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Witches' broom disease of cocoa in Bahia: attempts at eradication and containment

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Attempts during 1989 to eradicate the first recorded outbreak in Bahia of witches' broom of cocoa caused by *Crinipellis perniciosa* and the subsequent efforts to contain the spread of the pathogen are described. Factors that militated against successful eradication are evaluated in the light of subsequent experience of the disease in the region. Copyright © 1996 Elsevier Science Ltd

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In 1746, seeds of cocoa (*Theobroma cacao* L.) from the State of Para, Amazon, were planted in the municipality of Canavieiras, in the State of Bahia, Brazil (Rangel, 1982). Cultivation in this area increased and now accounts for 85% of cocoa produced in Brazil that was, until recently, the second largest world producer.

Witches' broom disease of cocoa caused by *Crinipellis perniciosa* (Stahel) Singer (Stahel, 1915; Went, 1904) is believed to have co-evolved with indigenous cocoa in the Amazon Basin (Baker and Holiday, 1957). The spread of this disease to virtually every country in South American, Panama and the Caribbean, where cocoa is grown, severely curtailed production, and remains a serious threat to those countries free of the disease. Presumably, cocoa seeds originally introduced into Bahia, Brazil were healthy and due to a geographical separation of about 2000 km from disease native and cultivated cocoa plantations, cocoa there remained uninfected until the late 1980s.

However, it was recognized much earlier that witches' broom would always pose a grave risk to the cocoa industry of this region (Evans, 1981) – more so since means of controlling an outbreak were limited (Pereira, 1985). In 1978, the Ministry of Agriculture created CAVAB – Campaign for the Control of the Spread of Witches' Broom, administrated by CEPLAC, a Brazilian Federal Government Organization responsible for the country's cocoa industry. A phytosanitation cordon was established consisting of quarantine inspection posts, positioned at strategic points on routes leading into Bahia and a Post-entry Plant Quarantine Station was sited at Salvador, Bahia, to ensure introduced plant material was only released if disease free. Considerable amounts of plant material, mainly *Theobroma* spp., were apprehended and incinerated, (decreasing in numbers between the years 1980 and 1986 were 3147 to 103, respectively); and probably delayed entry of the pathogen. Simultaneously, investigations were conducted on witches' broom at CEPLAC research facilities in the States of Para (Belem, Altamira), Amazon (Manaus) and Rondonia (Ouro Preto), with the aim of providing suitable control measures that might be used in the event of a possible outbreak in Bahia.

This possibility was realised when witches' broom was confirmed in Bahia in May 1989 (Pereira, Ram, Figueiredo and Almeida, 1990). How *C. perniciosa* came into the region is a matter of speculation but with the movement of cocoa workers between new plantings in the Amazon to Bahia, it seems most likely that infected material was introduced through human agency. Further, there is no detailed account of the initial eradication programme, its rationale and complexity, or an appraisal of the methods adopted. This paper presents such an account as a further contribution to our understanding of disease eradication in a tropical tree crop.

Survey of the outbreak

The first confirmed site of infection (Fazenda Conjunto Santana) was in the Municipality of Uruçuca, on either side of a secondary road in the direction of Banco Central, 2 km from the main north–south coastal Highway BR 101 (*Figure 1*). This zone is characterized as the *Almada Agrosistema*, economically and traditionally the most important in the region with 188,986 ha of cocoa and an annual production of 114,134 tonnes (Silva and Leite, 1988). With other adjoining *agrosistemas*, the area forms a continuous planting comprising 632,220 ha of cocoa so there was an urgent need to determine the extent and intensity of the outbreak.

An initial survey commenced on 26 May 1989. About 30 government agricultural workers and four field assistants, trained and supervised by plant pathologists and agriculturists, systematically inspected cocoa trees, marking those with visible brooms. Over 14 days, 600 ha with about 300,000 cocoa trees, were examined. The principal disease focus was spread over 12 ha, 11 ha on either side of the road and a further hectare

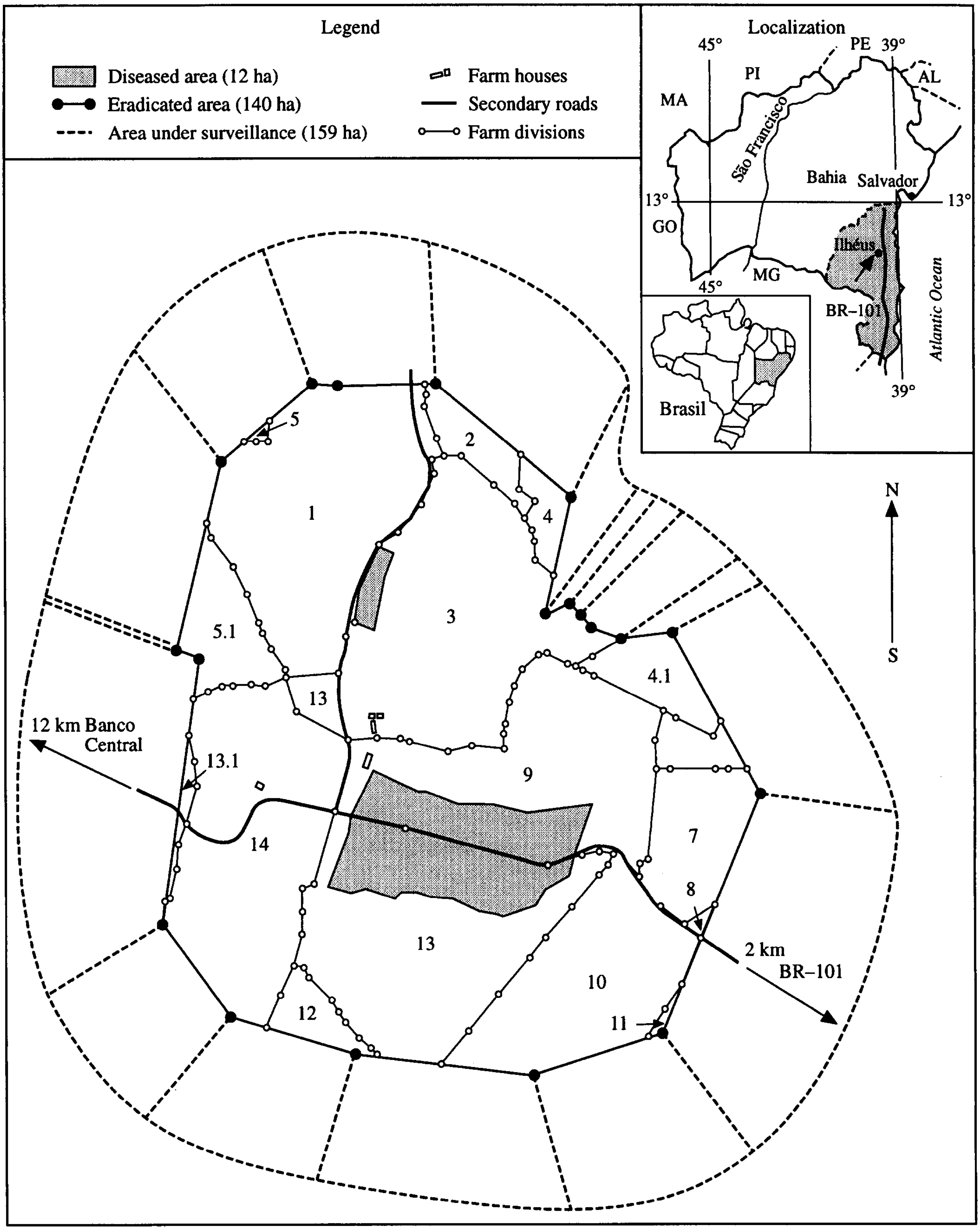

Figure 1. Localization and initial eradication field actions on the site of the first registered out-break of witches' broom in Bahia, Brazil

about 400 m north, windward to this area (*Figure 1*). A total of 112 infected trees were recorded, with between 1 and 15 broom per tree. One infected flower cushion and a single parthenocarpic pod were also found. Data were mapped to indicate the following:

1. limits of the disease, using as reference the outermost marked trees (shaded in *Figure 1*);
2. a surrounding area, defined by connecting points 350 m from the outer diseased trees, in which the disease might be expected to occur (eradicated area in *Figure 1*), the likely limit of dissemination of the pathogen by wind (Aragundi, Frias, Solorzano, Schmidt and Purdy, 1988);
3. areas under surveillance (broken line in *Figure 1*); and
4. farm boundaries, houses and installations.

The demarcation survey commenced on 5 June 1989 with two teams, each with a ground surveyor, two assistants and four workers with the necessary topographic equipment, markers, chain saws, axes and machetes. A strip of 10 m of felled cocoa and shade trees divided the suspect area, the central diseased and surrounding zone was 140 haa with 134 ha under cocoa.

The disease survey was a continuous process which increasingly required more personnel, both within the diseased area as well as in the region as a whole. Particularly, trees immediately surrounding the condemned area were inspected closely. Clearly a limit of 350 m for dissemination of *C. perniciosa* spores was an approximation so brooms that developed in the immediate vicinity were considered to have risen from latent infections and to be part of the original disease focus. Indeed, early in October 1989, 21 trees with young brooms were found within 50 m of the outer perimeter of the condemned area. Brooms were removed and trees marked for continued observation.

The rationale for eradication at Uruçuca

Eradication as a means of disease control appears a logical procedure when attempts to exclude a pathogen by quarantine measures have failed (Wheeler, 1969), but few eradication schemes have been completely successful. At most the programmes adopted have limited pathogen spread, thus reducing the immediate impact of the disease and allowing time to develop methods of disease management. In cocoa, management of swollen-shoot disease in Ghana probably best demonstrates eradication of millions of trees as a main control measure, this has remained in operation since 1946 (Thresh and Owusu, 1986).

Against that background many factors had to be considered when contemplating eradication of witches' broom in Bahia. Pressing factors for mounting an eradication scheme were: the importance of the cocoa industry to Bahia and Brazil; the known susceptibility of the genetic material grown; and climatic conditions in the region that met the requirements for pathogen development. Yet the favourable environment for disease development, both of host and climate, would also militate against successful eradication. It could be expected, too, that a drastic measure involving eradication of cocoa trees would be subject to wide criticism from people unfamiliar with the devastating effects of witches' broom. On the other hand, there was a political need to do something. If the outbreak was only kept under observation, then any other subsequent occurrence, whether coincidental or not, would inevitably be associated with the first outbreak and recriminations against CEPLAC and its personnel would follow.

Factors which appeared to favour eradication were: the evidence, from the relatively few dry brooms found at the disease focus, that *C. perniciosa* was established only recently; that it did not exist in the region as a saprophyte or on an alternative host; it had probably been introduced through human agency on a limited scale; and initially widespread dispersal of pathogen spores by wind was not expected. Additionally, the disease was discovered when the cocoa trees were in a phenological period of low susceptibility with virtually no flushing – this would allow time for eradication measures before susceptible tissue was available for infection by basidiospores – and the affected area plus its surrounding 'buffer' zone (134 ha) was a very small percentage (0.021) of the total area at risk (*Table 1*).

The implementation of a strategy of eradication was determined by the Ministry of Agriculture using legislation already in existence (Decree No. 24, 114 of 1934), allowing an early gazetted publication, authorizing eradication of witches' broom and a surrounding area as required in this particular case (Portaria #48 of 31 May 1989). Growers were informed of this notifiable disease on their farms, and that their land would be subject to quarantine regulations, including eradication of cocoa and other possible host plants if considered necessary. The Ministry of Agriculture delegated operational competence to the Cocoa Research and Extension Centres through their parent body CEPLAC, to take necessary action to eliminate this disease threat to the Brazilian cocoa industry.

Actions preceding eradication

Phytosanitation and chemicals were used to interrupt the disease cycle, protect susceptible tissue from further infection and/or eliminate infection (mycelium) within plant tissue, while surveys continued within the vicinity of the outbreak and over the region. The strategy was a bid for time and to ensure no other disease foci existed before implementing irreversible eradication measures such as destroying the plantation.

Within 3 days of the outbreak, bulldozers were used to prepare the ground for a field site of operations. A store shed, a large sheltered area (for meetings,

Table 1. Cocoa eradicated and farms affected at Uruçuca in relation to the State of Bahia

	Total in Bahia	Cocoa eradicated/ farms affected	% state total
Plantations (ha)	632,220	134	0.021
Production (tonnes)	438,413	120	0.027
Farmers (approx. no.)	30,000	14	0.047
Farms (approx. no.)	280,000	14	0.005

Source: APLAN, CEDEX, CEPLAC, Ilheus, BA., Brazil briefings, enclosure for watchmen, etc.), water tanks, toilets and showers were installed. A parking area was prepared for buses, trucks, a water tanker and small vehicles. Work commenced at dawn, 6 days a week, with defined pre-established time schedules.

Phytosanitation

Brooms, potentially the main source of inoculum (Evans, 1981), and infected tissue with typical symptoms (Rudgard, 1989) were removed by 17 pairs of workers, starting 26 May. Each pair was provided with pruning hooks, machetes, protective footwear and clothing. Removed brooms were collected in large polyethylene bags, and burnt at the end of each day in a closed cocoa dryer furnace. This and other logistics related to other eradication operations are summarized in *Table 2*.

Concurrently, a team of 16 farm workers harvested the cocoa, removed beans from pods, and immediately transferred them to fermentation boxes. This was to avoid pilfering and unauthorized movement of plant material, besides serving to evaluate any possible pod infection.

Fungicide application with motorized mist-blowers

Chemical control started the day following the conclusion of phytosanitation pruning. A team of three experienced mechanics ensured that about 50 motorized knapsack mist-blowers operated efficiently. Mixing tanks of 500 L capacity were positioned (and repositioned) at various predetermined sites. Six trained personnel, and drivers for a water tanker and two light trucks, were responsible for supplying water, measuring quantities of fungicides, providing fuel, etc. to the spraying teams.

Fungicides are not used routinely to control witches' broom in countries where the disease is established but appraisals of their use (Laker and Rudgard, 1989; Pereira, 1985) gave some basis on which to advise a spray schedule for the special circumstances of eradication, where cost was of relatively little importance. Two fungicides were selected, a copper-base contact compound, aimed at obtaining a protection cover to reduce infection on susceptible tissue (Dale, 1946; Stahel, 1915; Stell, 1932; Holliday, 1954; Thorold, 1953), and the other a triazole systemic fungicide triadimenol, shown to be effective (C.N. Bastos personal communication) on mycelium of *C. perniciosa* in tissue already infected (active or latent). Both fungicides were available in the quantities required. The combination of these two fungicides had previously been suggested by Pereira (1985), in a possible chemical control strategy for witches broom.

Doses of 9.6 kg ha^{-1} of 50% cuprous oxide ('Cobre Sandoz'), twice the standard quantity, was applied to give prolonged protection for a period of over 60 days on susceptible cocoa tissue known to protect against *Phytophthora* spp. (Pereira and Lellis, 1985). The dose of triadimenol was 1 L ha^{-1} of the formulation, (Bayfidan 25%). The two products were applied in a mixture using motorized mist-blowers calibrated to spray about 200 L ha^{-1}, at a flow rate of about 280 ml in 45 sec per tree. Spraying commenced on 9 June 1989 with government and contracted workers (*Table 2*) and all operators were supplied with full protective clothing. The disease focus was sprayed twice, the surrounding area once, and 10 ha were re-sprayed because of rain.

Table 2. Field operations for eradication of cocoa at Uruçuca, Bahia, Brazil

Operations	Men	Period (1989)	Man–days
Initial disease survey	30	26 May to 8 June	532
Preparation of oper. site	22	27 May to 3 June	154
Demarcation/infected area	14	5 June to 20 July	560
Intensive tree to tree survey in the vicinity (approx.)	6	June to October	774
Extensive sample survey in the region (approx.)	8	June to November	1440
Removal of brooms	48	26 May to 7 June	528
Removal of pods	16	June	400
Spray application/mist blowers			
Mechanics + drivers + fungicide preparation	12		
Spray Operators	162		
Entire operation		9 to 24 June	1564
Spray application/helicopter			
Initial preparation	5		
Pilot + support	16		
Entire operation		28 to 29 June	42
Herbicide trunk application			
Herbicide application — scrub land			
Entire operation	101	30 June to 20 July	1818
Timber elevation	4	14 to 30 August	56
Felling			
Preparation (chain saws)	14	3 to 16 July	168
Felling cocoa trees	30	17 July 18 August	840
Felling shade trees	44	14 August to 1 September	660
Burning			
Preparing pyres	30	30 August to 10 October	1020
Burning central area	74	30 August to 10 October	2368
Burning of surrounding area	44	by early November	1100
Social service	2	June to October	127
Total		May to November	14,151

Aerial application of fungicides

A helicopter, Bell Jet Ranger II, was equipped with a boom and nozzle spraying gear. Nozzle and other application parameters were selected specifically to ensure that two different droplet spectra, relatively fine and coarse, were emitted, ensuring cover of the cocoa and shade tree canopies. Set at a flow pressure of 20 p.s.i., 22 nozzles for fine droplets (8010) and a further 22 nozzles for coarser droplets (8015) were arranged alternately on the boom, orientated vertically downwards. The respective flow rate for each nozzle type was 2.77 and 4.15 L min^{-1} totalling 152.20 L min^{-1} for the entire boom. At an air speed of 96 km h^{-1} and a swath of 20 m, 47.6 L was applied per ha. The dose and types of fungicides corresponded to that of ground applications. Balloons filled with a helium/nitrogen mixture (70/30%) were positioned and anchored, serving as beacons to indicate the limits of the disease suspect area, and over farm houses and water sources where fungicide was not applied. Applications were made in an east–west direction, when climatic conditions permitted, on 28 and 29 June 1989. For both fungicide operations, a total of 2900 kg of the copper fungicide and 290 L of triadimenol formulation were used.

Host destruction

No further disease outbreaks were found in the widespread surveys during the period of fungicide applications. This gave some confidence to proceed to the next stage of the eradication strategy, the destruction of cocoa. Also, since the host range of *C. perniciosa* covers other plants (such as wild species of Solanaceae; *Bixa orellana*, Bastos and Andebrhan, 1986) it was also considered necessary to remove associated shade trees, bushes and vegetation in the entire 140 ha of the outbreak.

Tree trunk application of herbicides

Simple experiments involving types of herbicides, dose, mode of application and rate of translocation were undertaken. A standard mixture of 2,4-D(2,4-dichlorophenoxy acetic acid) and picloram (4-amino-3,5,6-trichloropicolinic acid) in a proportion of 240/64 g L^{-1} (Tordon 101) was prepared in a dilution of 1:1 in water and applied in numerous ways to cocoa tree trunks – injected through drilled holes, brushed on sections of trunk with the bark removed or squirted into a downward cut after the bark was eased off the trunk. The last mode of application appeared to be efficient and less time consuming. By this method the herbicide translocated to new growth or susceptible tissue within 48 h.

For ease of safety of operation, the herbicide was diluted only at a single central point. Twelve empty plastic beer crates were used as carriers for 24 one litre plastic bottles, with a single hole drilled in each of their tops. Empty bottles were filled with the herbicide mixture only at this site. Further, the supply team who distributed these crates to field personnel also checked that at the end of the day all bottles were returned.

Each cocoa tree received about 10 ml of the mixture squirted from the plastic bottles onto the bark openings about 20 cm apart at a height of 30 cm. On average, three applications were made per tree. For shade trees about 60 ml of the mixture were injected into each of four to six holes previously drilled. However, while this method appeared to be more effective, herbicide squirted onto the exposed cambium after the bark was cut and eased away with axes, was less time-consuming and was also used. Cocoa trees died within 10–14 days but shade trees took longer to die.

The entire 140 ha was treated by 20 July 1989 and 98,300 cocoa trees and approximately 12,060 shade trees received a total of 1510 L of the commercial mixture of 2,4-D and picloram.

Other tasks undertaken simultaneously included the spraying of pasture and scrub land with the herbicide glyphosate (a total of 280 L). Further, in the period 14–30 August 1989, a team of four timber specialists counted and classified all shade trees, and determined their volume to estimate wood value.

Felling and burning of all vegetation

As cocoa and shade trees were desiccating following herbicide treatment, there was concern that the large quantity of wood would attract clandestine saw millers to a ready supply of timber, or the farm community to easily accessible fire-wood. The outcome would be excessive movement of people in the area and widespread dispersal of vegetative material, other than cocoa, that might be infected. Therefore, it was decided to burn all vegetation.

In July teams of 12 selected workers were trained to operate chain saws and two mechanics were employed to maintain 11 chain saws in good working condition. On 17 July, this team and further contracted workers with chain saws and axes commenced felling the cocoa trees, starting with the central area. When necessary, bulldozers were used to direct the fall and ensure organized heaps for each burning. To provide a fire-break, all combustible material was cleared from a strip of land surrounding the entire condemned area and swept towards the nearest pyre.

Burning commenced on 30 August. Cocoa and shade trees were arranged in piles on a mat of leaves and twigs, and 8000 L of diesel and 200 L of kerosene were used to assist burning. After the initial fires, remaining material was re-arranged and again set alight. By 10 October the central disease area was completely burnt and most of the surrounding 'buffer' area by early November 1989.

Human safety and environmental considerations

Inevitably, an eradication programme of this magnitude attracted attention and caused concern to environmental groups. Some press comments were ill-informed and unhelpful, for example that 'Agent Orange' (2,4,5-T) was being used, a confusion with the widely recommended herbicides (2,4-D and picloram) which were used and posed minimum risk.

In terms of human health and safety, the prevention of accidents was a paramount consideration during the entire programme. All field operators received an adequate supply of protective clothing, and those working with pesticides or machinery were appropriately equipped. Groups of people were trained to constitute specialized teams thereby keeping risk of mishaps to a minimum. To avoid any contamination, food was supplied to the workers in the field, only after they had all showered and changed their clothes.

When trees were felled, the electric company was called to disconnect energy lines. A fire break of over 10 m separated the outer boundaries of the suspect area to avoid flames spreading to neighbouring farms.

In addition, three families of farm workers, totalling 17 people, living within the area and others in the vicinity area were counselled by social service personnel of CEPLAC. Arrangements were made for their evacuation to work on other farms, or in the case of one elderly worker, his process to receive retirement benefit was initiated. Examinations were also made on the general state of health of people within and around the eradication zone. This included special medical attention, a full vaccination programme for 40 children, 5 years or under, care for the elderly and expectant mothers. Medical histories were kept so that further monitoring could be done later, if necessary. A vehicle with driver was on stand-by at all times for emergencies.

Although due consideration had been given to the selection of herbicides and their modes of application, specialists from the Cocoa Research Centre regularly monitored residues in water, soil and plants. Levels were found to be below tolerance limits acceptable for most food products.

A glasshouse was erected in the field and soil from the eradicated area was tested for residual herbicide effects. The results suggested that narrow-leaved crops could be planted immediately and broad-leaved crops after a fallow period of 1.5 years. In fact, bananas, cassava and pawpaw were grown in the area one year after the eradication operation and no phytotoxic symptoms were observed.

When environmentalists travelled to Bahia to examine the eradicated area, they were given free access to make observations *in situ* and received information as required.

A new outbreak

Eradication procedures within the diseased area in Uruçuca were reaching completion with some confidence of success. In addition to wider surveys, the intensive tree to tree examinations of 119,856 cocoa plants (about 170 ha) around the eradicated zone, did not encounter diseased plants. However, on 26 October 1989, the first author of this paper, received a request from a cocoa grower in the Camacan area, to look at specimens of cocoa material that he felt certain were of witches' broom and an examination confirmed that they were.

This second disease site was over 100 km from Uruçuca (*Figure 2*). The Camacan area is the second most important cocoa *agrosistema* of Bahia, with 101,110 ha of plantations producing about 50,869 tonnes (Silva and Leite, 1988). A visit to the farm suggested that this outbreak had existed for a long period, certainly years before the outbreak at Uruçuca. The disease was well established and displayed advanced symptoms.

As with the first outbreak, the introduction of the pathogen from the Amazon could only be attributed to human agency. The initial distribution of the disease in cocoa along the banks of the river Panelina suggested that infected material had been disposed there. Immediate evaluation as to the full extent of the spread was not possible but the intensity of the disease and continued outbreaks along the course of the river, reduced the possibility of eradicating witches' broom in this new focus, and consequently in the State of Bahia.

Containing the disease

Since eradication was no longer technically possible, disease progressed. Initially, new outbreaks were sparse, foci of infection were surrounded by vast areas of healthy cocoa and so efforts were then aimed at reducing inoculum and thus containing the spread of *C. perniciosa*. Various plans were formulated (Dorea, Menezes, Lima, Carletto and Setubal, 1990, Ferraz, 1989; Setúbal, Alvim, Carletto, Magno and Ram, 1990). In addition, in February 1990, a meeting was held at CEPLAC including researchers from other countries, to make recommendations for limiting the impact of the disease.

Since biological agents, or the use of disease tolerant cocoa for long-term management were virtually non-existent for application at farm level, and short-term control strategies involving chemicals have limited effect, disease containment through physical removal of brooms and other infected tissues, remained the only means of attempting to check the spread of the disease in the region.

However, many existing plantations in Bahia are debilitated with excessively tall trees and often poor canopy formation. These features restrict visibility, hindering field operators from locating distant diseased vegetative flushes. As a result, in Bahia a field worker can remove brooms from only about 36 trees per day. On this basis, a single phytosanitation pruning covering only the Almada (Uruçuca) and Camacan *agrosistemas*, would require a labour input of about 3.7 and 2.0 million man-days respectively. Therefore, part of the field programme had also to incorporate the reconfiguration of trees to ease further pruning that might be necessary later.

Three operations were used – removal of disease material, canopy removal and drastic structural pruning.

Removal of disease material

Brooms and infected flower cushions were removed and burnt. Diseased pods were destroyed more effectively by burying them after removal. Vegetative litter within the vicinity, suspected to contain dry infectious material, was swept into heaps and also burnt.

Canopy removal

At the international meeting of February 1990, methods for dealing with two types of disease situations were agreed. Where fruiting bodies of the pathogen were present, the canopies of cocoa trees with disease symptoms and interspersed healthy trees were removed. Where basidiocarps were not observed, only the diseased trees had their canopies removed while the surrounding trees were pruned drastically (see below). In both situations, four or five rows of healthy trees surrounding this affected area were pruned to facilitate observation of disease symptoms in the canopy in future inspections. All litter was removed from within plantations and burnt.

Infected trees were felled at a height of 40–50 cm above ground, all suckers were removed and live stumps retained in the field. The exposed trunk surfaces were painted with a suspension of copper fungicide (25 g a.i. 1 L^{-1} water), as a precaution against infection by other pathogens. Re-growth (coppice) of suckers was encouraged with the objective of developing a smaller and architecturally-improved tree, more easily manageable and accessible for future phytosanitation pruning. Felled canopies were chopped into pieces and burnt together with other, potentially-diseased, plant debris.

Drastic pruning

Up to three, apparently healthy trees immediately surrounding diseased plants, together with excessively tall trees or others with poor canopy formation, were pruned structurally. All branches were removed leaving 20–30 cm sections protruding from the main stem. A new, plagiotropically-oriented canopy was allowed to form from these cut stems. The felled branches were burnt. This programme was not favoured by farmers and extension personnel, who preferred less drastic pruning.

Training

Although all field operations for the eradication and containment programmes were conducted and co-ordinated by CEPLAC, when an outbreak was registered on a farm the owners supported efforts to contain the disease, mainly with assistance in kind such as accommodation, supply of additional farm labour and light equipment, etc. Nevertheless, accompanying the activities on their own farms was a form of training by demonstration.

Clearly, growers in the region needed some basic knowledge to undertake corrective measures independently and it was imperative to reduce inoculum levels of *C. perniciosa* at farm level. So training was considered a priority.

Material for courses was prepared by plant pathologists, extension and communication specialists. Within CEPLAC, all 346 agriculturist and technical assistants in 62 extension offices, together with 140 lecturers/staff members from the four CEPLAC's Agricultural Colleges were trained. Then as the next step, in Camacan alone, 45 previously trained personnel ran courses for 9977 growers covering 1425 farms, all within 2 months of the outbreak.

Public awareness campaigns were also undertaken through lectures at different community levels and groups. Often these were requested by various social and professional bodies. During the same period following the second outbreak, 51 lectures were given at which 3265 participants attended.

An overview of eradication and containment

As the data of *Figure 2* indicate, attempts to stop the advance of *C. perniciosa* were not successful and witches' broom has become well established in the cocoa plantations of Bahia. This is in contrast to the situation in Panama where this disease was first reported in 1978. A similar eradication procedure technically co-ordinated by the Food and Agriculture Organization of the United Nations continues to have a large measure of success. The advance of the pathogen from South to Central America has been limited by further widening the 40 km 'buffer zone' towards the Colombian border. To-date, approximately 120,000 ha of cocoa remain free of witches' broom allowing for continuing activities in cocoa or investments in crop diversification programmes (Source: FAO, Rome; Projects TCP/RLA/8964 and GCP/RLA/106/BEL in 1990/1991 and 1992/1993 respectively – the first author was project manager).

It seems almost certain that, in both Panama and Bahia, the disease was initiated by inoculum produced on infected material introduced into these regions. However, several factors have apparently contributed to these contrasting situations. In Bahia, there is considerable evidence that the disease was not only introduced but also spread through human activity after the initial infections were established. Moreover, the occurrence of two distinct disease foci at Uruçuca and Camacan, suggests that there was more than one introduction of diseased material. The pathogen was brought right into the centre of the cocoa region; it did not have to encroach gradually from the periphery (*Figure 2*). The outbreak at Camacan was undoubtedly the more serious in militating against the success of the eradication programme. Its unnatural distribution amongst cocoa bordering the river suggested that infected material had been distributed along its course and the occurrence of the outbreak was not made known early enough for any eradication to be effective. The disease had also been present there for several years.

The distribution of the cocoa in the two territories is also vastly different. In Panama, plantations are sparsely distributed in the narrow land mass of the isthmus, whereas in Bahia the large contiguous area of cocoa facilitated the spread of the pathogen.

Other factors undoubtedly contributed to the successful establishment of witches' broom in Bahia. The cocoa proved to be highly susceptible and its uniformity in this respect made containment by phytosanitation much more difficult than in some areas of the Amazon that have sparsely distributed plantings of heterogeneous material. Such susceptibility leads to problems of scale. More infected material has to be

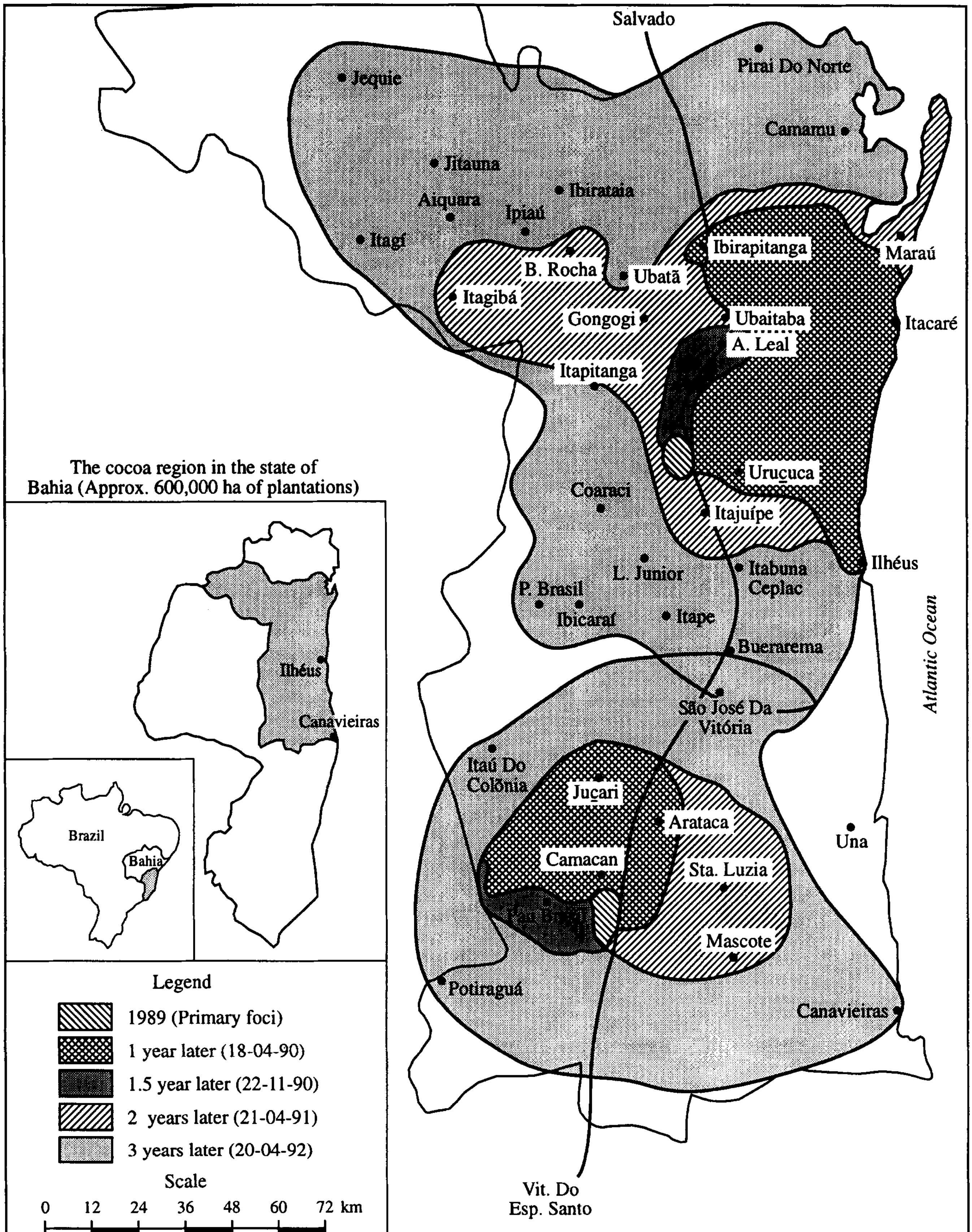

Figure 2. Geographical spread of witches' broom in the cocoa growing area of Bahia, Brazil, originating from the first sites of introduction of Uruçuca and Camacan

removed and dealt with to ensure that it does not contribute to the build-up of fungal inoculum. When eradication is attempted, as at Uruçuca, the infrastructure required is considerable and costly. Such as input of resources is justified initially if the evidence indicates the disease outbreak is recent and of limited distribution. There was such evidence at Uruçuca, and the eradication programme that was developed did appear to be reaching a successful conclusion, a situation that vindicated the measures taken. It was the discovery of the other, well-established and extensive outbreak at Camacan that ended any hopes of complete eradication. It was not just the enormity of scale in removing so many infected trees, although this in itself may well have proved physically impossible, but also that such an advanced infection would have generated a massive aerial spore load. The quantity of spores at the gradient limits would still be considerable and therefore would increase the chance of multiple infections.

No measure was made of disease severity but observations at Camacan indicated that the pathogen was extremely aggressive in terms of number of brooms per tree and in broom development. Later observations showed that it could produce many basidiocarps on diseased pods that had been cut and left uncovered on the ground. In part, these features reflected the susceptibility of the cocoa grown but they indicated also very clearly the suitability of the environment in Bahia for disease development, as had previously been deduced by Rocha (1983).

There were other factors that did not help. Although considerable resources were made available for eradication at Uruçuca the lack of compensation for the loss of cocoa trees or revenue alienated farmers, who then confused the financial assistance that they expected with the technical validity of the process. This made co-operative unified action more difficult.

Containment of the disease also depended on efforts by the farmers, most of whom had limited financial reserves in 1989, a result of repeated years of low income from cocoa. Phytosanitation, as recommended for the limitation of witches' broom, requires a considerable input of labour, and further, repeated fungicide sprays are needed to protect the developing fruit. While the data produced by the International Witches' Broom Programme (IWBP) did not offer more effective alternatives over the previous disease management strategy, it did send a clear warning that with low market prices for cocoa, management of the disease may result in a negative cost–benefit ratio (Rudgard, Andebrhan, Maddison and Schmidt, 1993). Yet, if existing disease management methods were not practised, then witches' broom will continue unchecked and even less harvestable cocoa will result.

A renewed effort to save the Brazilian cocoa industry has to be made. The present situation can be reversed to an economically viable position through an urgent injection of adequate funds for research in short- and long-term management. The selection of disease tolerant planting material should be a key feature of such programmes and the generation and application of technology aimed at an increasing productivity to support the higher cost of disease management.

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