collection' at Jima and several mother trees were tested with three different inocula: the isolate used in the seedling tests of Section 4.3 ('Standard'), a monoconidial isolate from accession F58, and inoculum from diseased berries in the field. The methods were as described under 4.3.3. No controls were used as the experiments were made during the rainy season when fluctuations in temperature and air humidity are less limiting to symptom development. Seedlings were inoculated whenever they had reached the right stage of development. Each treatment was duplicated. The results of this experiment have been published (VAN DER GRAAFF, 1978 a), together with those of a fourth inoculum. The latter results, which are not relevant to the present purpose, are omitted here.

Detached berry tests: An experiment comparable to the seedling inoculation test was made. Fully expanded berries were used from accessions of the French Collection at Jimma Research Station and from cuttings of mother trees. The same inocula were used as in the seedling inoculation test together with a monoconidial isolate that was obtained from Sidamo. Methods were according to Section 4.5.2. Inoculum density was 2.5×10^5 conidia.ml^{-1}. Treatments were replicated four times. A second experiment was made in 1978 when progenies of mother trees were tested with two monoconidial isolates and natural inoculum. The methods were according to Section 4.5.2 with the variations used in 1978. Fully expanded berries were collected so that all sample trees of a progeny had an average of one berry in each replication. The inoculum density was 10^6 conidia.ml^{-1} and the treatments were replicated three times.

TABLE 27a. The rôle of the cuticle studied by means of detached berry tests. Variables are wounding, coffee type and isolate (a mono-conidial isolate and inoculum from diseased berries collected from the field). Each treatment was replicated 4 times. Entries are treatment mean values of the fractions (angularly transformed) of diseased berries.

Wounding	Inoculum	Coffee type		
		F 58	S 952	741
+	Natural	49	38	44
+	Sidamo	67	51	48
-	Natural	37	24	16
-	Sidamo	34	33	30

TABLE 27b. Data from Table 27a arranged according to the variables coffee type, wounding and isolate.

Coffee types	Mean value	Wounding	Mean value	Isolate	Mean value
F 58	47	+	50	Natural	35
S 952	37	−	29	Sidamo	44
741	35				

TABLE 27c. ANOVA of the data from Table 27a. Data were analyzed according to an ANOVA of a factorial experiment with fixed effects. Note the significant three-way interaction, which probably indicates that the transformation was not fully satisfactory.

Source of variation	df	ss	*F*
Treatments	11	7481	
Coffee type (C)	2	1235	13.7**
Wounding (W)	1	4742	105.4**
Inoculum (I)	1	894	19.9**
C × W	2	86	1.0
C × I	2	44	0.5
W × I	2	54	1.2
C × W × I	2	426	4.7*
Error	36	1620	

5.3. RESULTS

5.3.1. *The rôle of the cuticle*

Results are presented in Table 27. Significant differences occurred between wounding and non-wounding, between two types of inoculum, and between coffee genotypes. The disease was increased by wounding but the differences between progenies remained.

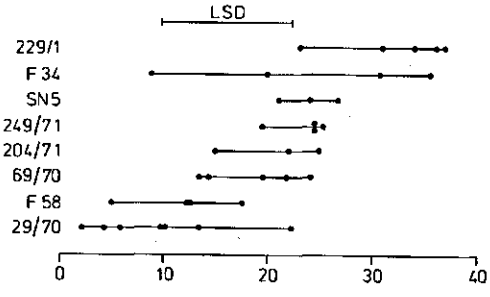


FIG. 29. Seedling inoculation test. Variation within and between single-tree progenies.
Abscissa: seedling inoculation test response.
Ordinate: coffee types, arranged in order of increasing disease response.
Entries: each dot represents one tree (mean of three replications).
The LSD at $p = 0.05$ is indicated.
Some trees of type F 58 were replicated only twice; their test responses are included to show the low response of the type in the seedling inoculation test. The low susceptibility of F 58 in this test is in sharp contrast to its high susceptibility in the field.

5.3.2. *Variation within and between single-tree progenies*

Results of the seedling inoculation tests are presented in Figure 29. All trees were replicated three times with the exception of those of F 58; these trees are only included in the figure to indicate the homogeneity in the seedling test. The LSD shown in the figure is only valid for test results from three replications. The LSD was calculated from the total experiment of which these experiments were part (Section 4.3.).

5.3.3. *Specific differential interactions*

Results of the seedling tests, in which a tree of F 58 and other coffee trees were tested with an F 58 isolate, a standard isolate and natural inoculum, are presented in Table 28. Main effects were significant, interaction was not. A similar result was obtained in the parallel experiment with detached berries (Table 29).

The analysis of variance of the third experiment in which progenies were tested with three isolates is presented in Table 30. Differences between progenies were highly significant but differences between inocula were not. Interactions were small but significant. Figure 30 shows the results in graphical form. Within progenies, differences between isolates regularly exceeded the LSD ($p = 0.05$), but complete inversions of the disease response did not occur.

TABLE 28a. A search for specific host-pathogen interactions by means of seedling inoculation tests. Eight host types were tested with tree pathogen isolates (two mono-conidial isolates: F58 and Standard; and conidia from diseased berries from the field: natural inoculum. Each treatment was replicated. Entries are mean values of treatment responses.

Coffee types	Pathogen isolates			Mean
	F 58	Standard	Natural	
4/5	18	25	40	28
8/78 (S 952)	23	28	38	30
7466	38	31	41	37
7429	36	36	46	40
6/331 (F 58)	41	35	60	45
6/407	38	47	59	48
7587	56	61	77	65
Unknown	71	72	65	69
Mean	40	43	53	45

TABLE 28b. ANOVA of data from Table 28a.

Source of variation	df	*F*
Coffee types	7	19.1**
Sources of inoculum	2	11.2**
Interactions	14	1.0
Error	24	

TABLE 29a. A search for specific host-pathogen interactions by means of detached berry tests. Eight host types were tested with four pathogen isolates (three mono-conidial isolates: Standard, F 58 and Sidamo; and conidia from diseased berries obtained from the field). Each treatment was replicated 4 times. Entries are mean values of tratment responses (angularly transformed fractions of diseased berries).

Coffee types	Isolates				
	Standard	F 58	Sidamo	Natural	Mean
S 952	29	34	47	44	39
4/5	36	41	39	40	39
F 60	38	41	42	40	40
F 59	41	44	54	49	47
69/70	43	43	51	54	48
F 54	53	59	61	47	55
F 58	66	53	64	67	62
F 18	63	70	73	64	67
Mean	46	48	54	51	

TABLE 29b. ANOVA of data from Table 29a.

Source of variation	df	ss	*F*
Treatments	31	12272	7.3**
Trees	7	10112	20.6**
Isolates	3	760	4.7**
Interactions	21	1400	1.2
Error	64	3479	

TABLE 30. A search for specific host-pathogen interactions by means of detached berry tests. ANOVA of 38 host types tested with 3 pathogen isolates: a field isolate directly obtained from diseased berries and mono-conidial isolates from diseased berries collected in Harerge and Sidamo. Each treatment (isolate per host type) was replicated three times. The data are graphically presented in Figure 34.

Source of variation	df	ss	*F*
Treatments	113	51011	7.5**
Isolates	2	298	2.5
Host types	37	38000	17.1**
Interactions	74	12713	2.9**
Error	228	13679	

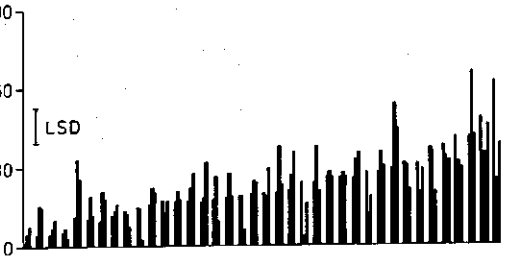


FIG. 30. A search for specific host-pathogen interactions by means of detached berry tests; 38 host types were tested with 3 pathogen isolates, a field isolate directly obtained from diseased berries and mono-conidial isolates from diseased berries collected in Harerge and Sidamo. Each treatment (isolate per host type) was replicated three times. The ANOVA of these data is shown in Table 30.

Abscissa: host types ranked in order of increasing disease response to the field isolate; the subdivisions represent responses per host type to the field, Harerge, and Sidamo isolate respectively.

Ordinate: fraction of diseased berries (angularly transformed).

5.4. DISCUSSION

5.4.1. *The rôle of the cuticle*

The small interactions found may be comparable to those occurring in other detached berry experiments (Sections 4.5.2. and 5.4.2). The persistance of differences in disease response after wounding indicates that the cuticle plays a minor role as a cause of differences in resistance, at least in the genotypes studied, thus contradicting the statements by NUTMAN and ROBERTS (1960 a) and confirming those made by FIRMAN (1964).

5.4.2. *Variation within and between single-tree progenies*

Figure 29 shows that the progenies had only a moderate degree of within-progeny variation, at least in comparison to between-progeny variation. In progeny 29/70, one off-type appears to be present among 7 trees tested. In 229/71, one tree appears to be an off-type. Progeny F 34 is heterogeneous. Progeny F 58 is of special interest: all trees have a rather low test response although they show a high disease severity in the field. The progenies 69/70, 204/71, 249/71 and SN 5 show a fair level of homogeneity. These results do not show obvious discontinuities; the progenies can be ranked in a continuum from high to low response; progenies at intermediate test response levels have the same degree of heterogeneity as the extreme progenies. The few off-types found in certain progenies may have resulted from cross pollination and thus may not be 'true to type'. The heterogeneity of accession F 34 suggests that its mother tree was heterozygous. The results permit the calculation of the heritability of CBD resistance as shown in these seedling inoculation tests. The heritability h^2 was 0.58 when calculated over 7 progenies with three trees each. (When more than three trees were present, three trees were chosen at random).

5.4.3. *Specific interaction*

No significant interactions occurred between pathogen and coffee types in the

seedling and detached berry tests used to study the French Collection accession F 58. It is therefore unlikely that the peculiar result shown by F 58 in the seedling inoculation test was caused by the occurrence of a vertical gene.

In the detached berry test of Figure 30, interactions were observed between host genotypes and inocula. The differences between the inocula were not much larger that the LSD at $p = 0.05$, thus indicating that no large differences in parasitic ability occurred. The interactions may have had a number of causes including variable reactions to different inoculum densities or percentages of germination, homogeneity of the berry samples resulting in differences in standard error between progenies, or low levels of specificity. There is little reason to believe that the interactions were caused by gene-for-gene mechanisms involving genes with major effects on resistance and pathogenic ability.

5.5. Conclusions

- Resistance to CBD is quantitatively expressed in the field, in field inoculation tests, in seedling inoculation tests, and in detached berry tests.
- the quantitative results were not due to the ease with which the cuticle was penetrated; although disease was higher in detached berry tests after puncturing the berries, differences between coffee types remained.
- Variation in levels of disease is continuous among coffee types in field inoculation tests, seedling inoculation tests, and detached berry tests.
- In seedling inoculation tests of trees randomly selected from certain single-tree progenies, continuous expression of resistance was observed among progenies, and variation among progenies was larger than within progenies.
- In experiments on specific interactions between certain components of the host and pathogen population differential interactions were sometimes found. If specificity causes differential interactions, its effects are limited. The differences between disease susceptibility in the seedling inoculation tests and in the field are not due to specificity.
- No indications have been found for qualitative vertical resistance. Indications for quantitative vertical resistance are unconvincing.

6. OTHER CHARACTERS: RESISTANCE TO DISEASES AND PESTS; YIELD, AND QUALITY

6.1. INTRODUCTION

6.1.1. *Resistance to diseases other than CBD, and to pests*

As indicated in Section 2.6, the Arabica coffee-parasites system was balanced before the introduction of Coffee Berry Disease. Resistance against diseases and pests was, through generations of farmers' selection, at an optimal level. Under those conditions, selection for higher levels of resistance is counterbalanced by other selection pressures, while losses caused by parasites are insignificant although many diseases and pests occur. Levels of horizontal resistance present in a heterogeneous population in an area where growth conditions vary only slightly, will oscillate slightly around the optimum resistance level. The absolute level of the optimum will vary between areas according to the growth conditions and resulting selection pressures in those areas. Whenever vertical resistance genes against certain parasites are also present in the population, multiline effects might, in part, substitute horizontal resistance. Changes in the agricultural system envisaged in the future can affect the level of resistance needed to prevent serious outbreaks of diseases and pests. Some examples have been cited in Section 2.6.

New cultivars that possess adequate CBD resistance should also possess sufficient horizontal resistance levels to other diseases and pests to remodel a balanced pathosystem. The situation for leaf rust *(Hemileia vastatrix)* is complicated in as far as vertical resistance genes are present in the population.

In the improvement programme, first indications on resistance to various diseases and pests were obtained from observations on mother trees. Multilocation testing of progenies was applied to obtain further information on undue susceptibility to diseases and pests. As will be indicated in the next sections, no differences in susceptibility to brown eye spot *(Cercospora coffeicola)* were observed in the multilocational tests. However, in material at Jima differences have been found (Section 6.2.3.).

Other methods had to be developed for slowly killing pathogens such as vascular wilts and root rots. The most important of these diseases is the wilt caused by *Gibberella xylarioides;* laboratory methods were developed to measure resistance.

6.1.2. *Yield*

Coffee in Ethiopia is a low input-low output crop; yields vary widely but are generally low. The yield potential of the various coffee types under high input conditions, and under differing climatic conditions and cultivation systems, can only be assessed after trials of long duration. No time was available for such trials, but it is possible to avoid genotypes with a poor yielding potential by the

exclusive use of progenies of trees that yield relatively well under the current growing conditions.

6.1.3. *Quality*

Coffee can be processed 'wet' or 'dry'. In the 'wet' process, cherries are pulped and beans are fermented under water to decompose the adhering, slimy mucilage. After fermentation, beans are washed and dried. In the 'dry' process the whole cherries are dried and 'hulled' later. At present, the bulk of the Ethiopian coffee is dry processed and graded according to percentage of impurities and place of origin. Inherent quality of coffee is best expressed through 'wet' processing. By this method, coffee types to be distributed to farmers can easily be tested.

6.2. Resistance to diseases and pests

6.2.1. *Assessment of mother trees*

Before 1975, diseases and pests were noted whenever they were obviously present. From 1975 onward, the following diseases, disorders, and pests were systematically scored:

Fungal diseases:

1) Leaf rust (*Hemileia vastatrix*);
2) Leaf blight (*Phoma tarda*);
3) Stem dieback (*Phoma tarda*);
4) Brown eye spot (*Cercospora coffeicola*);
5) Tree death caused by *Gibberella xylarioides* and various basidiomycetes.

Diseases of unknown etiology:

6) Crinkle leaf;
7) Weak spot;
8) Hot and Cold;
9) Dieback.

Pests:

10) Blotch leafminer (predominantly *Leucoptera caffeina*, Crowe, pers. comm.; and *Leucoptera meyricki*);
11) Serpentine leafminer (*Chryhiomystis aleutrenta*, *Melanogromyza coffea*);
12) Berry boring moth (*Prophantis smaragdina*);
13) Other insects (berry borer, stem borers, scales, aphids).

Physiological disorders:

14) Overbearing dieback;
15) Deficiencies.

Trees were scored at their initial selection and subsequently once a year at the end of the rainy season, between August and November. Scoring continued for three years after the initial selection (4 seasons). All diseases were, rather subjectively, scored as nil, low, intermediate, and heavy. The occurrence of tree death, deficiencies, and the presence of other insects was noted. Low infestation for items 1, 2, 4, 6, 10 and 11 indicated less than 1% of the leaves affected. In principle,

trees with a higher disease level than 'low' for any of the diseases 1 through 4 were discarded. Pest infestation was always low.

6.2.2. *Multilocation trials*

6.2.2.1. Material and methods. The Coffee Agronomy Section planted progeny trials at the substations at Metu, Agaro, Wenago, and Gera. The 1976 trials comprised mainly 1974 selections and some 1973 selections; the 1977 trials consisted of 1975 selections and some 1974 selections. (Extension of the trials to Tepi and Dembi Dolo was planned but only partly realized and no data for these two locations are available). Data reported here cover the trials planted in 1976.

Metu is situated at 8.2 N and 35.4 E, the substation is located at 1,550 m; the average annual rainfall over 1976 and 1977 was 1899 mm (See also Table 1). The substation lies next to the Sor river, which causes high air humidity and heavy dews resulting in heavy leaf rust infections. Agaro is located at 7.5 N and 36.4 E, its altitude is 1,600 m and the average annual rainfall is 1551 mm. The area around Agaro is considered to be one of the best for coffee cultivation in the country. Blotch leaf miner outbreaks have occurred since spraying against CBD started (CROWE, pers. comm.). Wenago is situated at 6.2. N and 38.1 E, its altitude is 1,660 m. Rainfall data are not available. At the substation, severe attacks by *Phoma tarda* were observed. Gera (7.7 N and 36.2 E, altitude 1,900 m, average rainfall 2007 mm over 1976 and 1977) was chosen for propagation and a progeny trial because of the high CBD level in the area. Leaf blight and stem dieback damage were noticeable. Progenies at Metu, Agaro and Wenago were planted in plots of a single row of 5 trees, at Gera the plots consisted of a single row of 10 trees. Spacing within rows was 1,25 m and between rows 2.50 m. At Metu, Agaro and Wenago, plots were arranged according to a Random Complete Block Design with two replications, and at Gera with four replications.

Progenies were scored for the first time in 1978. Methods used for scoring were:

a) Percentage leaves affected:
   - leaf rust
   - leaf blight
   - brown eye spot
   - blotch leaf miner
   - serpentine leaf miner

b) Percentage tips affected:
   - tip dieback
   - crinckle leaf

c) Percentage of a tree affected:
   - dieback

d) Percentage bearing branches affected:
   - overbearing dieback

e) Percentage berries affected:
berry boring moth

f) Four class scoring – nil, low, medium, high:
weak spot, hot and cold

g) The occurrence of tree death and its possible cause, and of deficiencies and insects not indicated above, was recorded.

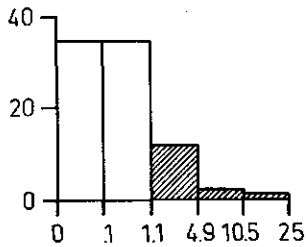


FIG. 31. Multilocation trials. Frequency distribution of progenies according to the percentage of leaves showing leaf rust. Data from Agaro, 1978. Data are mean values of 2 replications (plot size: 5 trees).
Abscissa: percentage of rusted leaves.
Ordinate: number of progenies.
Shaded: progenies considered to have an unacceptable disease level.

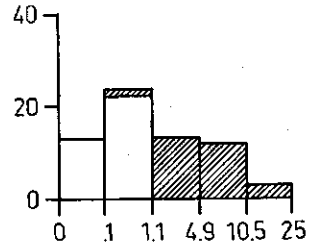


FIG. 32. Multilocation trials. Frequency distribution of progenies according to the percentages of leaves showing leaf rust. Data from Metu, 1978. Data are mean values of 2 replications (plot size: 5 trees).
Abscissa: percentage of rusted leaves.
Ordinate: number of progenies.
Shaded: progenies considered to have an unacceptable disease level.

TABLE 31. Multilocation trials. Correlation between replications according to the rankings of disease or pest severity (leaf rust, leaf blight, and blotch leaf miner). The correlation between the rankings of the leaf rust severity in the trials at Metu and Gera is also indicated. Entries are: number of progenies (n), number of replications (k), Kendall's rank correlation coefficient (τ) where two rankings were compared, and Kendall's coefficient of concordance (w) where more than 2 rankings were compared. The significance of τ and w is indicated by $p(\tau = 0)$ and $p(w = 0)$.

Parasite	Location	n	k	τ	$p(\tau = 0)$	w	$p(w = 0)$
Leaf rust	Metu	65	2	0.18	4.10^{-2}		
Leaf rust	Agaro	78	2	0.21	2.10^{-2}		
Leaf rust	Metu/Agaro*	75	n.a.	0.22	8.10^{-3}		
Leaf blight	Gera	78	4			0.41	$< 5.10^{-3}$
Blotch leaf miner	Agaro	72	2	0.39	9.10^{-5}		

* In the comparison Metu/Agaro mean values of the leaf rust scores of both replications were normally used; in a few cases also data from progenies were used of which only one replication at Metu was available.

TABLE 32. Multilocation trials. Disease and pest severity according to the provenance of progenies. Entries are the number of progenies per provenance (n) and the mean values of the percentages of attacked leaves per progeny and per provenance ($\bar{x}$).
For each parasite, the rankings of the data per provenance were compared by Wilcoxon's rank sum tests, with corrections for ties. For each parasite, data marked with the same letter do not differ at $p = 0.05$. Data from trials at Metu (leaf rust), Gera (leaf blight) and Agaro (leaf miner); observations made in 1978.

Provenance	Leaf rust		Leaf blight		Leaf miner	
	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$
Metu	24	1.3 a	28	0.9 a	20	16.8 a
Washi	19	1.8 a	21	2.8 b	16	24.8 b
Agaro and surroundings	18	4.1 b	20	1.6 b	16	29.1 c

6.2.2.2. Results. Those diseases and pests in which differences in susceptibility were observed that could be statistically confirmed are separately reported:
a) Leaf rust. In the trials at Metu and Agaro, a significant rank correlation was found between replications with regard to the rankings of the percentages of leaf rust per progeny (Table 31). The frequency distributions of the severity levels are presented in Figures 31 and 32. A strong rank correlation was also found between the trials at Metu and Agaro with regard to the rankings of the percentage of leaf rust per progeny (Table 31). The percentage leaf rust of the progenies was related to the provenance of the mother trees (Table 32).
b) Leaf blight. At Gera, a highly significant concordance (Kendall's w) was found between the replications with regard to the rankings of the severity ratings for leaf blight (Table 31). Figure 33 shows the frequency distribution of the mean

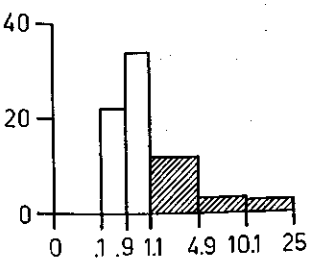


FIG. 33. Multilocation trials. Frequency distribution of progenies according to the percentage of leaves showing leaf blight. Data from Gera, 1978. Data are mean values of observations of 4 replications (plot size: 10 trees).
Abscissa: percentage blighted leaves.
Ordinate: number of progenies.
Shaded: progenies considered to have an unacceptable disease level.

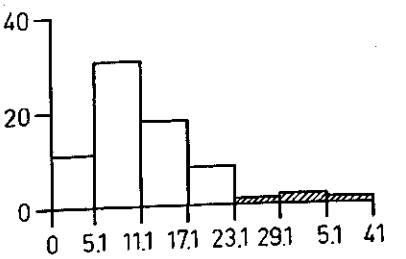


FIG. 34. Multilocation trials. Frequency distribution of progenies according to the percentage of leaves showing blotch leaf miner infestation. Data from Agaro, 1978. Data are mean values of observations of 2 replications (plot size: 5 trees).
Abscissa: percentage mined leaves.
Ordinate: number of progenies.
Shaded: progenies considered to have an unacceptable level of infestation.

severity level per progeny. The severity of leaf blight was related to the provenance of the mother trees (Table 31).
c) Blotch leaf miners. The percentage leaf miner damage at Agaro varied widely. The frequency distribution of the mean severity levels per progeny is presented in Figure 34. A highly significant correlation was observed between the replications with regard to the rankings of the percentage infested leaves per progeny (Table 31). The severity of the leaf miner damage was related to the provenance of the mother trees (Table 32).

6.2.2.3. Discussion. The correlations between replications, observed for leaf rust severity and leaf miner severity, and the concordance between the replications observed for leaf blight severity, may indicate differences in resistance levels to these parasites among the progenies. However, physiological differences like yield level and density of foliage may be of importance. For leaf rust severity, a significant correlation was also found between data from Agaro and Metu. Thus, progenies showing an unusual susceptibility at Metu also did so at Agaro. Nevertheless, a number of progenies showing susceptibility at Agaro were disease free at Metu and vice versa. Whether these differences are due to variations in the composition of the pathogen population with regard to vertical genotypes or to mere chance, is difficult to say. For leaf blight, the trial results were quantitative. Note that all progenies at Gera had some leaf blight. Nothing is known about the nature of the possible resistance. Genotypical differences in response to leaf blight have not been described previously. For blotch leaf miner, the results were also quantitative. Nothing is known about the nature of the possible resistance. Genotypical differences in response to blotch leaf miner in Arabica coffee have not been described previously.

To explain the relation between the provenance of the mother trees and the disease severity of leaf rust and leaf blight, and the occurrence of blotch leaf miners (Table 32), the selection of mother trees has to be considered again. At selection, not only CBD was taken into consideration, but trees had to be relatively free from other diseases and pests. Thus, trees with approximately the same low disease and pest level were selected at areas around Agaro, Metu and Washi. It must, however, be emphasized that few trees were rejected for their level of leaf rust or leaf blight and that none were rejected due to leaf miner. The later differences in susceptibility shown when the progenies were grown at one location may indicate that the ecological conditions for pest and disease development differ in the three selection areas. A major factor may be differences in rainfall (Section 2.5.2.). The differences between provenances may also be indicative for the resistance levels of the coffee populations in the three locations, as no particular outbreaks of diseases or pests were noticed and, as stated above, only a few trees were rejected because of the level of attack by diseases and pests. The only noticeable exception was the fairly high level of leaf blight that occurred at Washi. An adaptation of resistance levels to the ecological conditions relevant for pest and disease development is likely in traditional crops where gradual selection by farmers has taken place; resistance will only attain a

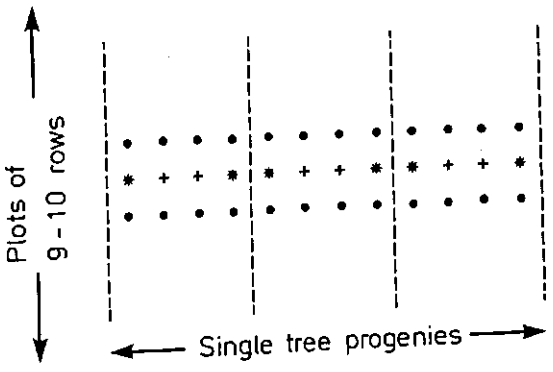


FIG. 35. Field observations of brown eye spot. Scoring of coffee types at Jima, 1978. The design permits the comparison of variation between – and within – coffee types in the absence of replications. The environmental variation can be estimated from the 'within-coffee type' pairs of trees.
**: 'between-coffee types' pairs of trees.
+ +: 'within-coffee types' pairs of trees.

level where damage becomes unimportant and at that level the remaining selection pressure will be counterbalanced by selection for other characteristics.

6.2.3. *Resistance to brown eye spot*

The level of attack by *Cercospora coffeicola* was always low in the multilocational trials and, consequently, no differences in the level of brown eye spot were found between the progenies. However, severe disease was observed in certain single tree progenies at Jimma Research Station. If these differences can be related to particular genotypes, it will indirectly suggest that other coffee genotypes, including cuttings of mother trees, present at the research station possess an adequate resistance level. In this section, therefore, the procedures and results of observations on brown eye spot are given.

6.2.3.1. Material and methods. Different levels of disease were observed among progenies of single trees collected in Harerge region. These progenies, part of the 'National Collection' at Jimma Research Station, were further studied. As the progenies were not replicated a special statistical technique had to be applied to discriminate between environmental and genetical variance. Progeny plots were 4 trees wide and 9 to 10 trees long, and adjoined at the long side. Spacing between trees was 2.50 × 2.50 m. Of each plot, four trees were scored in a row at right angles to the long side of the plot (Figure 35). Trees were scored for the percentage of diseased leaves in September, 1978. Results were arranged in pairs, thus forming pairs that consisted of trees of the same plot and pairs that consisted of trees of different plots. Percentages of disease were classified according to Table 33. The difference in disease class between the trees in each pair was determined.

6.2.3.2. Results. The frequency distribution of the differences in disease class between trees within each pair is given in Table 34. The frequency distribution of within-plot pairs was tested against that of between-plot pairs by Wilcoxon's rank sum test with a correction for ties. The differences of the within-plot pairs were significantly smaller ($p < 0.05$) than those of between-plot pairs, indicating a relation between disease severity and genotype.

TABLE 33. Field observations of brown eye spot. The percentage of diseased leaves per tree was estimated. For statistical purposes, the percentage scale was transformed into a seven-class scale (field score).

Percentage diseased leaves	Class
0	0
1	1
2–10	2
11–50	3
51–89	4
90–99	5
100	6

TABLE 34. Field observations of brown eye spot. Frequency distributions of the differences between trees, in tree pairs, according to their field score. Within-coffee type tree pairs consisted of two trees of the same type, between-coffee type tree pairs contained two trees of different coffee types. For details see text and Figure 39. According to Wilcoxon's rank-sum-test with corrections for ties, the frequency distributions differed significantly ($p < 0.05$).

Tree pair	Differences between paired trees					
	0	1	2	3	4	5
Within coffee types	12	8	1	–	–	–
Between coffee types	5	9	3	2	1	1

6.2.3.3. Discussion. *Cercospora coffeicola* does not normally cause a problem in coffee cultivation. Nevertheless, it is interesting to see that certain material derived from drier areas like Harerge shows an unacceptable level of brown eye spot in the wetter areas of Ethiopia and that disease severity is related to genotype. This implies that differences in resistance exist among Harerge coffee genotypes and that the coffee genotypes from western Ethiopia, being practically unaffected by the pathogen, have adequate resistance levels under prevailing growth conditions. Although nothing is known on the nature of the resistance, it is difficult to envisage vertical resistance as playing a major role. It is likely that the level of horizontal resistance has declined in drier areas, where the selection pressure is low. Comparable differences between coffee genotypes were reported by VAN DER VOSSEN and COOK (1975).

6.2.4. *Resistance to tracheomycosis*

The problems caused by *Gibberella xylarioides* have been indicated in Section 2.6. The pathogen causes a typical wilt, and the disease is endemic (VAN DER PLANK, 1975). It has been possible to establish differences in resistance and devise methods to measure the level of the resistance. The work was mainly performed by the associate expert – coffee pathologist, Mr. R. PIETERS, and the

results were published elsewhere (VAN DER GRAAFF and PIETERS, 1978; PIETERS and VAN DER GRAAFF, 1980). As indicated earlier, new coffee cultivars will need a higher level of resistance to *Gibberella xylarioides* than the coffee grown currently (Section 2.6).

6.3. YIELD, QUALITY AND VIGOUR

The yield prospects of mother trees were appraised in the general assessment of the trees made each year (Section 6.2.1.). Relative to other trees in the area, the yield was estimated as nil, low, intermediate, or good. In a number of areas, attempts were also made to obtain data on the weight of the crop. However, these data always proved unsatisfactory, as it was difficult to prevent picking by both legal and illegal pickers.

The vigour of mother trees was assessed together with other characters. Vigour was scored as nil, low, medium, or good. These data were, however, considered to be of minor importance.

'Wet processed' quality samples were often obtained from mother trees and assessed by CTDMA liquorers. Their quality in general was average, with some good ones from the Metu area. The quality of the progenies is assessed by CTDMA liquorers before a decision is made on their large-scale distribution (WHITE, 1980).

6.4. CRITERIA FOR DISTRIBUTION

6.4.1. *Diseases and pests*

The criteria for selection of susceptible and resistant material can be determined only intuitively; no objective method exists to determine a selection thresshold before the material has been studied over a number of years in several locations and before the importance of the disease in relation to yield has been determined.

In 1978, preliminary selection thresholds for leaf rust and leaf blight were set at 1 % of the leaves diseased in any of the replications at any location. For progenies observed for the second year, some additional leaf rust was accepted (up to 10 %), because the disease level is probably influenced by the cropping level in the previous year. The selection threshold for leaf blight was rather strict, because stumping, a promising cultural practice, is seriously limited by the disease. For leaf miner, the Coffee Entomology Section indicated that 25 % of the leaves mined was an appropriate selection threshold.

The incidence of tree death caused by *Gibberella xylarioides* will increase when modern agricultural practices are introduced. Therefore, a selection level was adopted that was approximately the median value of all coffee types tested. The fractions of the progenies accepted with regard to diseases and pests are indicated in Chapter 7 (Table 35).

TABLE 35a. Phases in the selection process from the selection of mother trees to the approval of progenies for distribution; selection criterium and fraction approved after selection.

Phase	Selection criterium	Fraction approved	Running product
Before planting progenies	Selection of mother trees	$\pm$ 0.005	5×10^{-3}
	Lost or dead mother trees	0.69	3.4×10^{-3}
	CBD tests and observations	0.34	1.1×10^{-3}
After planting progenies	CBD	0.55	6.3×10^{-4}
	Leaf rust	0.51	3.2×10^{-4}
	Leaf blight	0.56	1.6×10^{-4}
	Traceomycosis	0.60	9.5×10^{-5}
	Blotch leaf miner	0.66	6.3×10^{-5}
	Yield	0.80	5.0×10^{-5}

TABLE 35b. Data from table 35a. Some selection criteria combined to selection factors.

Selection factor	Fraction approved
All CBD selection criteria	9×10^{-5}
CBD after the selection of mother trees	0.19
Non-CBD criteria (excluding lost or dead)	0.09

6.4.2. *Yield*

With respect to yield, the current low level of production per unit area should be taken into account. At present, genotypic differences are less limiting to Ethiopian coffee production than agricultural practices, soil fertility, and ecological conditions. Indications have already been obtained that improved cultural practices can greatly increase the yield of traditional, unimproved coffee. However, neither the long term agronomic effects of these improvements nor their long term economic effects can be foreseen. Therefore, the distribution of genotypes with maximum yield potential is not yet needed as it is unlikely that yield potential will be a limiting factor in the near future. The gradual development and acceptance of better agricultural practices and the necessary higher inputs will only gradually increase the demand for the genotypes that respond maximally to such inputs. At the present stage, neither inputs or genotypes, nor their interactions are defined, and it was, therefore, decided to consider progenies for distribution of which the mother trees yielded average or above average during the whole observation period. Between seed distribution and planting of seedlings an extra year was available and thus it was theoretically possible to withdraw seedlings of progenies that yielded poorly in the first two years of bearing. Long-term observations on many locations are needed to study yield level and yield stability under different ecological conditions and agricultural practices. Only when such results have been obtained, it will be possible to identify the best genotypes.

6.4.3. *Quality*

As indicated in Section 6.3., quality assessments were made on progenies before they were recommended for distribution. Quality was variable, 'the selections released on basis of CBD resistance falling mainly in the medium class and some lacking flavour' (WHITE, 1980).

6.5. CONCLUSIONS

- Progenies differ in their level of attack by leaf rust, leaf blight, and blotch leaf miner. These differences are statistically significant, and it is therefore concluded that they are expressions of different genotypes.
- Attack by brown eye spot was always minimal and no differences between progenies could be established. That differences in resistance exist, was established in more susceptible material at Jimma Research Station thus indirectly indicating that resistance in the progenies was adequate.
- Differences in resistance to *G. xylarioides* were determined and used in the programme.
- Selection thresholds for various diseases and pests are arbitrary. Only long term studies will permit the determination of proper selection thresholds.
- Selection thresholds for leaf blight and tracheomycosis have been chosen in such a way that susceptibility to these diseases will less hamper coffee modernization than the susceptibility of the present *C. arabica* population.
- Visual yield assessments were made on mother trees. However, only observations in multilocation trials over many years can establish proper selection thresholds.
- Quality can easily be assessed; the present quality level is statisfactory.

7. EVALUATION OF THE PROGRAMME

7.1. Introduction

The immediate objective of the programme was to produce new *C. arabica* types in the shortest time possible. These coffee types should possess resistance to CBD that is adequate and long lasting, show sufficient resistance to other diseases and pests and have a reasonable yield and quality potential. Within this context resistance to CBD was of overriding importance in the earlier phases of the programme. In later phases, resistance to other parasites became more important. Yield can only tentatively be taken into consideration as long as no data from replicated trials are available. Quality can be assessed at an early stage. Thus, in the beginning, new coffee types should mainly be distributed to areas where CBD is the major limiting factor in coffee production. Distribution to other areas should be made when additional data on yield potential are available.

The long term objective of the programme is to produce new coffee types that possess known levels of pest and disease resistance, adaptability to various ecological conditions, and a good yield and quality potential; these cultivars will gradually replace the existing coffee population and thus initiate the modernization of coffee cultivation.

The short term objectives were met in the part of the programme realized until 1980. Seed of one progeny (200,000 seeds) was distributed early in 1978, while seed of the same and five other progenies was distributed in early 1979 (about 4.3 million). Larger scale distributions were made in early 1980 (about 15 million).

7.2. Remaining problems

Some of the remaining problems are discussed in the following sections.

a) The nature of CBD resistance: Complete certainty on the nature of resistance to CBD and, thus, on its durability cannot be provided without genetic experiments. Experiments on the genetics of Arabica coffee require several generations of 3 of 4 years each and, therefore, genetic analysis of the resistance was beyond the limits of the programme. Within the limits of the programme, all evidence points towards the horizontal nature of the resistance. An argument for the durability of the resistance is that the disease is the result of a new encounter between host and parasite; no co-evolved gene-for-gene system is to be expected. In general, diseases of this type are easily controlled through the deployment of resistant cultivars (Buddenhagen, 1977). Nevertheless, long term research is needed on the inheritance of the resistance to CBD.

b) Selection thresholds for other diseases and pests: The thresholds chosen are, until now, somewhat arbitrary; they may be too strict. Only careful, multilocational testing will establish adequate selection thresholds and will define the

adaptability of the new coffee types to various ecological conditions. Future selection thresholds should be matched to the local conditions of the areas, where selected progenies will be planted.
c) The nature of the resistance to other diseases and pests: The nature of the resistance to the various diseases and pests is undefined. Although fair levels of horizontal resistance to diseases and pests seem to be present in the *C. arabica* population, a multiline effect cannot be excluded. The measurement of resistance in the field can be hampered by the presence of a mixture of vertical pathogen and host genotypes. Therefore, further research with respect to resistance to leaf rust, blight, and various leaf miners is urgently needed.
d) Yield and quality: Yield and quality potential have been discussed in Sections 6.4.2. and 6.4.3. Yield potential can, at the present stage of programme development, only tentatively be appraised. With the introduction of modern methods of coffee production, more attention must be paid to yield and quality assessment.
e) Susceptibility to insignificant diseases and pests: Susceptibility may occur to diseases and pests that are at present so insignificant that they have not been recorded. Progenies that show such undue susceptibilities should immediately be withdrawn from distribution. Multilocational testing of progenies can help to prevent later disappointments.
f) Vulnerability to diseases and pests that are not present in Ethiopia: A number of diseases and pests of coffee are not present in Ethiopia. They probably have developed as parts of host-parasite systems of related species (grey rust, *Hemileia coffeicola;* yeast spot, *Nematospora corili;* and the omnivorous American leaf spot, *Mycaena citricolor).* Nothing is known about the susceptibility of the presently selected progenies to these parasites. Only by means of international testing the necessary information can be acquired. International testing is, presently, impossible for political reasons. Strict quarantine should be imposed to avoid introduction of the above mentioned parasites.

7.3. Reasons for quick success

The factors which facilitate a rapid adaptation of the *C. arabica* host-parasite system to CBD are discussed in the following sections.
a) Genetical variability: Ethiopia is the gene centre for *C. arabica.* The wide genetic variation of *C. arabica* made it possible to find genotypes with an adequate resistance to CBD, though the species had never been exposed to the causal fungus, a newcomer to Ethiopia.
b) The stability of the host-parasite system in relation to other pests and diseases. The stability of the system with respect to endemic pests and diseases considerably increased the chances to identify genotypes that combine an adequate level of resistance to CBD with resistance to other diseases and pests and with a good yield and quality potential.
c) The unimproved nature of the crop: In Section 6.4.2, it has been indicated why

material with a maximal yielding potential was not immediately needed. The rapid success of the programme was possible only because there was no immediate need for genotypes with a maximal yield potential.
d) The awareness of the limited time available: Economic and political pressures to accelerate the programme were intense. In order to gain time the multiplication phase was begun before all desirable characteristics had been defined, and the multiplication phase was made an integral part of resistance testing. The availability of the multiplication blocks considerably facilitated the ultimate testing for CBD resistance.
e) The recent start of Coffee Research in Ethiopia: Coffee Research in Ethiopia only started in 1968. CBD was observed for the first time in 1971. The programme of the Coffee Research Station at Jima still possessed enough flexibility to redesign objectives and to adapt major activities to meet the new and overwhelming problem of CBD.
f) The land reform in Ethiopia: The land reform of 1975 destroyed vested interests in the coffee industry in the country. Consequently, coffee research and, in particular, coffee pathology were less influenced by short term objectives; more resources could be devoted to medium and long term cultivar development. In addition, with the disappearance of the big land holdings, it was easier to obtain seed from mother trees and to obtain suitable land for propagation and for trials.

7.4. Economic evaluation within the programme

7.4.1. *The selection process*

The number of genotypes handled by the programme was constantly reduced, starting from the unselected population of coffee trees to the number of progenies finally distributed. The magnitude of these reductions is presented in the following sections; the step-wise reductions are shown in Table 35.
a) Selection within the coffee population: In individual years of the period 1976–1978, some 2 to 3% of the natural population of coffee trees at Gera showed no CBD. However, these trees were less accurately scored than trees which were under selection for CBD resistance. Trees under selection were also observed for yield level and attack by other diseases and pests. Therefore, it is estimated that between 0.1 and 0.5% of the total population was initially selected. It is difficult to ascertain whether this percentage was the same in the other selection areas. For example, the results of the seedling test may indicate a somewhat higher percentage of resistant material in the collection at Jima. However, the problems encountered in the seedling test (Section 4.3.3.) make it difficult to reach definite conclusions.
b) Dead and lost trees: Some mother trees died before the progenies were planted and other trees could not be found again. Progenies of such trees were not planted. These losses amounted to some 30% of the mother trees.
c) Reselection through tests and observations: Some 65% of the mother trees

tested was discarded by tests for CBD resistance and by field observations.
d) Assessment of progenies for CBD resistance. Some 45 % of the progenies that were tested in 1978 and of which the mother trees had passed the above selection criteria, were discarded because of insufficient CBD resistance.
e) Selection against susceptibility to other parasites: The percentage of progenies that were not distributed on account of susceptibility to other diseases and pests is shown in Table 35.
f) Selection for yield and quality: A preliminary assessment of yield potential was made at the time of selection by assessing the yield level of the mother tree and at the first year's yield of the progeny. One progeny out of six (16 %) was discarded in 1978 because of low yield. Quality was always satisfactory.

7.4.2. *Possible economies in the programme*

The most expensive part of the programme was the planting of progenies, and their maintenance after planting. Reduction of the number of progenies to be planted, therefore, would have been the best way to reduce the costs of the programme. The largest reduction in number of progenies considered for distribution was due to their susceptibility to other pests and diseases. Therefore, the reduction of numbers could have been realized by making the selection for these characters before planting took place. The reduction could have been obtained through multilocation testing before the planting of progeny plots and through the development of specific resistance tests for leaf diseases and pests, and through the timely development of resistance tests for tracheomycosis.

Multilocational testing before the planting of progenies would have been false economy as it would have caused delays. Money would have been saved within the programme but huge sums in accumulated losses would have resulted for the national economy with each year that the replanting programme was delayed. The development of resistance tests requires time and, therefore, encounters the same objection as the multilocational trials. In addition, it would have distracted qualified personnel from other important research activies. It should be noted also that hardly any reference material was available and that it was difficult to decide on which parasites to concentrate at the start of the programme.

In the course of the programme, data became available on the differences in resistance to vascular wilt in the 'French Collection' at Jimma Research Station (PIETERS and VAN DER GRAAFF, 1978), and tests were developed to assess resistance (PIETERS and VAN DER GRAAFF, 1980). However, the tests were only decisive for the plantings made in 1978. Earlier plantings could not be tested in time. Considerable economies could have been made in the programme if tests had been available at an early stage. The number of progenies to be planted might have been halved, reducing the planted area from 40 to 20 ha. However, the extent of the problem was only vaguely anticipated at the initiation of the programme and, therefore, research in the early phases was limited.

7.5. Ecomic impact of the programme on the coffee industry

Coffee susceptible to CBD will gradually be replaced by resistant coffee. Present thinking is to plant new coffee fields, which will gradually substitute the present coffee stands. The availability of seed will be limited until the newly planted fields will come into bearing. The seed production capacity of the farm at Gera does not exceed 30.000.000 seeds a year. This will suffice only to plant some 10.000 hectares and, if replanting were only done with Gera material, it would require more than fifty years to replace all the CBD susceptible coffee in Ethiopia.

The impact of the replanting can be tremendous. In the process, coffee can be changed from a traditional low input – low output to a modern high input – high output crop. The areas where coffee will be produced could also be planned in such a way that coffee is grown on slopes less suited for food production, leading to a land use with improved protection of soils against erosion.

7.6. Distribution to users

Distribution of selected seed involes two groups of users: State farms and, through the CTDMA, farmers' cooperatives.

State farms are large units established for large scale production. These units have their own resources for seed propagation and planting.

The CTDMA grows the seedlings in big nurseries producing some hundred thousand of seedlings per year. Distribution of seedlings will be made from these nurseries. Two situations can be distinguished:

a) Areas where the CIP (Coffee Improvement Programme) operates: This programme is located in a number of main coffee growing areas of Ethiopia. It aims at the increase of production of coffee and food crops. In those areas a credit scheme operates for coffee improvement. As indicated earlier, the improvement programme is included as a research component in CIP and its basic aim is to deliver seed which will be used in the CIP areas to rehabilitate the coffee stands.

b) Areas outside the CIP areas: To couple planting of selected progenies with modernization, credit facilities will have to be made available in these areas. Here, it should be realized that an operation, in which large parts of the coffee population will be replaced in a short period, will only happen once. If a large proportion of the material to be planted will again be grown under the traditional low input – low output conditions, a later modernization of cultivation will be difficult to realize.

7.7. Final remarks

It can be concluded that the programme is a good beginning to the modernization of coffee culture in Ethiopia. In the programme, it has been attempted to

identify those coffee types which are expected to meet some of the phytopathological risks of modern cultural practices (See Section 6.4.1.).

Many aspects of the *C. arabica* ecosystem in Ethiopia are unknown and many problems remain and may still arise. The large number of genotypes present at Gera provides flexibility and permits adjustments. However, even this large collection represents only a fraction of the total types in Ethiopia and many more types must be collected from the Ethiopian coffee population before many genotypes will disappear due to large scale replanting. The collection and maintenance of such a 'gene bank' may be too heavy a burden to Ethiopia; the importance and uniqueness of the material fully justifies an international effort to establish and maintain a 'gene bank' and to support research on the collections.

Concerning the present programme, much research remains to be done. Agronomic studies are needed but pathological, entomological and genetical research is also required to tackle the next generation of problems (ZADOKS, 1979). It is, however, unlikely that these problems will ever reach the level of economic loss that was posed by Coffee Berry Disease.

In the course of the years, it was attempted to exclude CBD from the Harerge growing area. This attempt was unsuccessful and the disease there is very damaging now. Harer coffee has premium on the world market and attempts are being made to identify resistance in the Harer 'gene pool'. Whether this material has enough variation remains to be seen. The methods described in this publication could also be applied to the Harer coffee to exploit whatever variation is available.

7.8. CONCLUSIONS

- Long terms research is needed on the mechanism, nature and inheritance of resistance to CBD, other diseases, and pests.
- The number of multilocational trials should be greatly expanded to determine selection thresholds for diseases, pests and yield potential that match local conditions and to determine susceptibilities to diseases and pests that are insignificant at present.
- International testing should be considered to determine susceptibility to diseases and pests not occurrring in Ethiopia.
- Strict quarantine should be imposed to avoid the introduction of new coffee parasites in Ethiopia.
- The heterogeneity of the coffee population, its unimproved nature, the conditions of research, and the political changes all permitted quick achievements in the coffee selection programme.
- It was not feasible to economize in the programme without seriously endangering its time schedule.
- The anticipated large scale replanting offers an unique opportunity for the modernization of the Ethiopian coffee cultivation.

- Much effort is needed to preserve the genetic variability of *C. arabica*. An international endeavour is indicated to establish and maintain a gene bank and to support research on collections.

SUMMARY

This publication describes the execution of a research programme in Ethiopia to obtain *Coffea arabica* types that possess durable resistance to CBD, adequate resistance to other diseases and pests, and a reasonable yield and quality potential.

Chapter 1 deals with the economic value of *C. arabica* to Ethiopia, coffee research, losses due to CBD and possible control of the disease. *C. arabica* is of tremendous economic value to Ethiopia; in recent years, the crop has been the main source of foreign currency. The best estimate of the total area under coffee is some 400.000 ha. Production per unit area is low, and reliable data on total production are not available. Some coffee research was done in the early 1950's; Jimma Research Station, the coffee station of the Institute of Agricultural Research, only began its operation in 1968. CBD was first observed in 1971, after which it spread rapidly over the whole of Ethiopia. The disease causes high losses; in the period 1974–1978, coffee arrivals at Addis Ababa were 28 % lower than in the period 1968–1972. The control of CBD by chemicals has little scope in Ethiopia. Therefore, a programme was designed to obtain coffee types that possess durable resistance to CBD, adequate resistance to other diseases and pests, and a reasonable yield and quality potential.

Chapter 2 deals with habitus, taxonomy, geographical distribution and cultivation methods of *C. arabica*, and the system *C. arabica*-parasites. Some particulars on habitus and taxonomy of *C. arabica* are described. The geographical distribution of *C. arabica* and narrowly related species is indicated; *C. arabica* is geographically separated from other *Coffea* species. Speculations in the literature about the origin of *C. arabica* as a natural cross between certain diploid progenitors appear to be inconclusive. Speculations on the occurrence of wild *C. arabica* in Ethiopia are futile, as undisturbed forests probably do not exist in the country. The history of coffee in Ethiopia is discussed. Ecological conditions of cultivation and cultivation methods are indicated. The relation between *C. arabica* and its parasites is considered in detail; theoretical considerations with regard to vertical and horizontal resistance, and their practical implications for a primitive crop such as *C. arabica* in Ethiopia, are discussed. It is concluded that the system *C. arabica*-parasites is well balanced under the traditional conditions of cultivation. Resistance is adequate to keep disease and pest damage at an insignificant level. The system becomes unadapted when new agricultural practices are applied, and the host is often susceptible to newly introduced pathogens and pests.

Chapter 3 deals with particulars of CBD, its origin, and its control; the disease is briefly described. The taxonomic position of the pathogen is discussed and it is concluded that the nomenclature of the pathogen and its related forms is unsatisfactory. The possible pathogenic ability of the related forms needs confirmation. A description of the disease cycle is given and the relation between climatic

conditions and disease development is discussed. It is emphasized that conditions for germination of the conidia do not alone determine disease development. Ecological conditions favouring CBD development after infection are poorly defined. The geographic distribution of the disease is reviewed: first reports were from Kenya but unrelated outbreaks may have occured at other places (Angola, Cameroon, Zaire). CBD is a new encounter disease and the pathogen was probably an insignificant parasite of another coffee species. Potential candidates are *C. eugenioides*, *C. canephora* and *C. excelsa*. Reports on differences in resistance to CBD are reviewed. The mechanism of the resistance, its nature, and its inheritance have been little studied. Resistance appears to be quantitative and durable. The chemical control of CBD is indicated. Control through resistance in Zaire and Kenya is reviewed. Resistance was of immediate concern in the selection programme in Zaire, but not in that of Kenya; therefore, in Zaire material with adequate resistance was selected while extremely susceptible material was recommended in Kenya. The selection programme in Ethiopia is briefly described.

Chapter 4 deals with the selection of mother trees, their subsequent assessment, the planting of progenies, and the assessment of progenies. Mother trees were selected in various parts of the country and were, after selection, observed for another three years. Their level of disease was compared with non-selected trees in the area. For Gera, one of the selection areas, the results of the observations are given. The population of mother trees strongly differed from the unselected trees in the area; within the group of mother trees some had consistently more disease than others. It was concluded that field observations are indispensable for the selection of mother trees, but, if used with the exclusion of other methods, the reliability of reselection within the group of mother trees is questionable. Tests on mother trees and on unselected trees were made to obtain more information on the difference between both groups and to find differences within the group of mother trees. In field inoculation tests, considerable differences were observed between the population of mother trees and the unselected population; differences among selected trees were smaller but statistically significant. Results were also presented for tests made on accessions in a collection at Jima. The correlation of field inoculation test with field observations was satisfactory. The methodology of the seedling inoculation test was extensively revised. In seedling inoculation tests, significant differences between trees were observed. The test results showed significant correlation with field observations, but some trees scoring well in the seedling inoculation test were diseased in the field. In the seedling inoculation test and the field inoculation test, selection thresholds were determined that were based on the level of disease in the field in 1975 and 1976. The effectiveness of the selection procedure was assessed by field observations on mother trees in 1977 and 1978; the combination of seedling inoculation test and field inoculation test was effective in eliminating unsatisfactory mother trees. The propagation of mother trees (responsibility Coffee Agronomy) was by seed. Gera, an area where CBD was at a consistently high level, was chosen for propagation. Progenies consisted of up to 1,000 trees. In most cases,

the mother trees had been tested before their progenies were planted. Planting from 1975 to 1979 involved some 156 progenies and some 120,000 trees. Statistically designed progeny trials were planted at substations. The resistance of progenies was appraised by field observations and detached berry tests. Field assessments, estimates of the percentage of diseased berries of individual trees, were made in 1977 and 1978. In addition, berry counts were made on marked branches in 1978. From field assessments on progenies, it was concluded that differences in CBD severity were, at least in part, related to host genotype and that most progenies showed satisfactory within-progeny homogeneity; off-types in progenies could easily be removed. In berry counts, the level of non-pathogenic berry drop varied among progenies. It was possible to correct for non-pathogenic drop and to determine the percentage berries dropped or damaged due to CBD. Detached berry tests were made to determine the stage at which the best correlation with field observations occurs. Only berries in the hard-green stage proved suitable. The mean results of the detached berry tests over the whole season, and the individual tests at the end of July and early August showed the best correlations with field observations. Combination of field observations and detached berry tests permitted the establishment of selection thresholds that allowed early distribution of seed of progenies.

Chapter 5 deals with the nature of CBD resistance. Horizontal resistance is assumed to have a long lasting effect and, therefore, the CBD resistance encountered was checked for characteristics of horizontal resistance: quantitativeness, continuous variation, and lack of specificity between components of the host and pathogen population. Some new experiments were performed: detached berry tests to elucidate the rôle of the cuticle; seedling inoculation tests to determine homogeneity within and variability between single tree progenies; and tests concerning specificity. Resistance to CBD is quantitatively expressed; the quantitativeness is not caused by the ease with which the cuticle was penetrated. Variation in disease level among coffee types appears to be continuous, a result confirmed in the seedling inoculation tests with single-tree progenies. In the experiments made on specificity between certain components of the host and pathogen population differential interactions were sometimes present. The effects were, however, small and it is improbable that they are caused by gene-for-gene specificity. The difference in susceptibility between inoculation tests and field observations was not due to specificity. No indications were found for qualitative vertical resistance. Indications for quantitative vertical resistance were not convincing.

Chapter 6 deals with yield, quality and resistance to pests and to diseases other than CBD. Observations are described on severity of diseases other than CBD and on pests in trials at Gera, Metu, Agaro, and Wenago. Satistical analysis indicated differences among progenies with regard to leaf rust, leaf blight and blotch leaf miners. Attack by brown eye spot was always minimal but certain genotypes from Harerge growing at Jima showed a much higher disease level than others, while coffee types from Western Ethiopia remained practically disease free, thus indirectly indicating that resistance in such coffee types is

adequate. Resistance to tracheomycosis, already described in other publications, is only referred to. Observations on yield were made on mother trees. Observations on quality were, whenever possible, made on mother trees and also on progenies. Selection thresholds were determined for leaf rust, leaf blight, blotch leaf miner and tracheomycosis. Selection thresholds for leaf blight and tracheomycosis were high and it may, therefore, be assumed that the resistance to those diseases will allow the use of new agronomic practices. The yield observations made on mother trees may have eliminated the types with the lowest yield potential. Quality was always satisfactory.

Chapter 7. In this chapter the entire programme is evaluated with regard to the short and long term objectives. The short term objective was met when seed distribution began in early 1978. For the fulfilment of long term objectives, remaining problems are: the lack of absolute certainty on the nature of resistance to CBD; the arbitrary levels of the selection thresholds; the lack of knowledge on yield and quality potential; potential susceptibility to presently insignificant diseases and pests; and potential susceptibility to diseases and pests not (yet) present in Ethiopia. The reasons for quick success are: genetic variability; the stability of the host-parasite system with respect to 'native' diseases and pests; the traditional and unimproved nature of the crop; the relatively recent establishment of coffee research; and the land reform of 1975. The approximate percentage of mother trees or progenies passing the various selection thresholds are given. Although, in retrospect, economies could have been made through an earlier selection for other characters, these changes in the programme would invariably have resulted in delays in the programme and thus in huge accumulated economic losses due to CBD. Seed distribution and the effect of the anticipated large scale replanting are discussed. It is concluded that the replanting offers an unique opportunity for the modernization of the Ethiopian coffee cultivation. As a great deal of genetical heterogeneity will disappear in the process, much effort is needed to preserve the genetic variability of *C. arabica*. An international endeavour is indicated to establish and maintain a gene bank and to support research on collections.

ACKNOWLEDGMENTS

The author wishes to express his gratitude to Mr. R. A. ROBINSON with whom he had the privilege to work for one year. He also thanks Mr. R. PIETERS, FAO associate expert from 1975 to 1978 for his very valuable cooperation. The author also gratefully acknowledges the cooperation of the staff of coffee pathology at Jimma Research Station: ATO ADANE GEBRE, ATO BERHANU NADEW, ATO FEKADEH WORKINEH, ATO JAMAL ABALGARO, ATO MASRESHA AKLILU, ATO MEHARI ZEWDIE, ATO MESERET WONDIMU, ATO MESMURE MEKONEN, ATO METAFARIA H/YMER, ATO TADESA HABTEWOLD and ATO TESHOME TADESA; the respective acting officer in charge and officer in charge, ATO MICHAEL SIUM and ATO GEBREMARIAM SHEKOUR; the head of the coffee department, Dr. MESFIN AMEHA; the staff of coffee agronomy, in special Mr. R. G. WHITE, FAO coffee agronomist, and the staff at Gera. Dr. H. A. M. VAN DER VOSSEN kindly showed the seedling inoculation test. The author also expresses his gratitude to Professor J. C. ZADOKS for his detailed reviews and corrections of the draft texts. Professor T. M. WORMER and Mr. R. A. ROBINSON critically read parts of the text. Mrs. K. TEDESCO ZAMMARANO advised about the english text. Mrs. L. BALVETTI and my wife, Y. P. W. M. VAN DER GRAAFF-MOERINGS, typed the numerous drafts. Mr. S. G. WEVER made the drawings.

SAMENVATTING

Deze publicatie behandelt de uitvoering van een onderzoeksprogramma in Ethiopië om *Coffea arabica* typen te verkrijgen met duurzame resistentie tegen koffiebesziekte, adequate resistentie tegen andere ziekten en plagen, en een acceptable opbrengst en kwaliteitspotentieel.

Hoofdstuk 1 behandelt de economische waarde van koffie voor Ethiopië, koffie onderzoek, verliezen veroorzaakt door koffiebesziekte, en mogelijkheden tot bestrijding van deze ziekte. *C. arabica* is van bijzonder grote economische waarde voor Ethiopië. Koffie was in de afgelopen jaren de voornaamste bron van buitenlandse valuta. Waarschijnlijk is de beste schatting van de totale hoeveelheid land onder koffie 400.000 hectare. De produktie per oppervlakte-eenheid is laag. Betrouwbare schatting van de totale produktie zijn niet beschikbaar. In de vijftiger jaren werd een bescheiden begin gemaakt met koffie onderzoek. Jimma Research Station, het koffieproefstation van het Institute of Agricultural Research begon zijn activiteiten in 1968. Koffiebesziekte, voor de eerste maal waargenomen in 1971, verbreidde zich snel over geheel Ethiopië. De ziekte veroorzaakt grote oogstverliezen; in de periode 1974–1978 waren de koffieleveringen in Addis Abeba 28% lager dan in de periode 1968–1972. Chemische bestrijding van koffiebesziekte in Ethiopië is niet erg zinvol. Daarom werd een programma samengesteld om koffietypen te verkrijgen met een duurzame resistentie tegen koffiebesziekte, met een adequate resistentie tegen andere ziekten en plagen en met een goede potentiele opbrengst en kwaliteit.

Hoofdstuk 2 behandelt de habitus, taxonomische positie, geografische verspreiding, en teelt van *C. arabica* en de relatie van *C. arabica* met haar parasieten. Bijzonderheden betreffende de habitus en de taxonomische positie van *C. arabica* werden beschreven. Arabica koffie is geografisch gescheiden van andere *Coffea* soorten. De speculaties in de literatuur over de oorsprong van *C. arabica* als een natuurlijke kruising tussen bepaalde diploïde voorouders zijn niet overtuigend. Speculaties over het voorkomen van wilde koffie in Ethiopië zijn tamelijk zinloos, daar onverstoorde bossen waarschijnlijk niet voorkomen in dit land. De geschiedenis van het gewas in Ethiopië wordt kort besproken. Ecologische omstandigheden en teeltmethoden zijn beschreven. De relatie tussen *C. arabica* en zijn parasieten is in detail behandeld. Theorieën met betrekking tot horizontale en verticale resistentie en hun practische implicaties voor een primitief gewas als *C. arabica* in Ethiopië worden besproken. De conclusie is dat het systeem *C. arabica*/parasieten in de traditionele teeltwijze goed uitgebalanceerd is. Resistenties tegen ziekten en plagen houden de schade op een voldoende laag niveau. Het systeem voldoet niet meer wanneer nieuwe teeltmethoden ingevoerd worden. Het gewas is vaak gevoelig voor nieuw-ingevoerde ziekten en plagen.

Hoofdstuk 3 behandelt bijzonderheden van de koffiebesziekte. De symptomen van koffiebesziekte worden kort beschreven. Bespreking van de taxonomische positie van de schimmel leidt tot de conclusie dat de naamgeving van het pathogeen en van verwante vormen onbevredigend is. De mate van ziekteverwekkend vermogen van verwante vormen is onduidelijk. Het ziekteverloop wordt beschreven en het verband tussen klimatologische factoren en ziekte worden besproken. De conclusies zijn: (a) de omstandigheden voor de kieming van conidiën zijn niet de enige die het ziekteverloop bepalen en (b) de ecologische omstandigheden die de ontwikkeling van de ziekte bevorderen na de infectie zijn nauwelijks bekend. De geografische verbreiding van de ziekte is nader bezien; de ziekte werd voor het eerst waargenomen in Kenya. Uitbarstingen elders kunnen onafhankelijk zijn (Angola, Kameroen, Zaire). Koffiebesziekte is het gevolg van een nieuw contact tussen pathogeen en de waard. Daarvoor was de schimmel waarschijnlijk een onbelangrijke parasiet van een andere koffiesoort. Mogelijk oorspronkelijke gastheren zijn *C. eugenioides*, *C. canephora* en *C. excelsa*. De variatie in resistentie tegen koffiebesziekte wordt besproken. Er is weinig bekend over de werking, aard en vererving van de resistentie. De resistentie lijkt kwantitatief en duurzaam te zijn. De chemische bestrijding van de ziekte is kort behandeld. De bestrijding in Zaire en Kenya wordt besproken. In Zaire werd, anders dan in Kenya, ook op resistentie geselecteerd terwijl in Kenya uiterst gevoelig materiaal aanbevolen werd. Het selectie-programma in Ethiopië wordt kort beschreven.

Hoofdstuk 4 bespreekt de selectie van moederbomen, de daaropvolgende beoordeling, het planten van nakomelingschappen en de beoordeling daarvan. Moederbomen, geselecteerd in een aantal gebieden in Ethiopië, werden na hun selectie gedurende drie jaar beoordeeld. Hun ziekteniveau werd vergeleken met dat van niet geselecteerde bomen in hetzelfde gebied. De resultaten van de waarnemingen in Gera, een van de selectiegebieden, zijn gegeven. De groep moederbomen verschilde sterk van de groep ongeselecteerde bomen aldaar; binnen de groep van moederbomen waren sommige bomen steeds zieker dan andere. Veldwaarnemingen bleken onmisbaar te zijn voor de selectie van moederbomen, maar waren ontoereikend voor herselectie binnen de groep van moederbomen. Moederbomen en ongeselecteerde bomen werden getoest om meer informatie te verkrijgen over het verschil tussen beide categorieën en om verschillen binnen de groep van moederbomen te bepalen. In de veldinoculatietoest werden grote verschillen tussen de groep moederbomen en de groep ongeselecteerde bomen waargenomen, terwijl tussen moederbomen de verschillen kleiner maar wel significant waren. Een aantal typen uit een collectie te Jima werd ook getoetst. De correlatie tussen veldinoculatietoets en veldwaarnemingen was goed. De kiemplantinoculatietoets werd aanzienlijk gewijzigd. In de toets werden significante verschillen tussen moederbomen gevonden. De toestsresultaten waren significant gecorreleerd met veldobservaties, hoewel er bomen waren met een goed resultaat in de kiemplantinoculatie en hoge ziektecijfers in het veld. Voor de kiemplantinoculatietoets en de veldinoculatietoets werden selectie-

drempels bepaald aan de hand van het ziekteniveau in het veld gedurende 1975 en 1976. De doeltreffendheid van de selectieprocedure werd beoordeeld met behulp van veldwaarnemingen aan moederbomen in 1977 en 1978; de combinatie van kiemplantinoculatietoets en veldinoculatietoets was doeltreffend om ontoereikende moederbomen weg te selecteren. Resistent materiaal werd vermeerderd door middel van zaad. De vermeerdering vond plaats te Gera, een gebied waar koffiebesziekte steeds ernstig was. Nakomelingschappen bestonden uit maximaal 1000 bomen. Het merendeel van de moederbomen was getoetst voordat hun nakomelingschappen geplant werden. Een 156 nakomelingschappen met een geschat totaal van 120.000 bomen werden geplant tussen 1975 en 1979. Proefvelden werden aangelegd op enkele regionale proefstations. De resistentie van de nakomelingschappen werd getoetst door middel van veldwaarnemingen en met een losse-bessentoets. Het percentage zieke bessen per boom (ziektegraad) werd in 1977 en 1978 geschat. In 1978 werden ook bes-tellingen aan takken uitgevoerd. Verschillen in de ziektegraad waren, tenminste gedeeltelijk, gerelateerd aan het genotype van de waard. De nakomelingschappen bezaten een voldoende binnen-nakomelingschap-homogeniteit. Afwijkende bomen konden gemakkelijk uit de nakomelingschappen verwijderd worden. Bij bestellingen varieerde het niveau van niet-pathogene besval aanmerkelijk tussen de nakomelingschappen. Het bleek mogelijk om na correctie voor deze niet-pathogene besval het percentage val en aantasting door koffiebesziekte te bepalen. Losse-bessentoetsen werden uitgevoerd om het ontwikkelingsstadium van de bes te bepalen, waarin de toetsresultaten het beste correleerden met veldwaarnemingen. Alleen bessen in het hard-groene stadium voldeden. De veldwaarnemingen gaven de hoogste correlatie met losse-bessentoets resultaten gemiddeld over het hele seizoen, alsmede de individuele toetsen van eind juli en begin augustus. De combinatie van veldwaarnemingen en losse-bessentoetsen leidde tot de bepaling van selectiedrempels en aldus tot een snelle uitgifte van zaad van nakomelingschappen.

Hoofdstuk 5 behandelt de aard van de resistentie tegen koffiebesziekte. Horizontale resistentie wordt verondersteld een lange effectieve levensduur te hebben. Daarom werd gevonden resistentie getoest aan aspecten van horizontale resistentie zoals quantitatieve, continue variatie en een afwezigheid van specifieke interacties tussen componenten van waard en pathogeen populatie. Enkele nieuwe proeven werden gedaan: losse-bessentoetsen om de rol van de cuticula te verduidelijken, kiemplantinoculatietoetsen om de homogeniteit binnen en tussen de boomnakomelingschappen te bepalen, en toetsen voor het bepalen van specificiteit. Resistentie tegen koffiebesziekte is kwantitatief. Het gemak waarmede de cuticula doorboord wordt speelt hierbij geen overwegende rol. De variatie in ziekteresistentie tussen koffietypen is continu, zoals bevestigd werd in kiemplantinoculatietoetsen met nakomelingschappen. In de proeven over specifieke interacties tussen gedeelten van de waard populatie en van de pathogeen populatie werden soms differentiële interacties gevonden. De verschillen in ziektegraad, waarvan de interacties het resultaat waren, waren echter klein en het is

twijfelachtig of deze verschillen veroorzaakt zijn door gen-specifieke effecten. Aanwijzingen voor kwalitatieve verticale resistentie werden niet gevonden; de aanwijzingen voor kwantitatieve verticale resistentie waren niet overtuigend.

Hoofdstuk 6 bespreekt opbrengst, kwaliteit en resistenties tegen andere ziekten dan koffiebesziekte en tegen plagen. De waarnemingen over het niveau van ziekten en plagen in proefvelden te Gera, Metu, Agaro en Wonago worden beschreven. Statistische analyse toont aan dat er verschillen tussen de nakomelingschappen bestaan met betrekking tot aantasting door *Hemileia vastatrix*, *Phoma tarda*, en *Leucoptera caffeina*. De schade veroorzaakt door *Cercospora coffeicola* was altijd gering maar sommige genotypen uit Harerge vertoonden in Jima een veel hogere ziektegraad dan andere, terwijl koffietypen uit West Ethiopië practisch ziektevrij bleven. Deze waarneming toont indirect aan dat de resistentie in koffietypen uit West Ethiopië voldoende is. Voor resistentie tegen tracheomycose is naar andere publicaties verwezen. De opbrengstbeoordelingen werden aan moederbomen gedaan. De kwaliteit werd, indien mogelijk, bepaald aan de hand van monsters afkomstig van moederbomen en nakomelingschappen. Voor *Hemileia vastatrix*, *Phoma tarda*, *Leucoptera caffeina* en *Gibberella xylarioides* werden selectiedrempels vastgesteld. De selectieniveaus voor *Phoma tarda* en *Gibberella xylarioides* zijn zo laag dat gevoeligheid voor deze ziekten van weinig belang zal zijn als nieuwe teeltmethoden ingevoerd worden. Dank zij de opbrengst-beoordeling verricht aan de moederbomen, zijn de typen met een lage potentiële opbrengst uit het programma verwijderd. De kwaliteit van de koffie voldeed altijd.

Hoofdstuk 7 evalueert het programma met betrekking tot zijn korte-en langetermijn doelstellingen. Aan de doelstelling op korte termijn werd voldaan toen de zaaduitgifte begon in 1978. De redenen voor het snelle slagen van het programma zijn: de grote genetische variabiliteit, de stabiliteit van het waard-parasietsysteem ten opzichte van inheemse ziekten en plagen, het traditionele 'primitieve' gewas, het nog jonge koffieonderzoek en de landhervorming in 1975. De percentages moederbomen en nakomelingschappen, die de selectiedrempels passeerden, zijn aangegeven. Hoewel, achteraf gezien, bezuinigingen mogelijk geweest waren indien de selecties voor andere eigenschappen vroeger gemaakt waren, zouden de benodigde veranderingen geleid hebben tot vertragingen in het programma en daardoor tot extra geaccumuleerde economische verliezen door koffiebesziekte. De uitgifte van zaad en het effect van de voorziene herinplant op grote schaal zijn besproken. Herinplant biedt een unieke mogelijkheid om de koffieteelt in Ethiopië te moderniseren. In het modernisatieproces zal veel genetische verscheidenheid verloren gaan en daarom moet aandacht aan het behoud van de genetische verscheidenheid van *C. arabica* besteed worden. Internationale steun is vereist om een 'genenbank' te stichten, te onderhouden, en onderzoek aan de collecties te doen.

LITERATURE

ANDREWS, F. W. 1950–1965. The flowering plants of the Anglo-Egyptian Sudan. Vol. 2. Buncle, Arbroath, Scotland, 485 pp.

ANONYMOUS. 1975. Institute of Agricultural Research of Ethiopia. Interim Report. UNDP/FAO Rome AG: DP/ETH/71/533. 87 pp.

BOCK, K. R. 1956. Investigations on coffee berry disease - Laboratory studies. E. Afr. Agric. J. **33**: 97–103.

BOEREE, R. M. 1976. Terminal report of the coffee survey project (Interim version). FAO, Rome, AGO: DP/76/341, 62 pp.

BERTHAUD, J., GUILLAMET, J. -L., LEPIERRIES, D., and LOURD, M. 1980. Les caféiers sauvages de Kenya: Prospections et mise en culture. Cafe, Cacao, The **24**: 101–112.

BUDDENHAGEN, J. W. 1977. Resistance and vulnerability of tropical crops in relation to their evolution and breeding. The Genetic Basis of Epidemics in Agriculture. Ann. N. Y. Acad. Sci. **287**: 309–326.

BUTT, D. J., and BUTTERS, B. 1966. The control of coffee berry disease in Uganda. 1. Meeting E. Afric. Spec. Comm. Coff. Res. Nairobi.

CARVALHO, A., FERWERDA, F. P., FRAHM LELIVELD, J. A. MEDINA, D. M., MENDES, A. J. T., and MONACO L. C. 1969. The breeding of Arabica coffee. In: Ferwerda, F. P., and Wit, F. (Eds.): Outline of perennial crop breeding in the tropics. Misc. Pap. Agric. Univ. Wageningen **4**: 198–216.

CENTRAL STATISTICS OFFICE, ADDIS ABABA. Statistical Abstract: Volumes 1963 to 1977.

CHEVALIER, A. 1929. Les caféiers du Globe. Fasc. I. Généralités sur les caféiers. Encyclopédie Biologique 5, Paul Lechevalier Ed., Paris, 196 pp.

CHEVALIER, A. 1947. Les caféiers du Globe. Fasc. III. Systématique des caféiers et Faux caféiers; Maladies et Insectes nuisibles. Encyclopédie Biologique 28, Paul Lechevalier Ed., Paris, 356 pp.

CHIPP, T. F. 1929. The Imatong Mountains, Sudan. Kew Bull. **6**: 177–197.

CHOKKANNA, N. G. 1970. Coffee Development. UNDP/FAO, Rome, AGP:SF/ETH/79. Cyclostyled, 19 pp.

COFFEE AND TEA DEVELOPMENT AND MARKETING AUTHORITY, 1977. Coffee Statistics Handbook. 1961–62 to 1975–76. Addis Ababa, Ethiopia. 46 pp.

COFFEE AND TEA DEVELOPMENT AND MARKETING AUTHORITY, 1979. An outline of a five-year project (1980–1984) for spraying against Coffee Berry Disease (CBD). Addis Ababa, Ethiopia. Stencilled, 33 pp.

COOK, R. T. A. 1973 a. Work in progress in coffee research. Series III, Part IV. Detecting disease resistance in coffee plants. Kenya Coffee. **38**: 275–277.

COOK, R. T. A. 1973 b. Screening coffee plants for CBD resistance. Coffee Res. Found. Kenya Annu. Rep. 1972/73: 66–68.

COOK, R. T. A. 1975. Screening coffee plants for resistance to CBD. Coffee Res. Found. Kenya. Annu. Rep. 1973/74: 64.

CORDEMANS, J. 1973. Final Report. UNDP/FAO Technical Assistance Coffee Mission, YEMEN/69/020–AGP. Sana'a, cyclostyled, 27 pp.

DOUGHTY, L. R. Undated. Notes on coffee breeding. Typescript. 8 pp.

FERNIE, L. M. 1966. Some impressions of coffee in Ethiopia. Kenya Coffee: **31**, 115–121.

FIRMAN, I. D. 1964. Screening of coffee for resistance to Coffee Berry Disease. East Afr. Agric. For. J. **29**: 192–194.

FIRMAN, I. D., and WALLER, J. M. 1977. Coffee Berry Disease and other *Colletotrichum* diseases of coffee. Commonw. Mycol. Inst. Phytopathol. Pap. 53pp.

FOUCART, G., and BRION, L. 1963. La lutte contre les ennemis du caféiers d'Arabie au Rwanda. Bull. Inf. INEAC **12**: 141–152.

GAMACHU, D. 1977. Aspects of climate and water budget in Ethiopia. Addis Ababa University Press, 71 pp.

GASSERT, W. L. 1976. Zur Epidemiologie der Kaffeekirschenkrankheit *(Colletotrichum coffeanum* Noack sensu Hindorf) in Aethiopien. Dissertation, Tropeninstitut Justus Liebig Univ., Giessen, 120 pp.

GIBBS, J. N. 1969. Inoculum sources for Coffee Berry Disease. Ann. Appl. Biol. **64**: 515–522.

GILKES, P. 1975. The dying lion. African/Middle East Ed. Davison, Devizes, England. 307 pp.

GOVERNMENT OF ETHIOPIA, NATIONAL COFFEE BOARD. 1975. Coffee improvement project, 36 pp. + 18 annexes & map.

GRASSIAS, M., and KAMMACHER, P. 1975. Observations sur la conjugaison cromosomique de *Coffea arabica* L. Cafe, Cacao, The **29**: 177–190.

GRIFFITH, E. 1968. Control of Coffee Berry Disease. Kenya Coffee **33**: 393–396.

HEIM, R., and SACCAS, A. 1950. La trachéomycose des *Coffea excelsa* et Robusta des plantations de l'Oubangui-Chari. C. R. Acad. Sci. Ser. D **231**: 536–538.

HENDRICKX, F. L. 1939. Observations phytopathologiques à la station de Mulungu en 1938. Rapport annuel pour l'exercice 1938. Publ. Inst. Nat. Etude Agron. Congo: 117–128.

HENDRICKX, F. L., and LEFEVRE, P. C. 1946. Observations préliminaires sur la résistance de lignées de *Coffea arabica* L. à quelques ennemis. Bull. Agric. Congo **37**: 783–800.

HINDORF, H. 1970. *Colletotrichum* spp. isolated from *Coffea arabica* L. in Kenya. Z. Pflanzenkrankh. **77**: 328–331.

HINDORF, H. 1973 a. *Colletotrichum* population on *Coffea arabica* in Kenya. I. A method for the systematic separation of fungus populations. Phytopathol. Z. **77**: 97–116.

HINDORF, H. 1973 b. *Colletotrichum* population on *Coffea arabica* in Kenya. II. Qualitative and quantitative differences in the *Colletotrichum* population. Phytopathol. Z. **77**: 216–234.

HINDORF, H. 1973c. *Colletotrichum* population on *Coffea arabica* in Kenya. III. The distribution of *Colletotrichum* species on different parts of the coffee bush. Phytopathol. Z. **77**: 324–338.

HINDORF, H., and MOGK, M. 1975. Verluste durch die Kaffee-kirschen-Krankheit *(Colletotrichum coffeanum* Noack) in verschiedene Stadien der Kirschen-Entwicklung. Z. Pflanzenkrankh. **82**: 193–200.

HINDORF, H., and MUTHAPPA, B. N. 1974. A comparison of *Colletotrichum coffeanum* Noack from South India and Kenya. Phytopathol. Z. **80**: 9–12.

HOCKING, D. 1966. Brown blight *(Colletotrichum coffeanum* Noack) of Arabica coffee in East Africa. Ann. Appl. Biol. **58**: 409–421.

INSTITUTE OF AGRICULTURAL RESEARCH; JIMMA RESEARCH STATION. 1971. Progress report for the period April 1970 to March 1971. Addis Ababa, 86 pp.

INSTITUTE OF AGRICULTURAL RESEARCH; JIMMA RESEARCH STATION. 1972. Progress report for the period April 1971 to March 1972. Addis Ababa, 63 pp.

INSTITUTE OF AGRICULTURAL RESEARCH: JIMMA RESEARCH STATION. 1973. Progress report for the period April 1972 to March 1973. Addis Ababa, 106 pp.

INSTITUTE OF AGRICULTURAL RESEARCH; JIMMA RESEARCH STATION. 1974. Progress report for the period April 1973 to March 1974. Addis Ababa, 98 pp.

INSTITUTE OF AGRICULTURAL RESEARCH; JIMMA RESEARCH STATION. 1978. Coffee Department, Jimma Station Progress Report. Part 1, Coffee Research, April 1974 to March 1978. Addis Ababa, 125 pp.

INTERNATIONAL COFFEE ORGANIZATION. 1979. Ethiopia. Verification of stocks 30 September 1978 and the production of coffee. 9 pp. + annexes.

KENDALL, M. G., and STUART, A. 1973. The advanced theory of statistic II 3rd Ed., Griffin, London, 723 pp.

KRANZ, J., and MOGK, M. 1973. *Gibberella xylarioides* Heim & Saccas on arabica coffee in Ethiopia. Phytopathol. Z. **78**: 365–366.

LAMPARD, J. F., and CARTER, G. A. 1973. Chemical investigations on resistance to coffee berry disease in *Coffea arabica*. An antifungal compound in coffee cuticular wax. Ann. Appl. Biol. **73**: 31–37.

LEJEUNE, J. B. H. 1956. Report to the Government of Sudan on coffee production. FAO, Rome. FAO 56/12/8720. Expanded Technical Assistance Report No. 566, 15 pp.

LEJEUNE, J. B. H. 1958. Rapport au Gouvernement Impériale d'Ethiopie sur la production caféière. Rome. FAO 58/3/1881, Expanded Technical Assistance Report No. 797, 49 pp.
LOUARN, J. 1976 Hybrides interspécifiques entre *Coffea canephora* Pierre et *C. eugenioides* Moore. Cafe, Cacao, The **20**: 33–52.
MATHER, K., and JINKS, J. L. 1971. Biometrical genetics. 2nd ed. Chapman and Hall Ltd., London, 382 pp.
MCDONALD, J. 1924. Annual report of the Mycologist for the year 1922. In: Kenya Dep. Agric. Annu. Rep. 1922: 111–115.
MCDONALD, J. 1925. Coffee berry disease. Tropical Agriculturist **64**: 163–165.
MCDONALD, J. 1926. Report of the Mycologist. In: Kenya Dep. Agric. Annu. Rep. 1925: 141–148.
MCDONALD, J. 1929. Annual report of the Mycologist. In: Kenya Dep. Agric. Annu. Rep. 1928: 187–197.
MCDONALD, J. 1932. Annual report of the Senior Mycologist for 1931. In: Kenya Dep. Agric. Annu. Rep. 1931: 118–130.
MCDONALD, J. 1935. Annual report of the Senior Mycologist. In: Kenya Dep. Agric. Annu. Rep. 1934. **II**: 24–39.
MCDONALD, J. 1937. Report on coffee berry disease investigations in 1936. Mon. Bull. Coffee Board Kenya **22**: 30–34.
MENDES DA PONTE, A. 1966. Spraying Arabica coffee with calcium superphosphate for the control of coffee berry disease, usually attributed to *Colletotrichum coffeanum* Noack. Kenya Coffee **31**: 21–22.
MEYER, F. G. 1965. Notes on wild *Coffea arabica* from Southwestern Ethiopia, with some historical considerations. Econ. Bot. **19**: 136–151.
MEYER, F. G. 1968. Further observations on the history and botany of the Arabica coffee plant, *Coffea arabica* L. in Ethiopia. In: FAO Coffee Mission to Ethiopia 1964–65. FAO, Rome: 1–5.
MONACO, L. C. 1968. Considerations on the genetic variability of *Coffea arabica* populations in Ethiopia. In: FAO Coffee Mission to Ethiopia 1964–65. FAO, Rome: 49–69.
MULINGE, S. K. 1973. Coffee berry disease in Ethiopia. FAO Plant Prot. Bull. **21**: 85–86.
MULLER, R. 1964. L'anthracnose des baies du caféier d'Arabie *(Coffea arabica)* due à *Colletotrichum coffeanum* Noack au Cameroon. Inst. Fr. Cafe Cacao Bull. **6**, 38 pp.
MURAKARU, G. N. W. 1976. Influence of age of coffee seedlings on infection by *Colletotrichum coffeanum* (Noack) [*Glomerella cingulata* (Stonem.) Spauld & Von Schrenk] Kenya Coffee **41**, 55–57.
NARASHIMHASWAMY, R. L. 1968. Report on a visit to coffee areas in Ethiopia. In: FAO Coffee Mission to Ethiopia 1964–65. FAO, Rome: 33–48.
NUTMAN, F. J., and ROBERTS, F. M. 1960a. Investigations on a disease of *Coffea arabica* caused by a form of *Colletotrichum coffeanum* Noack. 1. Some factors affecting infection by the pathogen. Trans. Br. Mycol. Soc. **43**: 489–505.
NUTMAN, F. J., and ROBERTS, F. M. 1960 b. Investigations on a disease of *Coffea arabica* caused by a form of *Colletotrichum coffeanum* Noack. II. Some factors affecting germination and infection, and their relation to disease distribution. Trans. Br. Mycol. Soc. **43**: 634–665.
OKIOGA, D. M. 1976. Occurrence of strains of *Colletotrichum coffeanum* resistant to methyl benzimidazol-2-ylcarbamate (carbendazim) and chemically similar compounds. Ann. Appl. Biol. **84**: 21–30.
PARLEVLIET, J. E., and ZADOKS, J. C. 1977. The integrated concept of disease resistance: A new view including horizontal and vertical resistance in plants. Euphytica **26**: 5–21.
PERSON, C. 1974. Consultancy report on the coffee berry disease program at Jimma Research Station. FAO, Rome, 7 pp.
PIETERS, R., and VAN DER GRAAFF, N. A. 1980. Resistance to *Gibberella xylarioides* in *Coffea arabica:* evaluation of screening methods and evidence for the horizontal nature of the resistance. Neth. J. Plant Pathol. **86**: 37–43.
RAMA MURTHY, A. 1968. Observations on the tip leaf colour and branching habit in Ethiopian Arabica coffee collections. In: FAO Coffee Mission to Ethiopia 1964–65, FAO, Rome, Appendix IV, 6 pp.

RAYNER, R. W. 1952. Coffee berry disease – a survey of investigations carried out up to 1950. E. Afric. Agric. J. **17**: 130–170.
ROBINSON, R. A. 1974. Terminal Report of the FAO Coffee Pathologist to the Government of Ethiopia. FAO, Rome, AGO/74/443, 16 pp.
ROBINSON, R. A. 1976. Plant Pathosystems. Springer, Berlin. 186 pp.
ROBINSON, R. A. 1979. Permanent and impermanent resistance to crop parasites; a re-examination of the pathosystem concept with special reference to rice blast. Z. Pflanzenzuecht. **83**: 1–39.
RODRIGUES JR., C. J., BETTENCOURT, J. A., and RIJO, L. 1975. Races of the pathogen and resistance to coffee rust. Annu. Rev. Phytopathol. **13**: 49–70.
SACCAS, A. M. 1951. La Trachéomycose (Carbuncullariose) des *Coffea excelsa, neo-arnoldiana* et *robusta* en Oubangui-Chari. Agron. Trop., Paris **6**: 453–506.
SACCAS, A. M. 1956. Recherches expérimentales sur la Trachéomycose des caféiers en Oubangui-Chari. Agron. Trop., Paris **11**: 7–38.
SMALL, W. 1926. On the occurrence of a species of *Colletotrichum*. Trans. Br. Mycol. Soc. **11**: 112–137.
SNEDECOR, G. W., and COCHRAN, W. G. 1976. Statistical methods. 6th ed. Ames, Iowa, USA. 593 pp.
SNOECK, J., and PETIT, R. 1964. Etude comparative des productions de diverses lignées de *Coffea arabica*. Bull. Inf. INEAC **13**: 145–171.
STEINER, K. G. 1972. The influence of surface wax obtained from green berries of six selections of *Coffea arabica* on the germination of *Colletotrichum coffeanum*. Kenya Coffee **37**: 179.
STEWART, R. B. 1957. Leaf blight and stem dieback of coffee caused by an undescribed species of *Ascochyta*. Mycologia **49**: 430–433.
SYLVAIN, P. C. 1955. Some observations on *Coffea arabica* L. in Ethiopia. Turrialba **5**: 37–53.
SYLVAIN, P. C. 1958. Ethiopian coffee – Its significance to world coffee problems. Econ. Bot. **12**: 111–139.
TAG, P. 1966. Notes on a visit to Angola. Kenya Coffee **31**: 23.
TAPLEY, R. G. 1964. Coffee Berry Disease in Tanganyika. Tanganyika Coffee News **38**: 45.
THOMAS, A. S. 1942. The wild *Arabica* coffee on the Boma Plateau, Anglo-Egyptian Sudan. Emp. J. Exp. Agric. **10**: 207–212.
THOMAS, A. S. 1944. The wild coffees of Uganda. Emp. J. Exp. Agric. **12**: 1–12.
TOTHILL, J. D. (Ed.). 1954. Agriculture in Sudan. Oxford Univ. Press, London, 974 pp.
VAN DER GRAAFF, N. A. 1978 a. Selection for resistance to coffee berry disease in Arabica coffee in Ethiopia. Evaluation of selection methods. Neth. J. Plant Path. **84**: 205–215.
VAN DER GRAAFF, N. A. 1978 b. Research on coffee pathology. FAO, Rome, AG:DP/ETH/74/002 Assignment Report. 32 pp.
VAN DER GRAAFF, N. A. 1979. On the occurrence of coffee berry disease in Brazil. FAO Pl. Prot. Bull. **27**: 118.
VAN DER GRAAFF, N. A., and PIETERS, R. 1978. Resistance levels in *Coffea arabica* to *Gibberella xylarioides* and distribution pattern of the disease. Neth. J. Plant Path. **84**: 117–120.
VAN DER PLANK, J. E. 1963. Plant Diseases: Epidemics and Control. Academic Press, New York, 349 pp.
VAN DER PLANK, J. E. 1968. Disease resistance in plants. Academic Press, New York, 206 pp.
VAN DER PLANK, J. E. 1975. Principles of plant infection. Academic Press, New York, 216 pp.
VAN DER VOSSEN, H. A. M. 1973. Plant breeding. In: Coffee Res. Found. Kenya Annu. Rep. 1972–73: 54–56.
VAN DER VOSSEN, H. A. M. 1975. Plant breeding. In: Coffee Res. Found. Kenya Annu. Rep. 1973–74: 40–51.
VAN DER VOSSEN, H. A. M. 1976. Plant breeding. In: Coffee Res. Found. Kenya Annu. Rep. 1974–75: 84–103.
VAN DER VOSSEN, H. A. M. 1977. Plant breeding. In: Coffee Res. Found. Kenya Annu. Rep. 1975–76: 72–87.
VAN DER VOSSEN, H. A. M., and COOK, R. T. A. 1975. Incidence and control of Berry Blotch caused by *Cercospora coffeicola* on Arabica coffee in Kenya. Kenya Coffee **40**: 58–61.
VAN DER VOSSEN, H. A. M., COOK, R. T. A., and MURAKARU, G. M. W. 1976. Breeding for resistance to coffee berry disease caused by *Colletotrichum coffeanum* Noack (sensu Hindorf) in *Coffea*

arabica L. I. Methods of preselection for resistance. Euphytica **25**: 733–745.
VAN DER VOSSEN, H. A. M., and WALYARO, D. J. 1978. Plant breeding. In: Coffee Res. Found. Kenya Annu. Rep. 1976–77: 76–95.
VERMEULEN, H. 1966. Plant Pathology. In: Coffee Res. Found. Kenya Annu. Rep. 1964–65: 57–60.
VERMEULEN, H. 1970 a. Coffee berry disease in Kenya. I *Colletotrichum* spp. colonizing the bark of *Coffea arabica*. Neth. J. Plant Path. **76**: 277–284.
VERMEULEN, H. 1970 b. Coffee berry disease in Kenya. II. The role of *Glomerella cingulata* in the *Colletotrichum* population colonizing the bark of *Coffea arabica*. Neth J. Plant Path. **76**: 285–292.
VON STRENGE, H. 1956. Wild coffee in Kaffa Province of Ethiopia. Tropic. Agric. Trinidad **33**: 297–301.
WALLER, J. M. 1971. The incidence of climatic conditions favourable to coffee berry disease in Kenya. Exp. Agric. 7: 303–314.
WHITE, R. G. 1980. Assignment report on coffee agronomy. FAO, Rome, AG:DP/ETH/78/004 Assignment Report. 25 pp.
WORMER, T. M. 1964. The growth of the coffee berry. Ann. Bot. London **28**: 47–55.
ZADOKS, J. C. 1979. Proposal to survey and improve the resistance of coffee in Ethiopia against diseases and pests. FAO Consultancy Report, typescript, 19 pp. + appendix.
ZEVEN, A. C., and ZUKOVSKY, P. M. 1975. Dictionary of cultivated plants and their countries of diversity, excluding ornamentals, forest trees and lower plants. Pudoc, Wageningen. 219 pp.

CURRICULUM VITAE

Nicolaas Adriaan van der Graaff werd geboren te Dordrecht op 9 oktober 1945. Te Dordrecht volgde hij het Christelijk Lyceum en legde hij in 1963 het eindexamen HBS-b af. Vanaf 1963 studeerde hij biologie aan de Rijksuniversiteit te Leiden. In 1971 behaalde hij het doctoraal examen met als vakken plantenanatomie, biochemie en plantenfysiologie. Tijdens zijn studie vervulde hij een student-assistentschap plantenanatomie en gaf hij biologie-lessen aan het Develstein College te Zwijndrecht. In 1973 was hij voor een half jaar verbonden aan het Rijksherbarium te Leiden; gedurende deze periode verrichtte hij houtanatomisch onderzoek. Eind 1973 trad hij als assistent-deskundige in dienst bij de Voedsel en Landbouw Organisatie van de Verenigde Naties (FAO) en werd hij als koffieziektekundige te Jima, Ethiopië, gestationeerd. In januari 1975 werd hij benoemd tot FAO deskundige (koffieziekten) te Jima, Ethiopië, een positie die hij tot november 1978 vervulde. Sindsdien is hij verbonden aan de afdeling gewasbescherming van het hoofdkwartier van de FAO te Rome. Zijn activiteiten liggen op het gebied van resistentie van planten tegen ziekten en het bepalen van oogstverliezen door ziekten en plagen. Hij is voorzitter van de commissie voor 'duurzame' resistentie van de 'International Society for Plant Pathology'.