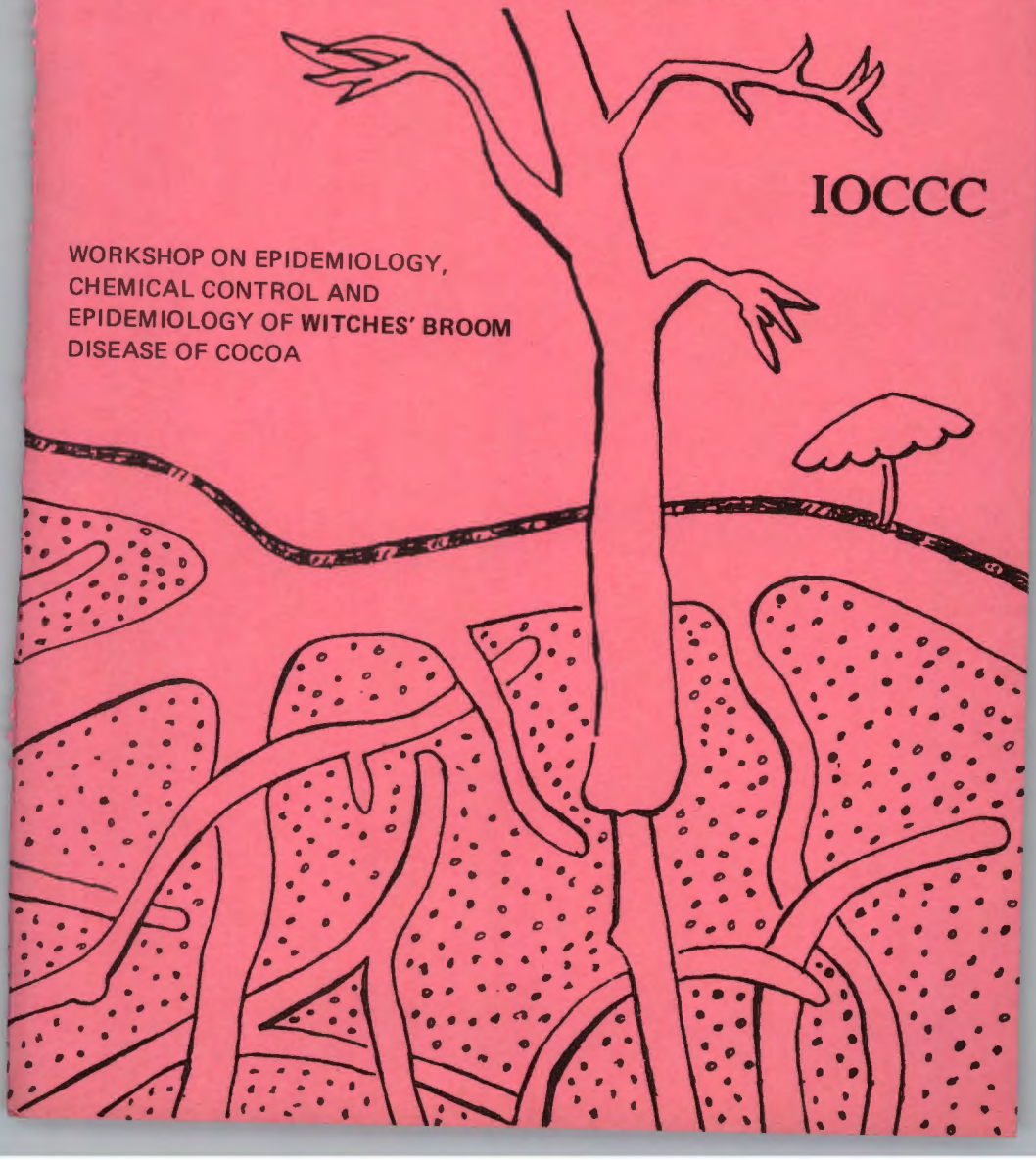
4th Workshop

MANAGING WITCHES' BROOM DISEASE OF COCOA

REPORT OF 4th WORKSHOP
OF INTERNATIONAL WITCHES' BROOM PROJECT
11 – 17 September 1987, Belem, Brazil.



IOCCC

WORKSHOP ON EPIDEMIOLOGY,
CHEMICAL CONTROL AND
EPIDEMIOLOGY OF WITCHES' BROOM
DISEASE OF COCOA

INTERNATIONAL WITCHES' BROOM PROJECT

(IWBP)

IWBP is an international project funded by chocolate manufacturers in Europe and North America with a number of International Agencies and with the governments of 6 cocoa producing countries. It is conducting fundamental research at a total of 16 centres in Europe, Latin America and the United States aimed at a reduction of the devastation caused by Witches' Broom disease of cocoa due to the pathogen Crinipellis perniciosa (Stahel) Singer.

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et de la Confiserie
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REPORT OF THE 4TH IWBP WORKSHOP

11th - 17th September 1987

Held at: Hotel Grao Para
Belem
Brazil

Hosts: IOCCC/CEPLAC-DEPEA

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Rapporteur: B.E.J. Wheeler

Edited by: R.A. Lass and S.A. Rudgard

C O N T E N T S

1. INTRODUCTION TO IWBP

Almost one-third of the world supply of cocoa is produced in the Americas but in many countries maximum production is severely curtailed by Witches' Broom (WB) disease. It occurs in the upper Amazon region of Brazil, in Bolivia, Colombia, Ecuador, Grenada, Guyana, Peru, Surinam, Trinidad and Venezuela. This widespread distribution also places at risk other areas where it is not yet present, such as Bahia, Brazil - the second largest concentration of cocoa plantings in the world - or proposed new plantings of cocoa such as in Amazonia, Brazil. In the Brazilian Amazon pod losses have reached 95 per cent on occasions, and almost all infected pods are a total economic loss. Moreover, there is NO assurance that its absence from cocoa producing countries outside the Americas will continue.

These features make a co-ordinated, multi-centre, multi-national research program on WB a top priority and so a project proposal was formulated by scientists in countries where the disease is important. The pathogen (Crinipellis perniciosa) causes overdevelopment of cocoa meristematic tissues leading to hypertrophied and proliferated growth, to give the characteristic Witches' Brooms (Escoba de Bruja/Vassoura-de-Bruxa/Balai de Sorciere). It also infects many pods. Infected pods fail to ripen and the beans either become liquified or adhere to the pod husk and are commercially valueless. In view of this serious threat, the International Office of Cocoa, Chocolate and Sugar Confectionery (IOCCC) with some other International Donor Agencies are funding a US $ 700,000 multinational research project over a period of about 5 years from 1st July 1985. The objective of the Project is "to develop an economic management system to control Witches' Broom disease of cocoa in a number of cocoa growing environments".

In early July 1985 participants in IWBP met at Pichilingue, Ecuador, for the 1st IWBP Workshop to develop a major research programme on the epidemiology of Crinipellis perniciosa and the decisions on this were published in October 1985 in the 'Report of the 1st IWBP Workshop'. The experiments to investigate the epidemiology are now under way in twelve sites in six countries.

It was considered important to start to consider the evaluation of candidate chemicals for disease control and a preliminary discussion was held at the 2nd IWBP Workshop held in Wageningen, Holland in October 1985. This discussion was published in the 'Report of the 2nd IWBP Workshop'.

The 3rd IWBP Workshop was held at Granja Luker, owned by Chocolateria Luker and situated near Manizales in Colombia from 7-12th July 1987. The experimental Protocol (agreed in July 1985) was carefully and extensively reviewed at this Workshop and amended as necessary. An experimental Protocol for recording climatic data at two sites were Witches' Broom disease is presently absent was also developed and data recording at these sites started in mid-1987. Guidelines for conduct of Inoculum and/or Gradient Experiments and for Chemical

Evaluations were drawn up. A number of these experiments are now completed and the results were discussed at the 4th IWBP Workshop.*

Copies of all these reports are available free of charge from Dr A Van Tulder, IOCCC, Avenue de Cortenbergh 172, Brussels, 1040, Belgium.

2. NARRATIVE REPORT OF 4TH IWBP WORKSHOP

2.1 OPENING SESSION

Participants arrived in Belem on Wednesday 9th and Thursday 10th September 1987. The 4th IWBP Workshop was held at the Hotel Grao Para in the Praca da Republica in the centre of the city. The names, addresses, telephone and telex numbers (where applicable) of all the participants are included as Appendix A to this report. Secretarial and organisational support was provided by CEPLAC/DEPEA.

The 4th IWBP Workshop started at 08.00 on Friday 11th September 1987 with a welcome address by the Director of CEPLAC's Departamento Especial da Amazonia, Dr Ilton Morais. His address was as follows:

> "In 1974, the Brazilian government decided to increase national cocoa production to maintain its position in the world market which was expanding at that time. The Amazon region was chosen as the area for expansion of the crop in view of its suitable soils and climate. The programme reached 100,000 hectares of new plantations in 1987, thereby:
>
> 1. Increasing production from 2,500 tonnes to 60,000 tonnes.
>
> 2. Strengthening the cultivation of cocoa with the addition of more than 7,000 farmers, particularly smallholders, and the accumulated social benefit of 30,000 companies directly associated with the crop.
>
> 3. Accumulating a mass of genetic material with 17,000 genotypes, perhaps the biggest germplasm bank in the world.
>
> 4. Developing the cultural control of Witches' broom (phytosanitary pruning) so that farmers can live with the disease.
>
> Witches' broom disease continues to be the principal limiting factor in the programme, necessitating the determination of alternative control methods. In this context, this workshop is very important to the future cultivation of cocoa in the Brazilian Amazon and other Latin American countries.

* [In the language of IWBP, 'Guidelines' do not have to be followed at every participating experimental site whereas it is expected that a 'Protocol' should be followed at every site].

> In the name of CEPLAC, we would like to welcome the scientists here and thank them for their collaboration in the resolution of the problem of Witches' broom. We would also like to express our confidence that the objectives of the Workshop will be reached during this week, and that the results will help improve control methods of this disease. "

There then followed an address from Dr H. Flotzinger (President of IOCCC) which was delivered by R.A. Lass (Executive Chairman, IWBP) on his behalf. This address was as follows:

> "I am sorry not to be present in person at this Workshop which is being held in Belem, Brazil from 11th - 17th September 1987.
>
> As President of IOCCC I extend my fraternal greetings to all the participants in the 4th Workshop of the International Witches' Broom Project or IWBP as it has become to be known.
>
> The name of our international organisation of trade associations for the world's cocoa, chocolate and confectionery manufacturers has changed since the start of IWBP in July 1985. The organisation used to be called the International Office of Cocoa and Chocolate abbreviated by IOCC. It is now called the International Office of Cocoa, Chocolate and Sugar Confectionery abbreviated to IOCCC. I mention this in case some of you have been puzzled by these two abbreviations.
>
> Our objectives remain the same despite our name change as does our commitment to cocoa research and to IWBP. My members have committed themselves over 5 years to donate a substantial sum to this Project which got under way on the 1st July 1985. A little over two years have now passed and we are looking to you scientists to be making good progress towards the goal of economic management systems for controlling this disease in the various cocoa growing environments. These two years have passed very quickly as no doubt will the next three years in like manner. It is thus of paramount importance that we should not lose sight of the objective of IWBP. We are most encouraged by the excellent collaboration between the participants from the various countries, cultures and language zones in the Project and hope that this will continue long after the end of IWBP in its present form.
>
> We believe that these Workshops are a most important part of IWBP and so we are very happy to provide the funds for you all to meet and progress the work of this Project. I wish you all well and close this brief address in the hope that you have a most successful Workshop."

The Chairman of the Project Scientific Committee of IWBP, Dr L H Purdy then welcomed participants to the 4th IWBP Workshop as follows:

"The success of this Project is largely due to the involvement of those collecting the data. I hope that during this Workshop we will address the future of the phytosanitation studies within IWBP and will develop guidelines or a protocol for their conduct. An expert working group has already prepared a document as a basis for discussion during the Workshop. I hope that we shall progress with our discussions as well as we have done in the past."

2.2 Adoption of Agenda and Objectives of 4th IWBP Workshop

The Agenda for the 4th IWBP Workshop was thoroughly discussed and adopted. The final version is included as Appendix B to this report. It was noted that there were two observers to this meeting namely R.H. Fulton (tropical crop consultant), whose attendance was kindly funded by ACRI, and A.J. Kennedy (Head, Cocoa Research Unit, University of West Indies) funded by his Unit's funds.

The Objectives of the 4th IWBP Workshop were fully discussed and then adopted as follows:

" 1. To report briefly on the present status of the 'Comparative Epidemiology Experiment', by country.

2. To discuss 'Comparative Epidemiology Experiment' protocols 1 and 1A.

3. To discuss analysis of data by site and for the 'Comparative Experiment'.

4. To report on chemical evaluation studies by country.

5. To discuss 'Inoculum/Disease Gradient Experiments' by country.

6. To discuss phytosanitation studies and how such can become part of the IWBP.

7. To develop guidelines for phytosanitation studies.

8. To discuss publication of the Monograph presenting results and conclusions from IWBP.

9. To discuss other research that may be associated with, or related to, the IWBP that might be considered to become part of the IWBP.

10. To discuss disease resistance breeding and selection.

11. To discuss the future direction of IWBP in relation to long-term IWBP objectives by country, and the application of the IWBP format to other areas of need.

12. To consider format of report for IOCCC and when it should be submitted to them. "

[It should be noted that objective 11 was referred to the Project Scientific Committee for preliminary discussion and objective 12 was deferred until the subject had been considered by the Project Management Committee meeting in Berne on 28th September 1987 and subsequently to the 5th IWBP Workshop to be held in Trinidad in November 1988].

2.3 The Objective of IWBP

This was restated by R.A. Lass as follows:

> "TO DEVELOP AN ECONOMIC MANAGEMENT SYSTEM TO CONTROL WITCHES' BROOM DISEASE OF COCOA IN A NUMBER OF COCOA GROWING ENVIRONMENTS".

To achieve this a number of subsidiary objectives have been previously established as follows:

1. "TO STUDY SYSTEMATICALLY INFECTION DYNAMICS OF WITCHES' BROOM DISEASE RELATIVE TO TIME (BOTH SEASONS AND YEARS) WITH RESPECT TO THE CRITICAL ENVIRONMENTAL FACTORS."

   [To achieve this the Comparative Epidemiology Experiment has been set up].

2. "TO EXAMINE AND EVALUATE THE REACTION OF THE PATHOGEN TO AVAILABLE SYSTEMIC, PROTECTIVE AND ERADICATIVE FUNGICIDES INCLUDING THE APPLICATION TO THE SOIL AND THE EFFECT ON BASIDIOCARP DEVELOPMENT OF BROOMS SPRAYED WHEN GREEN."

   [To achieve this experimental guidelines have been drawn up and a number of chemicals are being studied].

3. TO EXAMINE INOCULUM AND/OR DISEASE GRADIENT EXPERIMENTS".

   [To achieve this experimental guidelines were drawn up at the 3rd IWBP Workshop and will be reported on at the present meeting]

4. "TO EXAMINE AND EVALUATE PHYTOSANITARY PRACTICES AND THEIR IMPACT ON WITCHES' BROOM DISEASE."

   [To achieve this a protocol/guidelines for phytosanitary studies will be discussed at the 4th IWBP Workshop].

Furthermore the need to develop planting material resistant to the disease has been obvious for many decades. Informal discussions with the Project Liaison Officer during his visits to the participating institutions has indicated a desire to consider prospects for breeding planting material resistant to the disease. With this in mind a session in this Workshop has been allocated to discuss this issue though clearly IWBP can do little more than develop an appropriate strategy and perhaps prepare a project for submission to some other international donor agency.

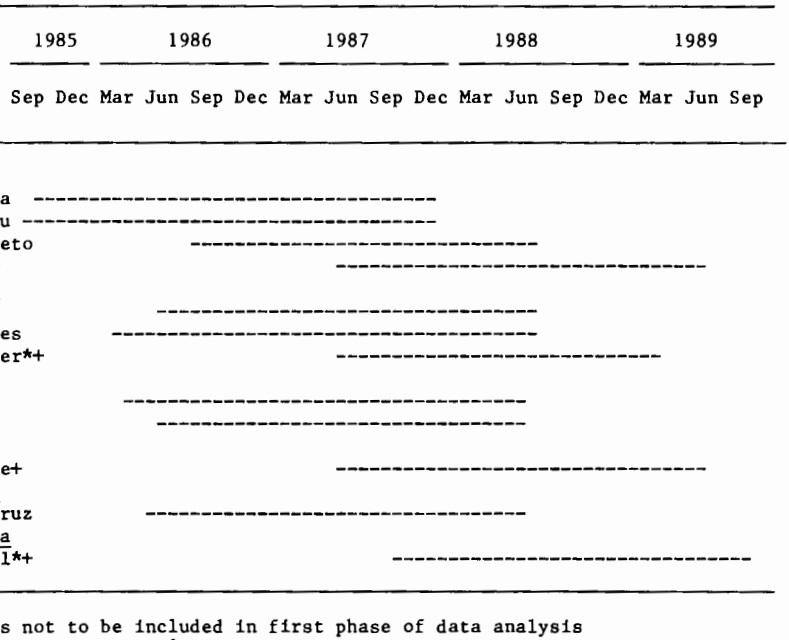
3. Comparative Epidemiology Experiment

3.1 Status Report: Project Liaison Officer, S.A. Rudgard

Two reports (Circular Numbers 30 and 34) indicating the status of the experiments have already been presented. So far, over half of the projected data is in the computer and disks with the relevant data files have been sent to the various countries. Data collection at some sites, e.g. Tome Acu and Altamira in Brazil, is approaching the end of the second year. Thus a critical stage is near, that of deciding the form of analysis for core data of the project. The first objective is to progress the analysis of data at the level of each site so that the main parameters are clear to all participants. Then the comparative nature of the experiments can be considered leading to an appraisal of the relationships between the disease and environment.

Consideration also needs to be given to the use of data outside the core data of the project, to the continuation of data sets beyond 2 years where this is considered useful or of special value and to further work indicated by analysis of the data sets. These last two aspects, particularly, are matters for discussion within the Project Scientific Committee both in relation to their integration into the present aim of production of a management program within 5 years and to funding.

FIGURE 1: Data sets available for Comparative Epidemiology Experiment



\+ : Sites not to be included in first phase of data analysis
* : Sites where witches' broom is absent

3.2 SITES

Altamira, Brazil: Joao Bomfin

Data from week 46 (Nov) 1985 were presented. Symptoms of flush infections appeared from weeks 14 to 40 in 1986 and slightly earlier in 1987. The number of infections trebled in 1987 but was still low. In both years there were approximately 49 per cent terminal brooms and 21 - 26 per cent axillary brooms. Symptoms on flower cushions appeared between weeks 12 and 32. Throughout 1986 the number of new fruits set remained fairly constant and so generally did the number of fruit <12 weeks old, available for infection, though there was a slight peak at the end of the year. The percentage pods with WB reached a peak during weeks 4 to 28. On average infected pods at harvest were 16 weeks old and healthy ones 22 weeks old. In both years there were approximately 49% terminal brooms and 21-26% axillary brooms. Symptoms on flower cushions appeared between weeks 12 and 32.

Ouro Preto, Brazil: Paulo Albuquerque

Data were presented for the first year, from week 36, 1986. Flushing was initially intense possibly because of the initial treatment of the site. Subsequently, the number of infections increased between weeks 6 and 24 (1987) but the total (40) was low. Cushion infection reached a peak between weeks 4 and 22 but, again, the numbers were low and mostly there were only dead flowers (35). The peak harvest of healthy pods occurred in May/June. Few pods appeared affected by Witches' Broom until week 18 but overall about 30 per cent of the pods were diseased. Basidiocarps were produced between weeks 6 and 17. About three times as many basidiocarps formed on vegetative brooms in the middle of the canopy as on those at the top of the canopy. Significant numbers of basidiocarps formed on cushion brooms but none on other types e.g. brooms on the ground. Rain started in week 34 (1986) and there were two main periods, before and after week 2 (1987), the rain being more frequent during the second period.

Tome Acu, Brazil: Ausier Luuz Pacheco de Carvalho

Data from September 1985 were presented. The proportions of vegetative infections were approximately, 33 per cent terminal brooms, 26 per cent axillary brooms plus 18 per cent axillary brooms associated with stem swellings and 18 per cent brooms arising from leaf base infections. Total fruit production was similar in both 1986 and 1987 but the proportions of diseased pods varied, the 1986 and 1987 figures respectively being: healthy 60 per cent and 40 per cent, affected by witches' broom 30 per cent and 51 per cent, and with blackpod (Phytophthora), 10 per cent and 4 per cent.

Basidiocarps were produced from weeks 1 to 26. In 1986 53 per cent of the total basidiocarps formed on brooms at the top of the canopy and 34 per cent on brooms suspended at mid-canopy height. In 1987 the proportion at both heights was similar (48%). Few basidiocarps were produced on cushions (1986 <2%, 1987, 0.3%) or on other objects. Most rain fell between November and May/June, 1987 having slightly less rain than the previous 2 years.

Bahia, Brazil: Ricardo Miranda

Data recording as in Protocol 1B started in April 1987 in a site at CEPEC, Itabuna, of 10 year old Catongo hybrids (3m x 3m) with Erythrina fusca shade trees at 24m spacing. The site is near a hydrology/water relationships experiment which has been running for 2 years.

Data were presented to illustrate the five climatic areas in Bahia (based on rainfall) and for group 2 (in which the CEPEC site occurs), the rainfall distribution and temperature profiles. Phenological data from another experiment at CEPEC were also shown.

Colombia: Fabio Aranzazu

Data were presented from the two sites, at Manizales (from March/April 1986) and Llanos (from July 1986) respectively.

At Manizales there is no real dry season and rain is frequent though there are peaks between April and June and between October and December. Basidiocarps were produced virtually throughout the year with little difference in the activity on brooms hung at the top or in the middle of the canopy. Similar patterns of basidiocarp production were obtained from cushion brooms and brooms on the ground. Sometimes more basidiocarps formed on ground brooms than on suspended brooms; at other times suspended brooms were more productive..

There were well marked peaks of flushing reflecting the uniformity of the clonal cocoa at this site but few vegetative infections. Flowers were present at most times though numbers were relatively low early in 1987 when there was a break in the rain. Cushion brooms reached a peak in June/July and numbers increased considerably within this period in 1987. All pods were removed at the start of the trial since many were affected by Witches' broom, Moniliophthora or Phytophthora. New pods developed after 4 to 5 months and those with suspected Moniliophthora were subsequently removed twice weekly. Other diseased pods were removed at harvest. Here, there was relatively little infection (<10% WB) probably because there was comparatively little rain when the fruits were young.

At the Llanos site, heavy rain occurred during September, October and November and basidiocarp production followed the rainfall pattern closely. Numbers of basidiocarps declined once rain was less than 15 mm/wk and none formed during the dry season. When the rains resumed, basidiocarps were again produced but fewer of them because the brooms were beginning to rot. Basidiocarps were produced on ground brooms in a similar pattern, occasionally more abundantly then on the suspended brooms. Generally, there was little infection on the vegetative flush but there was a marked increase in cushion infection during rain.

Pichilingue, Ecuador: Jaime Aragundi and Alan Maddison

Data were presented mainly from the Station site (established 21 months) with some from the Farm site (established 14 months).

At the Station site in 1986 there was a small peak in basidiocarp production at the beginning of rain and a further small peak in March/April. There was little difference in numbers formed on brooms suspended at the top and in the middle of the canopy. Few basidiocarps formed on pods but cushions and ground brooms contributed significantly to basidiocarp numbers. No infections were observed during the first flush peak but subsequently the different classes of infection appeared over a long period extending into the dry season. Terminal and axillary brooms seemed to be related to flushing but stem swellings appeared over a long period with no obvious connection with flushing. There were no strong connection with the numbers of basidiocarps present.

There was no infection in the early flowering but then the appearance of dead flowers followed the production of basidiocarps. Cushion brooms were slow to appear. The production of pods was low in 1986 and more were affected by *Lasiodiplodia* than by Witches' broom. The Witches' broom fruits were mostly infected during the early peak of basidiocarp production when inoculum remained relatively low.

There was some rain during the ensuing dry season but this did not induce basidiocarps. At the beginning of the wet season (1987) the old brooms in the canopy contributed significantly to the total number of basidiocarps. Generally, however, basidiocarp production was less in 1987 though there was more infection on the canopy. Brooms on the ground contributed little in 1987 possibly because the second set of brooms collected during the dry season became covered by leaves during September/October when the trees flushed and also development of ground cover led to a visibly quicker decay of old brooms.

Flushing in 1987 followed a different pattern to that of 1986. Infections appeared later than in 1986 but there were more of them. Flowering overall was slightly less in 1987 but more in January/February and fewer cushions were infected than in 1986.

The farm site showed several differences from the Station site, including more production of basidiocarps during the dry season, and less synchronization in flushing from tree-to-tree.

Grenada: T.N. Sreenivasan

The site was established at the beginning of August 1987. The collection of data will be supervised by Jennifer Andall, assisted by a high school graduate. Passport data for the site were presented.

Trinidad: Steve Mohan

Data were presented for the first year, June 1986 to March 1987. During the period May 1986 to March 1987 there were two main flushes in June and January respectively but only 15 vegetative brooms were recorded, 9 terminal, one axillary and five associated with stem swellings. The low number of infection courts present during maximum basidiocarp activity may account for this low infection. Cushion infection as indicated by dead flowers reached a peak in September but the numbers of other infections remained low throughout. Pods

were harvested from July 1986 to June 1987 with a peak collection in January, 20-22 weeks after cherelle set. The amounts for 50 trees were: ripe, healthy 367 (47.3%), affected by Witches' Broom 308 (39.7%), with black pod 78 (10%), others 23 (3%). There were relatively more (21.2%) pods with Phytophthora from the 10 experimental trees. Generally, but not conclusively, most pods with Phytophthora were collected from the lower part of the tree, those affected by Witches' Broom from the middle and ripe, healthy pods from the middle/top. The average weekly rainfall was 47mm with a peak of 298 mm in week 48 (November). Total rainfall was 1454 mm.

Venezuela: Ramon Silva Acuna

The site was established in week 32 of 1987. A brief description of its location, the distribution of the sample cocoa trees and of the shade trees was given. The meteorological site and the position of broom sets in the cocoa canopy were also illustrated.

Calibration of Belfort Instruments Wetness Indicator

Alan Maddison presented results from experiments to compare readings taken from the Belfort and Campbell instruments with visual observations of wetness on canopies of trees within the farm site at Pichilingue. The Belfort instrument was outside the canopy and readings were taken as the percentage scale deflection caused by the relative tautness of a string sensor. The Campbell instrument records the percentage scale deflection from electrical wetness sensors at the top of the canopy site. Comparisons were made between the length of wetness periods in hours recorded by direct visual observation and periods of any scale deflection in both instruments. Periods associated with both rain and dew were not accurately represented by this method. Correlations were not significant ($r = 0.04$, Belfort; $r = 0.26$, Campbell).

The mean value of percentage scale deflection that best represented directly observed periods was calculated for all cases. Correlations between periods above 25 per cent deflection and actual length of period were highly significant for both instruments ($r = 0.87$ and 0.99). The regression coefficients were 0.98 and 1.14 for the Belfort and Campbell respectively in wetness periods caused by dew. The regression constants were close to zero in both cases. Periods above 25 per cent deflection in the Belfort instrument were also highly correlated with wetness caused by rain ($r = 0.90$), giving a regression coefficient if 1.11 and a constant close to zero (-0.49).

3.3 Comparative Data Analysis

The Project Liaison Officer has started to analyse data from the Comparative Epidemiology Experiment in 1987. Data could only be analysed where a full 12 months were available, and not all the sites had sent a year's data to the PLO by July 1987. Thus only five sites could be compared in time for the 4th IWBP Workshop: Manizales, Pichilingue (Station), Altamira, Tome Acu and Santa Cruz.

Initial analysis examined basidiocarp production on vegetative brooms suspended at the top of the canopy, and the main meteorological data.

All sites had a distinct dry season in the year when little or no rain fell, except for Manizales where two dry seasons occurred. Basidiocarps were only observed in weeks with rain, and total production was similar in Tome Acu, Altamira and Pichilingue.

TABLE 1: BASIDIOCARP PRODUCTION ON VEGETATIVE BROOMS

Site Name	Total Produced	Weeks Active	% Brooms Active	Mean /active broom	Mean weeks active	Basidiocarps /Broom /week
Tome Acu	997	20	76	13	3	4.4
Pichilingue	728	20	56	13	3	3.7
Santa Cruz	1877	17	97	19	7	2.8
Altamira	826	26	83	9	4	2.5
Manizales *	828	18	74	11	5	2.4
**	915	21	93	10	4	2.3

* Early 1986 wet season
** Late 1986 wet season

Brooms produced about twice as many basidiocarps in Santa Cruz and Manizales and the proportion of brooms that produced basidiocarps was highest at these two sites and lowest in Pichilingue. The average number of basidiocarps was also highest at Santa Cruz and Manizales, and lowest in Altamira. The period of basidiocarp production varied from 17 weeks in Santa Cruz to 39 weeks in Manizales.

TABLE 2: METEOROLOGICAL DATA

Site Name	INOCULUM PERIOD		RAINFALL			TEMPERATURE				
	Start	Finish	Total	Days	% Rainy Days	Mean Max	Hrs >30°	Mean Min	Hours <20°	
Tome Acu	4	23	1994	110	79	31.4	2.9	23.0	0.0	99
Pichilingue	3	22	1458	97	69	30.0	1.9	21.9	0.3	73
Santa Cruz	33	49	893	79	66	32.7	4.0	18.7	4.7	53
Altamira	5	30	1385	118	64	28.6	0.6	20.4	1.7	52
Manizales *	10	27	640	62	52	29.0	1.0	17.9	8.7	39
**	34	1	869	65	49	30.7	2.3	20.0		

* Early 1986 wet season
** Late 1986 wet season

The total rainfall during the inoculum period varied from 893 mm in Santa Cruz to 1994 mm in Tome Acu (Table 2). Rainfall per week during these periods was lowest in Manizales and Santa Cruz, and the percentage of rainy days was also lowest for Manizales. Maximum temperatures were highly related to the number of hours over 30°C per day, as were minimum temperatures with the number of hours below 20°C. Temperatures above 30°C and below 20°C are considered unfavourable for the fungus, and the average number of hours per day in these ranges was highest in Manizales and Santa Cruz.

A preliminary analysis was made of other data relating to phenology and infection. These results were also presented at the 4th IWBP Workshop.

3.4 Discussion on the Methodology of the 'Comparative Epidemiology Experiment

The results from the 5 sites which have already forwarded 12 months data were discussed at considerable length both during and after the individual presentations. The methodology for conducting the experiment was considered by participants to be still appropriate with a few minor amendments. These amendments (paragraph 3.5.1) were adopted by the 4th IWBP Workshop in Session XIII at the end of the Workshop.

It was agreed that there should be a standard format for presenting from the Comparative Epidemiology Experiment. The possible ways of doing so were discussed at length. It was agreed that graphical presentation of the site data would be most instructive. A series of templates and a blank table would be circulated to facilitate the presentation of core data within the project. Details of these templates are given below (paragraph 3.5.2). It was agreed that these together with the amendments adopted (paragraph 3.5.1) should constitute IWBP PROTOCOL 1C. These templates will be used at the 5th IWBP Workshop in Trinidad in November 1988. However, it was accepted that for each country there may be other aspects which could be presented in an individualistic, creative way and interpretation of data should be left to each individual site operator and country coordinator.

The publication of any data by IWBP should also be delayed until the students involved in the project had finished and presented their theses.

3.5 Text of Protocol 1C of the Comparative Epidemiology Experiment

3.5.1 Amendments

The following amendments to IWBP Protocol 1A were adopted:

Amendment 19 — Delete the item on wetness in paragraph 2f (iii). Replace with the following: Wetness: The % deflection recorded every hour.

Amendment 20 — Insert new sentence at the end of paragraph 2 d (ii): Where ground brooms become covered by leaf litter or

other material, e.g. from ant activity, the cover should not be removed to assess basidiocarps.

Amendment 21 — Insert new sentence at the end of paragraph 2d (iv): Counts should be made on residual parts of suspended pods even after most of the pod tissue has been lost.

The following amendment to IWBP Protocol 1B was adopted:

Amendment 1 — Delete the item on wetness in paragraph 2 d (iii). Replace with the following:
Wetness: The % deflection recorded in every hour.

3.5.2 Site Data Analysis: Templates

a. Graphs

In each of the following sets of templates, the x-axis is time (52 weeks) from the beginning of data. There will thus be two graphs for each parameter, one for each year. In sets 1 to 6 incidence of rain and in sets 2 to 5 presence of basidiocarps are to be indicated by horizontal lines. The following description indicates the parameters for the y-axes:

Set 1 — Basidiocarps
Suspended vegetative brooms at the top of the canopy
Suspended vegetative brooms at the middle of the canopy
Pods hung at the top of the canopy
Pods hung at the middle of the canopy
Infected cushions
Brooms on ground (pruned)
Brooms on ground (natural)
Pods on ground

Set 2 — Phenology
Flushing : flush points
Flushing : new leaves
Flowering : active cushions
Flowering : open flowers
Fruiting : new pods (cherelles)
Fruiting : developing pods

Set 3 — Flush Infection
Swellings on pulvinus/petiole
Stem swellings/cankers
Axillary brooms associated with infected petiole
Axillary brooms associated with stem swellings
Axillary brooms
Terminal brooms
Others
Total

Set 4 — Cushion Infection
Dead flowers/star blooms
Dead flowers/star blooms and chirimoyas
Dead flowers/star blooms, chirimoyas and brooms

Chirimoyas
Chirimoyas and brooms
Brooms

Set 5 Harvest

Three templates (A, B, C) with parameters indicated (+)

Type	Units (A)	10 sample trees (B)	All site trees(C)
Ripe (R)	+	+	+
Wilted (CH)	+		
Witches' broom (W)	+	+	+
Moniliophthora (M)	+	+	+
WM	+	+	+
Phytophthora (PH)	+	+	+
WPH	+	+	+
Others (OTH)	+	+	+

Set 6 Meteorology

Rain	Total	Bars
	Days with > 5 mm	
	> 15 mm	
	> 30 mm	Scale (1-7)
Wetness	Days with > 8 hrs	
	> 25% after 20.00h	
Temperature	Maximum	Points
	> 30°	Bars
	Mean	Lines
	< 20°	Bars
	Minimum	Points
Relative Humidity	Maximum	Points
	> 95%	Bars
	Mean	Lines
	< 70%	Bars
	Minimum	Points

Tables

A blank table will be provided for the following:

1. Matrix: correlation coefficients

Flushing
Flowering

3.6 Action to be taken on the Comparative Epidemiology Experiment

The following points were noted and agreed.

i. A document has been prepared in three languages that describes the symptoms of Witches' broom disease in cocoa. It was agreed that the document should be circulated to all participants of the Workshop. In addition, photographs should be commissioned to illustrate the various symptoms. The final version of the document in three languages could then be printed as a pamphlet by IWBP.

ii. The Project Liaison Officer will be responsible for the drafting and circulation of Templates for site data analyses. All sites involved in the first phase of the Comparative Epidemiology Experiment will have finished data recording by July 1988. Completed templates for each site should be available by November 1988, and it is envisaged that individual site analyses will be complete by July 1989. The comparative analyses will also be prepared by that time.

iii. The decision to cease recording of data on the Comparative Epidemiology Experiment after 2 seasons (which would be more or less two years) should be emphasized. It is not intended that as much as three years data would be collected at any one site.

4. Experiments on Chemical Evaluation

4.1 Introduction

Guidelines for chemical evaluation were developed and adopted during the IWBP Workshop. Experiments have been conducted in several countries, and are in progress in others. This work was discussed and results were presented on the evaluation of fungicides for control of Witches' broom completed between July 1986 (3rd IWBP Workshop) and September 1987. Experiments that were unfinished or due to start before July 1988 were outlined.

4.2 Report on Chemical Evaluations Completed

BRAZIL: Presenter, Cleber Bastos

Extensive screens of all types of fungicide *in vitro* and *in vivo* were conducted in Rondonia. Chemicals were tested on young developing pods, seedlings, and necrotic and dead brooms. Several promising protectant compounds were selected from these tests and applied in field trials. None of the organic fungicides gave significant control of Witches' broom on pods when applied eight times at 15 day intervals. Various formulations of copper compounds, in some case blended with organics, gave good disease reduction. The effectiveness of Bordeaux mixture was reduced as application intervals were increased from 15 to 30 days.

Two triazole fungicides hexaconazole and triadimenol (technical names) were tested for activity against *C. perniciosa*. Hexaconazole showed good activity when sprayed onto growing points before and after inoculation of young seedlings. It gave very little activity applied as a soil drench,

and bioassays confirmed that it was not translocated well. Bayfidan controlled development of C. perniciosa in cocoa seedlings both as a spray applied before and after inoculation, and as a post-inoculation soil treatment. Bioassays showed that the chemical was translocated in seedlings and adult plants.

UK: Presenter, Stephen Rudgard

Two triazole fungicides were tested against C. perniciosa in seedlings. Hexaconazole was tested as a foliar spray, and gave good control of disease especially when applied post-inoculation. Triadimenol was applied as a soil treatment and gave control only applied 10 days before inoculation.

VENEZUELA: Presenter, Humberto Reyes

Results were presented from two field trials. Plantvax (Oxycarboxin) was tested in the first trial, both in granular form applied once to the soil and liquid form applied by mistblower at the same time. Brooms were collected and weighed and numbers were greatly reduced in all treatments, but especially well in the spray treatment. Calixin, Cobox and a laboratory test compound were applied singly and in mixtures using mistblowers in the second trial. The chemicals were sprayed at 30 day intervals for 5 months. Only two treatments, the laboratory test compound alone and a mixture of it with Calixin, reduced numbers of pods with Witches' Broom and significantly increased yield. Numbers of cushion brooms were greatly reduced in all treatments.

4.3 Report on Chemical Evaluations in Progress

ECUADOR

Experiments are planned to evaluate several fungicides against C. perniciosa initially on seedlings in the glasshouse, and later in the field on pods and whole trees. The compounds to be tested are:

1. Triadimenol; granular and emulsifiable concentrate
2. Oxycarboxin; granular
3. Hexaconazole; wettable powder
4. Chlorothanil; flowable

TRINIDAD

Experiments are already in progress using the following compounds:

1. Triadimenol
2. Hexaconazole
3. Flutolanil
4. Chlorothalonil

Compounds 1-3 are being tested as soil drenches on rooted cuttings in the greenhouse, and as sprays on necrotic brooms to suppress basidiocarp production. Field trials are in progress to test all compounds as sprays applied to pods and trunks, and also fungicides 1-3 applied as soil drenches to mature trees.

VENEZUELA

Field trials as outlined above will continue for a further year, using only those treatments that gave control of disease.

4.4 Discussion on Chemical Evaluation Trials

After discussion, it was agreed that there was now no need to continue screening more candidate chemicals since there was no great hope of using those not yet registered. It would be more appropriate to concentrate effort on those now available which were registered or likely to be registered shortly. In this context present results (4.2) showed that there were several interesting chemicals which needed to be tested further. To facilitate this the 'Guidelines for Chemical Evaluation Experiments' (5.2 of the Report of the 3rd Workshop of the IWBP in Manizales) were amended as detailed below (4.5).

4.5 Amendments to Guidelines for Chemical Evaluation Experiments

The following amendments were adopted:

Amendment 1 — Insert the following new item in Section 2 (Field Tests) immediately after 'Experimental Layout':

i. Soil Application

Plots should be of the following size: 4 x 3 (12 trees): one border row plus at least 2 experimental trees. This is one replicate. There should be a minimum of 5 replicates of each treatment: firstly, a control (where either there is no treatment or water application with no chemical); additional treatments should include at least 2 doses of chemical and at least two schedules of application interval.

In areas where high pod infections cannot be expected, up to 10 pods on each tree, preferably at different heights, may be inoculated artificially. The technique should follow that given in paragraph 1c (Plant Material, Inoculation) of the Report of the 3rd Workshop of the IWBP, Manizales.

ii. Aerial Application

Amendment 2 — Insert the following new item in Section 2 immediately after 'Application':

i. Soil

Chemicals should be applied to the central trees (at least 2) in each plot. Leaf litter should be removed from a circular area, 1m radius from the trunk. The fungicide should be applied in a sufficient volume of water to irrigate thoroughly the soil in a circle 1m away from the trunk. The leaf litter should then be

replaced. Number of applications and additives will be determined by developing research.

ii. Aerial

Amendment 3 Insert the following new item:

5.5.3 LARGE-SCALE FIELD TRIALS

This trial, which would continue for at least 2 years would examine the cost benefits over a larger experimental area of a treatment(s) already proven in tests. It would provide data for economic aspects of application of the chemical in a given schedule and the increase in revenue provided by the treatment.

EXPERIMENTAL LAYOUT

Plots should be the following size: 30 x 30 (900 trees) to include one border row dividing plots. There should be a minimum of 3 replicates (either at one or distributed over several sites), and 2 treatments: (a) control where there is no treatment or water application with no chemical) and (b) the fungicide treatment. Plots should conform to existing cultural practices over the whole site, which should be chosen as one with a history of good production and known disease incidence.

Application

i. Soil

Chemicals should be applied to the central trees in each plot. Leaf litter should be removed from a circular area, 1m radius from the trunk. The fungicide should be applied in a sufficient volume of water to irrigate thoroughly the soil in a circle 1m away from the trunk. The leaf litter should then be replaced. Number of applications and additives will be determined by developing research.

ii. Aerial Application

Chemicals should be applied to the central trees in each plot using a motorized sprayer. Different makes of these are available in the various countries, and all specifications should be given. Number of applications, additives and volume of carrier will be determined by developing research. Minimum of 15 days between applications. Trials are to be conducted for a minimum of 2 years.

Evaluation

i. Pods

Assess harvests of ripe healthy pods and necrotic pods every 2 weeks in the central sprayed area and a corresponding area in the control. Place diseased pods into standard categories, e.g. those with Witches' Broom, Moniliophthora, etc. All seeds from healthy pods and economically-useful seeds from diseased pods should be weighed separately whilst wet, and wherever possible a dry weight obtained as well.

ii. Labour

Assess man-days for all cultural practices, pod harvests and breaking, and chemical application throughout the year.

iii. Total Costs

Assess all labour costs and those for chemical and any adjuvant used, and fuel for mistblower or other equipment. Costs are to be given in US dollar equivalent at the end of each year.

iv. Cost-benefit

A cost-benefit analysis should be completed using the farm-gate price of cocoa at the end of each year of the trial.

4.6 Action to be taken on chemical evaluation

Field trials are now required to investigate more fully the type of activity of the selected chemicals. Application interval, doses and the use of more than one compound all need to be considered. Suggestions of strategies for chemical control were elaborated by Dr J.L. Pereira in the Report 2nd IWBP Workshop. Mixed regimes using chemicals with different modes of action can be considered after preliminary field tests.

Protectant compounds, including coppers, consistently fail to give good disease control in the field when experiments in controlled conditions have shown excellent results. It may be that adjuvants have a role to play in this case, and some attention will be given to this subject.

There is a risk that systemic compounds may be translocated to the pods and into the beans. Residue tests in dry beans must be carried out and samples examined for taints caused by the chemical before large-scale field trials are attempted.

It was decided that chemical companies should be approached for assistance in taint and residue tests and in mounting the large-scale trials. Funds are not available for such work within the IWBP budget, and the three major companies involved (ICI, Bayer & Nihon) might be persuaded to finance trials.

Protective clothing for mistblower operators must be used at all times. IWBP cannot of course be held responsible for any injuries incurred during the course of field trials related to the project.

5. Inoculum/Disease Gradient Experiment

5.1 Introduction

Guidelines for an inoculum/disease gradient experiment were developed and adopted during the 3rd IWBP Workshop held in Manizales, Colombia in July 1986. So far only one such experiment has been conducted.

5.2 Summary of Results of Inoculum/Disease Gradient Experiment

The results of dispersion/infection studies in 1986 and 1987 at Pichilingue with the aim of understanding the movement of Crinipellis perniciosa in Ecuador were presented by Jaime Aragundi. The methods followed closely the guidelines in the Report of the 3rd IWBP Workshop, Manizales with a source of 3000 brooms suspended at three levels between 0.5 and 2m, susceptible trap plants at and 10, 20, 40, 80, 100 and 285m from source and rotorod spore traps at all positions except 100m. In 1986, trap plants (EET 19 and ICS 95) were exposed for 3 weeks (April 3-24) and 90 days (April 24 - July 23) respectively. In 1987, four types of cocoa, EET19, Sca 12 x Sil 1, Pandora x Pound 12 and ICS x Sil 1, were exposed in various experiments for 3, 4 or 5 weeks. Data for per cent infection were subjected to Gregory's multiple infection transformation and both these and the spore trap data were plotted on a log/log scale.

In 1986 the infection gradient was moderately flat with the spore dispersal slightly steeper. In 1987 neither was initially steep. Consistent differences in infection were obtained between the cocoa progeny used as trap plants. The tentative conclusions drawn were that duration of exposure affected the slope of the gradient, at least over the first 40m, but C. perniciosa has the ability to disperse and remain viable up to 285m.

5.3 Actions to be taken on the inoculum and/or Disease Gradient Experiment

A disease gradient experiment in Manaus, Brazil, is planned for early 1988, to quantify both horizontal and vertical gradients. An experiment is also due to start in June 1988 in the Llanos region of Colombia.

It is important that the 'Guidelines' for such experiments are followed as closely as possible (Report 3rd IWBP Workshop, p.16-18).

6. Phytosanitation Studies within IWBP

6.1 Introduction

6.1.1 The position at the 3rd IWBP Workshop

The relationship between phytosanitation, the management and husbandry of the cocoa plantation and witches' broom were discussed at some length at the 3rd Workshop in Manizales. It was agreed that at an appropriate time it was important to establish experiments within IWBP based mainly on removal of infected material, at different sites which data from the Comparative Epidemiology Experiment indicated were along the 'epidemic curve'.

6.1.2 The Philosophy of Studies on Phytosanitation within IWBP

Phytosanitation in the context of witches' broom is often limited in sense to the physical removal of brooms or other infected material. As such it is only one of several practices which aim economically to reduce pod loss, though it is generally accepted that removal will have a key role in any disease management programme. Within that wider context, phytosanitation is subject (like any other component) to a number of factors which operate at the level of the farm. These are: the present yield of the farm and the local price of cocoa, the availability and cost of credit, labour, and equipment, and the incidence of Witches' broom and other pod diseases. All these indicate the practicality of phytosanitation for that particular farm. However, underlying these practical considerations, there must be knowledge of the technical efficiency of removing infected material and it is this, specifically, which has to be addressed to IWBP in order to answer such question as: "Can removal reduce pod loss?"; "How thorough should it be?"; "How do adjacent sources of inoculum effect the efficiency of removing infected material?"

6.1.3 Present Studies on Phytosanitation

a. Brazil

Studies in Brazil, reported by Teklu Andebrhan, indicated aspects relevant both to the practical application of phytosanitation and its efficiency. A study at Benevides between 1980 and 1983 showed that the cost of removing brooms amounted to 20 per cent of the farm income. In this instance brooms were not moved off the site, to do so would have increased the existing removal costs by some 40-50 per cent.

Another study sought to examine the production of basidiocarps on brooms that were removed. This indicated that in terms of their productivity there was little point in removing brooms each month. In the first year after their formation relatively few brooms produced basidiocarps and only between 12 and 24 months was there a big increase in activity.

Other aspects considered phytosanitation in relation to crop management. Studies indicated that over 90 per cent of the pods are borne below 4m. There is no value in allowing trees to grow tall, on the contrary it militates against efficient sanitation. Current recommendations in Brazil are to keep young trees to about 3.5m by formation pruning downwards from the top. Trees treated in this way tend to grow more laterally and there is thus a need to increase spacing.

The effects of spacing and shade on the incidence of Witches Broom are matters of concern to farmers in Amazonia and many themselves have increased planting distance and/or removed some shade trees in the belief that these practices decrease Witches' Broom. Data from Manaus do suggest that there is a decrease with increased spacing. The effects of shade are complex. Experiments at Altamira and Tome Acu indicated that per cent flush infection was reduced by shade but flushing itself was low in shaded trees. Also shade removal is often associated with an increase in insect damage.

b. Ecuador

Studies at Pichilingue, reported by Alan Maddison, highlighted the problems associated with phytosanitation in a situation with high pathogen pressure, tall cocoa trees and another pathogen, Moniliophthora roreri, which causes as much or more pod loss than Crinipellis perniciosa. Early results from one experiment suggest that where fewer pods were affected by Witches' broom as a result of phytosanitation within the planting, more pods were affected by Moniliophthora. More data need to be collected before a full appraisal can be made but the need to consider the inter-relationship between these two pod diseases in Ecuador is apparent.

Other studies by an MSc student, reported by Jaime Aragundi, are also at an early stage. Details were given of the layout of the experiments which have the aims of evaluating the incidence of Witches' Broom in an isolated plot of cocoa following phytosanitation, of examining dispersal and infection gradients within a cocoa plot and of observing the distribution of Witches' broom below the canopy of the tree.

6.1.4 Problems of Experimental Design

In order to appraise the technical efficiency of phytosanitation two basic questions can be asked:

i. What is the relationship between the amount of pod loss and the proportion of infected material removed?

ii. How much does nearby cocoa, not subjected to phytosanitation, contribute inoculum to a planting where infected material has been removed?

The problem is to design experiments which can answer these questions unequivocally. This aspect was considered by a sub-committee (A.C. Maddison, S.A. Rudgard, and R.A. Schmidt) which met at Silwood Park (UK) in June 1987. Their report was circulated and formed the basis of discussions on experimental design at this Workshop.

It evoked a lively response and some alternative designs notably from Colombia, presented by Fabio Aranzazu. It led to a decision to have an experiment at several sites, the objective of which is given in 6.2 and the protocol (to be called "IWBP PROTOCOL 2" in 6.3 below.

6.2 Objective of the 'Comparative Phytosanitary Experiment'

It is recognised that farmers attempts to reduce losses by removal of infected material could be prejudiced if on neighbouring farms sanitation is not practised. However, in the absence of information on transfer of inoculum it is not possible to advise farmers about the risk involved.

The objective is to examine the effect of an infected plot on a neighbouring area where phytosanitation is practised at sites likely to ave different levels of inoculum.

6.3 Text of Protocol 2 for the 'Comparative Phytosanitary Experiment'

6.3.1 Site and Experimental Design

a. A cocoa planting of not less than 0.5 ha, at least 250m and preferable 500m from other cocoa is divided into two areas, A and B, consisting of 10 rows and a minimum of 35 rows respectively. Twenty trees in each row, ten either side of a central axis areas A and B constitute the experimental site (Figure 2).

b. The following are recorded:

1. Geographic location
2. Latitude/longitude
3. Elevation above sea level (m)
4. Topography
5. Soil
6. Shade
7. Planting material, age and height for the experimental site
8. Spacing
9. Map of planting, showing experimental site and distance to other cocoa

c. The experiment is maintained for a minimum of 27 months, including the "calibration" year.

6.3.2 Agronomic Practices

Any necessary structural pruning of the whole cocoa planting should be completed in month 1. Existing cultural practices, including chupon removal, will be maintained throughout the experimental site after month 1, but no more structural pruning will be done.

In the area outside the experimental site, all normal cultural practices will be continued.

6.3.3 "Calibration"

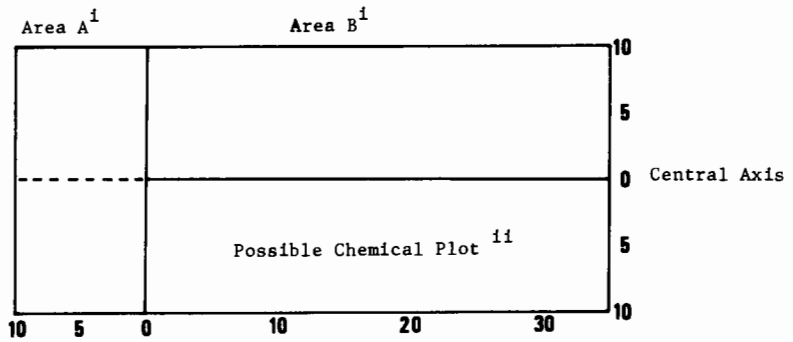
After approximately 12 months of site "calibration" (pod harvests, etc) all infected material is removed from area B. Area A remains a source area without removal.

6.3.4 Treatments

a. In area B, all infected material is removed after 12 months and 24 months, with secondary removals after 15 months and 27 months. The timing of the secondary removals can be adjusted to accord with local practice. Infected material is removed from the planting and destroyed.

b. A treatment, e.g. chemical spray, can be applied to one-half of the trees (10 trees) in each row of the experimental site within area B provided this maintains the area as one in which all infected material is removed.

FIGURE 2: Plan of "Experimental Site" from Protocol 2



i : See Section 6.3.3
ii : See Section 6.3.4.b

6.3.5 Collection of Data

a. Fruit

Numbers of harvested fruit, collected every 2 weeks, separated into various classes : ripe/healthy; diseased, Witches' broom, Moniliophthora, Phytophthora, others. Records are kept for each individual tree within the experimental site.

b. Brooms

When infected material is removed, the numbers of vegetative infections and cushion infections are recorded on six trees (randomly selected at the start of the experiment) in each row of the experimental site within area B (three trees from the treated and non-treated halves of the row).

At these times, vegetative infections and cushion infections are removed from 10 marked trees (randomly chosen, one from each row) of the experimental site within area A, and counted.

Immediately following the removal in month 15, 20 trees randomly chosen from those on which removal counts were made within area B and two trees of the 10 marked trees within area A are inspected branch by branch and remaining infections counted. Infections are classified within the categories used in Protocol 1A for flush and flower data sets.

c. Basidiocarps

Numbers of open, turgid basidiocarps are recorded on one day in each calendar month (if possible on a day after rain) on two collections of 100 brooms each suspended in the middle of the canopy as five samples of 20 brooms on five, randomly selected trees within the experimental site of

area A. One collection of brooms is randomly selected, the other collection is of productive brooms.

6.4 Action to be taken on Phytosanitation Studies

i. The following were noted:

CEPLAC (Brazil) agreed to install a site of the Comparative Phytosanitation Experiment near Altamira, according to Protocol 2. The special problems of siting an isolated experiment in Rondonia, chosen as the second site, were recognised. It was agreed that CEPLAC should be asked to seek a suitable site but if this was not possible, to circulate to the Project Scientific Committee the deviations required from Protocol 2, paragraph a, in order to proceed with this experiment. It was further agreed that if one requirement was a site less than 250m from another planting of cocoa then records should be taken of the number of infections per tree in that planting. Work at both sites in Brazil should start in late September or early October 1987.

There are five other sites under consideration which are due to come into operation in November 1987. ICA (Colombia) agreed to install sites in the Llanos region and Cauca Valley near Manizales. A site is planned by INIAP in the area around Quevedo in Ecuador, and a possible site is being considered for the Machala region in Southern Ecuador. FONAIAP (Venezuela) plans to install a site at El Penal in Tachira State near the Colombian border.

ii. There is a further problem which needs to be addressed by IWBP - that of developing a tool which will be more efficient in removing brooms. The Executive Chairman of IWBP has agreed to follow this up.

7. Experiments on Rehabilitation of Witches' Broom Infected Cocoa Fields

7.1 Introduction

The problems of dealing with cocoa where infection is at very high levels were discussed. The factor that limits the use of sanitation is the labour required to remove brooms individually, and in such cases where infection is out of control this is no longer an economical option. Experience has shown that there are several ways of dealing with the situation, the objective being to reduce pathogen pressure and recover pod production. All such methods involve radical measures that affect the trees ability to produce pods, and research would have to define the period in which production is lost. The cost-benefit of these methods would have to be assessed, and it was felt that an experiment should be designed to compare at least some of them. The problem is still essentially one of sanitation, but demands a different approach. Four types of disease control are commonly used, the first two being out of the question in highly infected areas;

1. Removal of brooms individually;
2. Removal of brooms individually and some very infected branches;
3. Removal of canopy at about 3m and any remaining cushion brooms;
4. Removal of whole tree at ground level and allow regrowth of chupons;

There are other factors that affect these procedures such as tree age, spacing and overhead shade. The height of the canopy will also affect the choice of treatment. It was decided that methods 3 and 4 above should be compared in a simple experiment, although the layout of the trial was not discussed in detail. It became apparent that there was a problem in terminology between the three languages and the essential terms have now been agreed on.

7.2 Objective

To test methods of rehabilitation of highly infected cocoa in relation to cost benefit.

7.3 Terminology

There have been frequent confusions concerning terminology and so IWBP have agreed the following shall be used in the Project in future:

English	Spanish	Portuguese
Pruning	Poda	Poda
Removal	Remocion	Remocao
Structural Pruning	Poda de Formacion	Poda de Formacao
Sanitary Pruning	Poda Sanitaria	Poda Sanitaria
Maintenance Pruning	Poda de Mantenimiento	Poda de Manutencao

7.4 Action to be taken in Experiments on Rehabilitation

It was agreed that it was not possible to finalise details of the experiment at this Workshop. The formation of a sub-committee was suggested to work out the experimental design. The Project Liaison Officer would gather information and opinions towards this end in visits to the participating countries in 1988.

8. Breeding for Resistance to Witches' Broom Disease

8.1 Introduction

Considerable interest in breeding for resistance to Witches' Broom has been expressed by institutions participating in IWBP in this subject (paragraph 2.3). Clearly IWBP cannot, and should not, embark on any programme of this type but it was thought useful to discuss this topic at the 4th IWBP Workshop and perhaps develop an action plan. This might then be elaborated into a project for submission to another international donor agency within the proposed lifetime of IWBP. With this in mind two experienced cocoa breeders (- Dr B.G.D. Bartley and Dr A.J. Kennedy) were invited to make presentations to the Workshop. The Project Scientific Committee then met that evening and fully discussed this issue.

8.2 Presentation by Basil Bartley

The background information on resistance to Witches' broom is given in the review paper presented to the 6th International Cocoa Conference in Caracas (The status of genetic resistance in cacao to Crinipellis perniciosa (Stahel) Singer, pp. 57-69). Much of the earlier work was concerned with the SCA family collected by Pound in Peru and many lessons have been learnt

from this work, not least that the attempts to obtain vertical resistance have not been satisfactory and that this type of resistance is probably not desirable. Possibly other varieties may have stable resistance but these have not been identified. Indeed, identification is the basic problem because resistance is connected with the relationship between host growth pattern and the inoculum/environment in which the host exists. There is a great need both to know about field reactions and other methods of assessing resistance. In this context information about the variability of the pathogen is important. This has been demonstrated between different geographical locations but it could be that variants of the pathogen exist in one area or even one cocoa field. If so, testing needs to be done with a range of isolates. When techniques are developed for individual isolates it will be easier to understand the reactions of the host which are a key feature in the selection process.

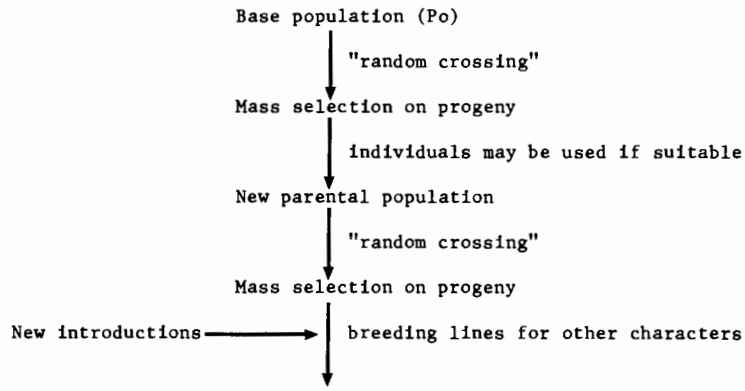
8.3 Presentation by Tony Kennedy

An equation ($R = ihO_p$) which relates response to selection (R), to selection intensity (i), hereditability (h) and the phenotypic standard deviation of the parental population (O_p) is central to an understanding of a breeding programme in which the overall aim is to increase R. In practice, the plant breeder has little control over either selection intensity or hereditability so can only hope to increase O_p by having a broad genetic base. In terms of resistance to Witches' broom, one can now assume that we are only interested in horizontal resistance where variation in the pathogen would be less important. A way in which this might be achieved is recurrent mass selection which aims to move forward the mean of the population (in respect of resistance) rather than that of the individual.

To do this requires first an adequate initial population. For Witches' Broom this might be achieved by selecting the best 20 individuals in a number of countries, exchanging them for tests in other countries and thus to select a base population on the best overall performance in all countries. It also requires a mass screening method. In the long term this is exposure of progeny in the field, but artificial inoculations are required for early tests to remove the most susceptible individuals. Ultimately for continued tests of this type later in the selection process, the mechanism(s) of resistance must be understood so that breeders can deal with characters, associated with resistance, which they can measure.

The philosophy of this approach differs radically from the approach in the past which sought to carry along other desirable characters of the cocoa in developing resistance to Witches' broom. Here the emphasis is on first improving that character. The salient feature of the recurrent mass selection/"random crossing" techniques is that with no selection pressure on them, the frequencies of genes for other characters do not change, but remain constant at values predicted by the Hardy-Weinberg equation. The implication is that having improved resistance to Witches' broom in this way, one has not selected out other characters.

Given a base host population which can be challenged with isolates representing the widest genotypic range of the fungal population, and a reliable means of testing and evaluating its response, then the procedure could be as follows:



8.4 Action to be taken to develop a Programme to breed for Resistance to Witches' Broom disease

It was agreed by the Project Scientific Committee that the competence and goodwill generated by IWBP presented a good opportunity for the preparation of a carefully coordinated programme on the above subject. This might then be developed into a major project proposal, or a number of smaller project proposals, for submission to a donor (or donors), for funds. Such a project proposal could involve many of the institutions participating in IWBP. If eventually successful in attracting a major donor it would not be part of IWBP as presently envisaged because this is due to end in 1990.

It was further decided by the Project Scientific Committee that a Small Expert Working Group should be established specifically to review the subject. A first draft of the Terms of Reference of this Working Group are proposed for consideration and are as follows:

1. Review existing breeding programme for Witches' Broom disease;

2. Review existing techniques for testing for Witches' broom disease;

3. Propose a programme to breed for resistance to Witches' broom disease;

4. Cost such a proposal on the basis of a first phase of 5 years and a second period also of 5 years;

5. Consider breeding needs for yield, and other desirable economic factors and, if possible, resistance to other diseases;

It was agreed by the Project Scientific Committee that this Expert Working Group should meet in Florida in December 1987 or February 1988. It would be led by Dr R. Schmidt and the other members would be Teklu Andebrhan, Tony Kennedy and Carmen Suarez. Their expenses to travel to Florida would be paid by IWBP.

9. Research activities associated with IWBP

9.1 Presentation by Dr T.N. Sreenivasan

Dr Sreenivasan illustrated with slides some of the fundamental studies of the life cycle of Crinipellis perniciosa which he and Henry Laker have done in Trinidad. These have added further to our knowledge of the pleiomorphism of the fungus in brooms. Following plasmogamy, which has been observed in the primary (parasitic) mycelium, there appear a sequence of hyphal forms including thick, convoluted, intercellular hyphae and thin intracellular hyphae which may be referred to as 'haustorial'. At some stage intracellular hyphae appear devoid of cell walls. An important feature is the development of chlamydosphores ultimately from a mycelium with clamp connections. These have been seen to germinate within vessels and to give rise to a thin mycelium which permeates the now necrotic host tissue. These may play an important role in allowing the pathogen to survive adverse conditions in dead brooms and, since they have been observed on the broom surface, could serve to disseminate the fungus. This would have important implications in respect of epidemiology. Further research is now in progress to determine the role of chlamydospores and investigate other aspects.

10. Publication of a Monograph on IWBP

The Project Scientific Committee had requested a small Expert Working Group to discuss the prospects for, contents of, and layout of such a Monograph. The document prepared by this Group is attached as Appendix C to this report.

In view of the uniqueness of IWBP in tropical crop epidemiology, it was thought that the publication of such a Monograph would be of great value to future generations of plant pathologists and could have a reasonable market. It was agreed that it needs to be published almost simultaneously in English, Spanish and Portuguese.

During the course of the 4th IWBP Workshop, the Project Scientific Committee had agreed that all potential authors should now begin to write experimental descriptions, etc for the 'Comparative Epidemiology Experiment' (in their own language) as to leave it longer would risk that the subject matter might no longer be fresh in the researchers' minds. It was agreed also by the Project Scientific Committee that the broad format of the Monograph should be as in the document prepared by this Expert Working Group (attached to this report as Appendix C).

11. Acknowledgments

Our thanks go to all participants in the 4th IWBP Workshop for their interest and enthusiasm. Particular thanks go to Dr Stephen Rudgard for acting as interpreter for many of the sessions and to Dr B.E.J. Wheeler who again acted as Rapporteur. His willingness to take on this onerous task deserves our gratitude. We particularly appreciated the enthusiasm shown by Teklu Andebrhan in making the detailed arrangements. In addition our thanks to his colleagues at CEPLAC/DEPEA and others of Instituto Colombiano Agropecuario (ICA) for their support and for inviting us to hold the Workshop in Belem.

12. Date for the 5th IWBP Workshop

It is proposed to hold the 5th IWBP Workshop from 3rd - 11th November 1988 or thereabouts at the Asa Wright Nature Centre, near Arima, Trinidad. Invitations will be issued nearer the time for appropriate participants. The Cocoa Research Unit, at the University of the West Indies has kindly offered to act as hosts (with IOCCC) for this meeting. Details of the Workshop arrangements will be confirmed closer to the time.

These dates have been chosen to permit the completion of the first phase of data analysis of the sites prior to the Workshop.

13. Dates for Future IWBP Workshops

It is presently proposed to hold the 6th IWBP Workshop in Gainesville, Florida in October/November 1989 and the 7th IWBP Workshop at or near Imperial College, Silwood Park, in September 1990. This is some three months after the end of IWBP as presently constituted and funded and it is anticipated that a number of the IOCCC Member Associations who are sponsoring this Project may wish to participate in that meeting.

14. Date of the meeting of the Project Scientific Committee

It is presently proposed that the Project Scientific Committee should meet between 3rd - 11th November 1988 during the course of the 5th IWBP Workshop. It is hoped that all members of the Project Scientific Committee will be able to participate.

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APPENDIX A: NAMES, ADDRESSES, TELEPHONE NUMBERS AND TELEX NUMBERS OF PARTICIPANTS IN 4TH IWBP WORKSHOP

[N.B. National dialling codes included in telephone numbers wherever possible]

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APPENDIX B: PROGRAMME 4TH IWBP WORKSHOP BELEM, BRAZIL
10th - 17th September 1987

Thursday 10th September 1987

Participants arrive in Belem.

Friday 11th September 1987

0800		Welcome by representative of CEPLAC (Ilton Morais)
		Welcome by representative of IOCCC (R.A. Lass on behalf of IOCCC President)
		Welcome by Chairman of Project Scientific Committee (L.H. Purdy)
		Introduction of participants
		Adoption of Objectives of 4th IWBP Workshop
		Adoption of Workshop Agenda
		Appointment of Moderator (L.H. Purdy)
		Appointment of Rapporteur (B.E.J. Wheeler)
0900-1000	SESSION I	PROGRESS OF COMPARATIVE EPIDEMIOLOGY EXPERIMENTS
		Report on data collection and analysis by Project Liaison Officer, S.A. Rudgard and as follows:

Tome Acu, Brazil	: Ausier Luis Pacheco de Carvalho
Altamira, Brazil	: Joao de Cassia do Bomfim Costa
Santa Cruz, Trinidad	: Steve Mohan
Ouro Preto, Brazil	: Paulo Alberqueque
Penal, Venezuela	: Ramon Acuna
Itabuna, Brazil	: Ricardo Miranda
Mt.Horne, Grenada	: T.N. Sreenivasan
Pichilingue, Ecuador	: Jaime Aragundi/Alan Maddison
Manizales, Colombia	: Fabio Aranzazu
Llanos, Colombia	: Fabio Aranzazu

1000-1015		COFFEE BREAK
1015-1215	SESSION I	Continued
1215-1330		LUNCH
1330-1600	SESSION I	Continued
1600-1615		COFFEE BREAK
1615-1745	SESSION I	Continued

Saturday 12th September 1987

0730-1000	SESSION I	Concluded
1000-1015		COFFEE BREAK
1015-1130	SESSION II	DISCUSSION ON PROTOCOLS 1 and 1A
1130-1215	SESSION III	SITE DATA ANALYSIS
		LUNCH
1330-1500	SESSION IV	COMPARATIVE DATA ANALYSIS
1500-1515		COFFEE BREAK
1550-1800	SESSION V	REPORTS ON CHEMICAL STUDIES: Imperial College : Stephen Rudgard Brazil : Cleber Bastos Venezuela : Humberto Reyes Ecuador : Jaime Aragundi Trinidad : T.N.Sreenivasan
2000-2200	SESSION IV	COMPARATIVE DATA ANALYSIS (continued)

Sunday 13th September 1987

0730	DEPARTURE TO CEPLAC GERMPLASM COLLECTION NEAR BELEM
0800	ARRIVAL AT GERMPLASM COLLECTION
1000	DEPARTURE FROM GERMPLASM COLLECTION
1015	ARRIVE AT TYPICAL PARA COCOA FARM
1215	LEAVE FARM
1230	ARRIVE MOSQUERO BEACH FOR LUNCH
1700	LUNCH (Hosted by IOCCC)
2000-2200 SESSION IV	COMPARATIVE DATA ANALYSIS

Monday 14th September 1987

0730-0900	SESSION VI	REPORTS ON GRADIENT STUDIES Pichilingue: Jaime Aragundi
0900-0930	SESSION VII	PHYTOSANITATION STUDIES AS PART OF IWBP PERSPECTIVES: Alan Maddison
0930-0945		COFFEE BREAK
0945-1130	SESSION VIII	PHYTOSANITATION STUDIES AS PART OF IWBP (continued) Brazil: Teklu Andebrhan Pichilingue: Jaime Aragundi

1130-1245	SESSION IX	ELABORATION OF PROTOCOL FOR PHYTOSANITATION STUDIES IN IWBP
1245-1345		LUNCH
1345-1645	SESSION X	DISCUSSION ON RESISTANCE BREEDING/SELECTION
1645-1700		COFFEE BREAK
1700-1730	SESSION IV	COMPARATIVE DATA ANALYSIS (concluded)
1730-1810	SESSION XI	PUBLICATION OF IWBP MONOGRAPH
2030-2330		MEETING OF PROJECT SCIENTIFIC COMMITTEE

Tuesday 15th September 1987

0730-1030	SESSION IX	ELABORATION OF PROTOCOL FOR PHYTOSANITATION STUDIES IN IWBP (continued)
1030-1045		COFFEE BREAK
1045-1300	SESSION IX	ELABORATION OF PROTOCOL FOR PHYTOSANITATION STUDIES IN IWBP (continued)
1300-1400		LUNCH
1400-1630	SESSION IX	ELABORATION OF PROTOCOL FOR PHYTOSANITATION STUDIES IN IWBP (concluded)
1630-1800	SESSION XII	DISCUSSION ON OTHER RESEARCH ACTIVITIES ASSOCIATED WITH OR ANCILLIARY TO IWBP BIOLOGY OF THE FUNGUS: T.N. Sreenivasan
1930		DINNER (Hosted by CEPLAC)

Wednesday 16th September 1987

0800-0945	SESSION XIII	ADOPTION OF REPORT
1000-1230	SESSION XIII	ADOPTION OF REPORT (concluded)
1230-1300		LUNCH
1400-1430		CLOSURE OF 4TH IWBP WORKSHOP R.A. Lass, Executive Chairman, Project Management Committee, IWBP I. Morais, Director, DEPEA
1800-2030		MEETING OF PROJECT SCIENTIFIC COMMITTEE

Thursday 17th September 1987

Participants departed from Belem

APPENDIX C: REPORT OF EXPERT WORKING GROUP ON IWBP MONOGRAPH

Suggested outline for a Compilation of the IWBP Comparative Epidemiology Studies

Some assumptions:

a. A comprehensive but brief "Monograph" is desirable.

b. The Monograph will consist of five parts: I Introduction, II Comparative Epidemiology Studies form such site, III Disease Gradient Studies, IV Phytosanitation Studies and V Summary Chapters.

c. Chapters for Part II will be authorised by those having done the research at each site; a standard format will be used.

d. Other chapters will be written by appropriate persons associated with the IWBP; an editorial committee will be assigned.

e. The copy will be prepared for a hard cover book for general appeal, although we will be prepared to retreat to a format appropriate to an audience if necessary.

Monograph Outline

1. Title:

    1. Witches' Broom Disease of Cocoa in Tropical America: Comparative Epidemiology (and Management)

or

    2. Comparative Epidemiology: Witches' Broom Disease of Cocoa in Tropical America

2. Contents:

    Title
    Editors Preface
    Experts Preface
    Table of Contents

3. Part I:

    Chapter I

    Introduction - IWBP structure, function, goals and objectives.

    Chapter II

    The Cocoa - Crinipellis perniciosa - Witches' broom pathosystem - the host, the pathogen, the disease, the epidemic, the impact.

4. Part II:

    Comparative Epidemiology Studies

Chapter 3

Comparative epidemiology, nature, scope, goals and objectives, protocol, locations.

Chapters 4-11

Country - Location

Each site will have a chapter which will be authored by the researchers for that site and all chapters will have the same format. Suggested Format (outline) for Chapters 4-11, Part II - Comparative Epidemiology Studies by country and location.

Introduction

Relevant historical information on epidemic, i.e. disease incidence and importance in the area.

Passport Data

Site information and any important deviations from protocol.

Epidemiology

Results of comparative epidemiology study to include:

climate
inoculum production
phenology
disease

A standard set of graphs and tables will be developed for this section.

Disease Management

5. Part III:

Disease Gradient Studies

Chapter 12

Country - Location

This Part could be done as Part II, i.e. with individual chapters for each site or perhaps as one chapter to be appropriately authored and placed in Part II.

6. Part IV

Phytosanitation Studies

This section would be similar to Part III, ie.. as an individual chapter or as one chapter in Part II.

7. Part V

Comparative Epidemiology

Chapter - Comparative Analysis of Witches' Broom Epidemics

Chapter - Guidelines for Disease Management

Chapter - Guideline for Future Research

8. Literature Cited (combined)
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July 1987

A.C. Maddison
R. Schmidt
S.A. Rudgard