COCOA GROWERS' BULLETIN

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Contents

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EDITORIAL

The pollination of cocoa is an aspect of cocoa cultivation of enormous importance due to it's significant impact on potential yield, but yet it is a subject which has received inadequate attention in nearly every cocoa growing region.

The environment clearly has a major impact on the numerical availability of cocoa pollinating insects. The preferred breeding environment is most usually in free water in decaying banana stems, upturned cocoa pod husks and similar locations where water is held. In Ghana the midges first appear in April and May and gradually increase in numbers until October, the population remaining high until the end of December. The arrival of a hot dry wind (the harmattan) in January causes a sudden fall in numbers as the breeding sites dry out. By March when flower numbers rise steeply at the start of the flowering season, pollination had virtually ceased. (after Entwistle, P.F. (1972) Pests of Cocoa, Longmans).

It is my belief that under certain circumstances, the availability of insects to pollinate cocoa flowers can be a limiting factor to the number of flowers pollinated and thus the potential yield of a tree or a whole field or farm. In Ghana only some 12 per cent of flowers are pollinated in the time of profuse flowering. It maybe that some cultural techniques might be identified that would increase the breeding sites for natural pollinators of cocoa by a meaningful amount. It also seems likely that widespread application of pesticides of high toxicity will substantially reduce the number of insects available for pollination.

Our knowledge on all aspects of pollination is generally very poor and should be substantially improved. In an attempt to stimulate an interest in pollination of cocoa this issue of Cocoa Growers' Bulletin contains an article entitled 'Pollination of Cocoa' by Dr Allen M Young who has worked on pollination of cocoa for many years in Latin America. It is hoped that the publication of this article will encourage agronomists and entomologists to study pollination further and thereby perhaps introduce changes in cultivation practices which might stimulate the formation of breeding sites for pollinating midges in cocoa farms to ensure a higher level of pollination than that which presently prevails in many cocoa growing areas.

R.A. LASS, Editor

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REVIEW OF PRODUCTION AND CONSUMPTION

May 1985 - January 1986
S J Turner, Cadbury Limited

REVIEW OF THE MARKET

It seems that over the last few years the market has lost much of its feel for the true value of cocoa against a background of wildly fluctuating exchange rates. It appears to be no longer feasible to compare surpluses and deficits, stock positions and expectations, in order to assess the forward risks in cocoa prices for either producers or consumers. Consequently the deficits of 1982/3 and 1983/4, which reduced world cocoa stocks to 20% of annual demand, did not provoke the steep rise in prices that a similar situation had caused in 1976. Furthurmore the general alleviation of that position has not seen a significant easing in prices: today's nearby Ghana cocoa is not much cheaper in actual terms than mid-1984.

PRODUCTION

Gill and Duffus's latest report (No. 322, March 1985) includes their 1985/6 forecasts. Production in 1985/6 is forecast at 1,885,000 tonnes, a fall of 46,000 tonnes over their revised 1984/5 estimate of 1,931,000 tonnes. The 1984/5 estimate is significantly higher than in our last review (1,833,000 tonnes) due mainly to a large Ivory Coast mid crop and a very heavy Ecuadorian crop. For 1985/6 Gill and Duffus predict increases amongst the major producers only in Ghana and Malaysia. The recovery of the cocoa industry in Ghana is particularly heartening since it suggests that the many years of decline there are finally being arrested.

CONSUMPTION

The latest Gill and Duffus forecast for 1986 Grindings is 1,831,000 tonnes, an increase of 19,000 tonnes on their latest 1985 estimate which itself has been revised upwards to 1,812,000 tonnes from 1,716,000 tonnes in May 1985. Demand is expected to grow strongly from the second half of the year following a brief lull in the first 6 months.

STOCKS

Gill and Duffus now estimate closing stocks for 1983/4 at 374,000 tonnes, the lowest level since 1976/7 in absolute tonnage, and just as severe in terms of the proportion of demand. They estimate stocks at the end of 1984/5 to be 500,000 tonnes and with a forecast 1985/6 surplus of 50,000 tonnes stocks by September 30th 1986 should be around 550,000 tonnes.

PRICES

Prices during 1985 have been reflecting currency- rather than cocoa-factors, with nearby Ghana cocoa ground £2300 at the start of the year (when the pound was at an all-time low against the dollar) to around a year-end value of £1897. The weakening dollar has helped prices fall to £1661 by end-February 1986.

WORLD COCOA PRODUCTION AND GRINDINGS DATA

Reproduced from Gill and Duffus Market Report 322

Dated March 1986
(all figures in thousand metric tonnes)

Production	1982/3	1983/4	1984/5 (estimate)	1985/6 (forecast)
WORLD TOTAL	1530	1510	1931	1885
Africa	853	853	1064	1038
S.America	505	466	654	603
W.Indies	53	52	53	53
Asia & Oceania	119	139	160	191
PRINICIPAL COUNTRIES				
Cameroon	106	108	120	115
Ghana	178	159	175	220
Equatorial Guinea	10	8	8	8
Ivory Coast	355	405	552	540
Nigeria	156	115	151	95
Brazil	336	302	412	384
Colombia	40	41	40	40
Ecuador	46	48	121	95
Mexico	42	35	42	40
Venezuela	17	16	15	18
Dominican Republic	40	39	39	39
Malaysia	65	80	93	120
Papua New Guinea	29	28	31	30

GRINDINGS	1983	1984	1985 (estimate)	1986 (forecast)
WORLD TOTAL	1649	1752	1812	1831
Western Europe	627	661	677	685
Eastern Europe & USSR	229	231	244	246
N.America	210	231	225	225
Central & S.America	334	359	385	384
Australia & N.Zealand	12	11	7	4
Asia	107	98	109	120
Africa	130	161	165	167
PRINCIPAL COUNTRIES				
United States	194	209	205	205
Germany (FR)	180	194	207	200
Netherlands	157	161	167	170
USSR	145	150	160	160
United Kingdom	77	90	91	95
France	53	52	40	42
Brazil	198	214	234	240
Ivory Coast	70	85	90	92

PRICES

Month-End prices for nearby shipment Ghana cocoa have been:-

1985	January	2281
	February	2272
	March	2110
	April	1928
	May	1881
	June	1860
	July	1778
	August	1833
	September	1915
	October	1831
	November	1778
	December	1897
	January	1855
	February	1661

COCOA POLLINATION

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INTRODUCTION

"Pollination" is a process by which pollen grains, are successfully transferred to the stigma and/or style of a flower. Effective pollination occurs when a sufficient number of viable pollen grains are deposited to bring about a full complement of seeds in a fruit. In self-incompatible plant species, including many varieties of Theobroma cacao, effective pollination requires the cross-transfer of viable pollen grains between flowers from different individual trees. Winder (1977c) was the last to review the subject of cocoa pollination and this review incorporates research completed since that date and indicates promising directions for further research.

Firstly it is thought helpful to outline some basic concepts on pollination and review present knowledge on cocoa pollination, excluding any consideration of hand or artificial pollination. A thorough understanding of natural pollination of cocoa, including both the floral properties related to pollination, the biology of pollinators and environmental factors influencing pollination in commercial cocoa farms, gives an understanding of the importance of natural pollination in the determination of crop yields. Some aspects of natural pollination in cocoa may eventually explain why cocoa growers are continually plagued by low rates of natural pollination and indicate how cocoa plantation management practices might be changed to increase rates of natural pollination of cocoa.

SOME RELEVANT BASIC CONCEPTS

Theobroma cacao Linnaeus, belongs to the family Sterculiaceae, one of five families representing the order Malvales in the New World. The classic monograph of Cuatrecasas (1964) points to the tremendous diversity within the genus Theobroma while much less is known about Herrania which is very close to Theobroma (Schultes, 1958) and was once classified with the latter. Within the genera Theobroma and Herrania a diversity of pollen grain surfaces is evident (Taylor, 1965). Such diversity of morphology indicates the use of diverse pollen vectors within the group. Studies of various plant groups have demonstrated the crucial role of pollen grain morphology as a determinant of optimal pollinators (Cerceau-Larrival and Roland-Heydacker, 1976; Heslop-Harrison, 1976, 1979; Skvarla et al., 1978).

Pollination biologists examine both floral properties and pollinator biology to understand how interactions between plants and pollinators may have evolved over long periods of time (Percival, 1965; Kevan and Baker,1983). The following floral properties influence pollination: (1) flower size, colour, fragrance, and structure; (2) location of flowers on the plant; (3) numbers of freshly-opened flowers present simultaneously; (4) occurrence of male and female sexual organs within the same flower, or separately in different flowers on the same tree or on separate trees; (5) orientation of flower to the environment (directed downwards, upwards, concealed, etc); (6) cauliflorous (located on trunks and lower branches) or in crown; (7) time of year for peak flowering or diffuse, even flowering throughout the growing season; (8) amounts of nectar and pollen, or other pollinator-rewards, and their nutritional value relative to other floral sources available at the same time.

We know from many studies that flowers, even those with highly specialised structures and related properties, are often visited by a broad range of animal visitors, but not all of these are necessarily effective agents of pollination (Kalin-Arroyo et al,1982). Recent studies have also revealed the existence of other floral rewards for pollinators, such as oils released from specialised floral glands at times when the flower is most receptive for pollination (Simpson and Neff, 1981; Simpson et al., 1983). It is important to understand that the incentive a flower offers as a reward for pollinators is often specific to a certain set of pollinators even though the flower may receive a large number of other floral visitors.

The flower contains the sex organ(s) for plants, and pollinator systems have evolved in response to the breeding system of that particular plant species. We must attempt to determine the pollinator system that originally adapted the tree species to its natural habitat and how the cultivation process has altered, or perhaps even obliterated, the original interaction between the tree's flowers and its most effective pollinators. This is often the most difficult aspect of pollination biology. Virtually all studies of cocoa pollination have been conducted in farms, and not in the natural habitat using truly "wild" populations of T. cacao. While we may learn much about the dynamics of pollination of cocoa in a farm situation and feel comfortable with this knowledge because that is what exists today, a complete understanding of pollination can only be obtained by a consideration of it in the evolutionary context as well. With further study this knowledge might assist cocoa growers to make more effective use of the farm habitat to enhance natural pollination.

SOME HISTORICAL ASPECTS

Many studies of cocoa flowers in both the New World and the Old World have shown that small-bodied flying insects, chiefly midges of the Diptera families Ceratopogonidae and Cecidomyiidae, are the most important pollinators of cocoa although not exclusively so (Jones, 1912; Wellensiek, 1932; Cope, 1939; Billes, 1941; Posnette, 1942, 1944; Soetardi, 1950; Gnanaratnam, 1954; Van der Knapp, 1955; Saunders, 1959; Walker, 1959; Dessart, 1961; Glendenning, 1962; Hernandez, 1965; Soria, 1970; Sampayan, 1966; Vello and Magalhaes, 1971; Edwards, 1973; de la Cruz and Soria, 1973; Kaufmann, 1973; 1974; 1975a,b,c; Amponsah, 1975; Winder, 1972; 1977a,b,c; 1978a,b; Wirth and Waugh, 1976; Young, 1981; 1982; 1983a; 1984a,b; 1985a,b,c). General aspects of the mechanism of cocoa pollination by insects has been reviewed at various times (Winder, 1977c; 1978a; Bystrak and Wirth, 1978; Young 1984e).

Several recent studies, have elucidated various aspects of both the general biology and population dynamics of ceratopogonid midges in cocoa farms (Fish and Soria, 1978; Soria, 1973; 1976; 1977a,b,c; Soria and Abreu, 1974; 1976; Soria and Wirth, 1974; 1979; Chapman and Soria, 1983; Young, 1983; 1984e; 1985a. Young (1983a) demonstrated that the larval populations of some species of ceratopogonid midges can be increased in a Costa Rican cocoa plantation (Finca Experimental La Lola) by experimental manipulations. Such observations suggest that at least one cause of low rates of natural pollination is a lack of pollinators, although clearly it is not the only factor determining fruit set. Young (1982, 1983a, 1984b) experimentally increased midge populations by increasing the availability of suitable organic substrates (chiefly rotting sections of banana tree trunks and cocoa pod husks) beneath cocoa trees in periods of high flowering (Young, 1984c).

When cocoa trees are hand-pollinated, greater numbers of pods mature than when trees are left to natural pollination (A.M. Young, unpubl. data; G. Enriquez and J. Galindo, pers. comm.). Herein lies one major frustration to cocoa growers. It is also observed that when cocoa is first introduced into a new region, levels of fruit set can often be high. It appears therefore that under certain conditions: for example when cocoa trees are in a healthy condition or when cocoa is a relatively new crop in a region, that rates of natural pollination can be high. There may be a direct relationship between the abundance of midges as pollinators and the level of natural fruit set. It can therefore be assumed that pollination is one of several biological factors limiting cocoa yield throughout the world.

FIGURE 1: Mature floral bud and freshly-opened flowers of *Theobroma cacao* L. (Sterculiaceae).

MECHANISMS OF POLLINATION

The actual process by which a small insect pollinates a cocoa flower has been described and reviewed several times (Soria, 1970; Entwistle, 1972; McGregor, 1976; Bystrak and Wirth, 1978; Winder, 1977c; 1978a). It appears that the cocoa flower is designed to accommodate a small-bodied (i.e., 2-5 mm long) insect capable of picking up many sticky pollen grains and eventually depositing these, either as smear or ball, on the stigma or style of the flower. The cocoa flower is pentamerous (Figure 1). The five anthers are largely concealed in five petal pouches that surround the pistil and are separated from it by a 'tube' arrangement of five elongate and filamentous staminodes. This basic floral design is present in other species of Theobroma, even though there has been considerable evolutionary divergence in the overall size of the flower and the relative sizes (and shapes) of specific floral parts (Figure 2), suggesting some divergence in pollination systems as well.

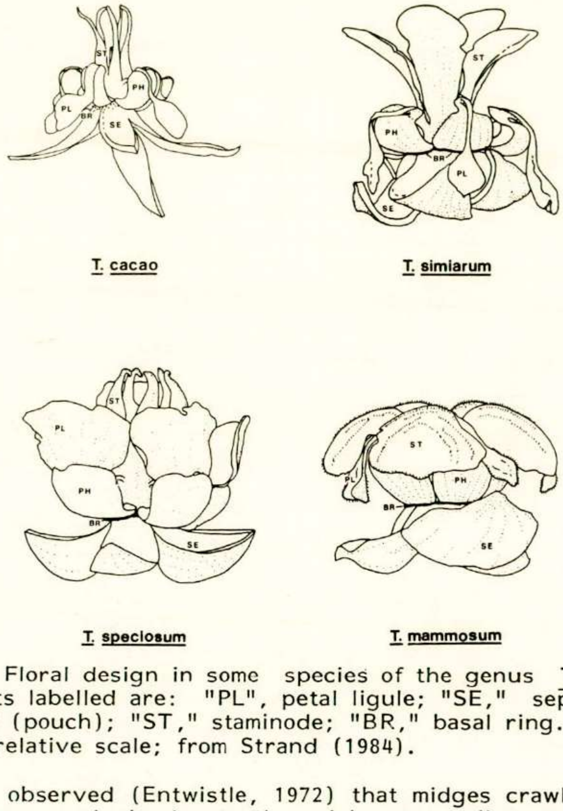

FIGURE 2: Floral design in some species of the genus Theobroma. Floral parts labelled are: "PL", petal ligule; "SE," sepal; "PH," petal hood (pouch); "ST," staminode; "BR," basal ring. Flowers drawn to relative scale; from Strand (1984).

It has been observed (Entwistle, 1972) that midges crawl into these petal pouches and inadvertently pick up pollen grains from freshly-dehisced anther sacs, usually in the daylight morning hours (Soria, 1970). A midge laden with pollen grains adhering to bristles on its thorax flies off to another flower, this time crawling down the narrow space between the pistil and staminode, and in doing so, deposits a ball of pollen grains along the way. If the pollen is viable, pollen tubes grow from the site of contact of the pollen ball, down the pistil and into the ovary. Unlike many other plants, pollination in cocoa can successfully occur at most points along the pistil, and not just on the stigmatic surface itself. The site of compatability resides in the ovary in cocoa (Enriquez, 1977; 1982). Intensive taxonomic studies have determined the many genera and species of Ceratopogonidae associated with the cocoa farm habitat in various parts of the world (Wirth, 1970; Wirth and Soria,1975; 1979; Wirth and Waugh, 1976; Azhar and Wahi, 1984). Small-bodied crawling insects have also been reported as cocoa pollinators (Harland, 1925; Muntzing, 1947; Entwistle, 1972).

Little is known about the mechanism by which insects are attracted to cocoa flowers, or more importantly the 'roadmap' of biological cues guiding an insect through the labyrinth of the cocoa flower. Pigmented nectar guides were once thought to orient midges to the petal pouches, but floral colour in general appears to play no appreciable role in this process (Soria et al. 1982; Alvim, 1984). In general, our knowledge of chemical systems in cocoa flowers is very poor (Miller, 1952; Soria et al. 1980; Young et al. 1984). Cocoa flowers are believed to produce both a fragrance and nectar secretion (Stejskal, 1969), while a more recent study confirms the presence of a chemically-complex fragrance in cocoa flowers (Young et al. in preparation).

Soria et al. (1980) could not attract midges to various chemical lures in cocoa plantations at Turrialba, Costa Rica but, when several fresh cocoa flowers are enclosed tightly in a glass vial and the vial placed in a warm environment, a very noticeable, mildly-pleasant, fragrance is apparent when the vial is opened. It seems that an oily hydrocarbon, pentadecene, is a major component of floral fragrance in cocoa, and that its molecular weight renders it a most effective volatile (Young et al. in preparation). The degree to which this substance, and several other components of floral fragrance, is an attractant to cocoa pollinators is currently being studied. It is often the ratio of various components within a fragrance that determines the degree to which that fragrance will attract pollinators (Williams and Whitten, 1983) and such ratios may change drastically throughout the day within a plant population, or from population to population. Specific ratios of such chemical components (volatiles) may function as attractants for pollinators in one plant species and as repellents in others. The fragrance profiles for cocoa and related species of Theobroma, show marked changes in the ratios of major components as well as qualitative differences in other components within the range of volatile molecular weights (Young et al., in preparation). An interesting puzzle emerging from the present work is that floral fragrance in cocoa and other Theobroma spp. bears a close resemblance to orchid fragrances, which suggests that wild bees may be the original pollinators of cocoa.

Cocoa flowers generally begin to open in the late afternoon and are fully open by 0500-0600 hours on the following day (Wellensiek, 1932; Young et al., 1984, 1986). Stigma receptivity and pollen release are both high in the dawn to post-dawn morning hours (Young et al., in preparation), suggesting a peak pollinating period of about 0630 to 1000 hr. Floral fragrance is also at a high level at this time, but also again in the early evening at 2000 hours (Young et al., in preparation). Chemically, the floral fragrance is more complex in the morning and evening than in late afternoon (Young et al., in preparation). The view of cocoa and allied species of Theobroma being highly specialised to attract only certain groups of pollinators at specific periods of the day is emerging from our studies. The degree to which these new data are consistent with what is generally held to be the prevalent view of pollinator activity and behaviour in cocoa remains to be confirmed.

The structure of the flower and the imprecise information available on floral physiology, point to insect-mediated pollination in cocoa. However, the means by which small-bodied midges effectively deposit substantial numbers of pollen grains on the style at one time in order to produce a pod with a full complement of seeds remains a mystery. It has been observed that ceratopogonid midges such as Euprojoannisia sp. deposit pollen 'balls' consisting of many pollen grains but some biologists continue to view this behaviour with scepticism given the body size of the insect relative to the size of the "critical mass" of pollen required for successful pollination. It would seem unlikely that small-bodied midges would be able to transport such pollen loads long distances within a cocoa farm. Theobroma flowers appear to have many features which suggest a bee-pollination syndrome: the flowers are attractively-coloured, emit a mildly-pleasant to very pleasant fragrance, production of the fragrance is intense in sunny morning hours, and the cocoa tree has a morphology indicative of a specialised pollination mechanism (Young, unpubl. data).

From previous research in the New and the Old World tropics, it is clear that small-bodied midges play a major role in pollination of cocoa. Research into their biology and the means by which the populations can be inexpensively managed in cocoa farms should continue.

SOME ENVIRONMENTAL FACTORS INFLUENCING POLLINATION

The degree to which natural pollination occurs depends on many environmental factors, which have been reviewed recently by Alvim (1984). In most cocoa-growing regions flowering is not evenly distributed throughout the year (Young, 1984c), but follows overlapping and interacting rhythms, one or more of which might well be correlated with rainfall, while others have little relation to any obvious external trigger in the environment (Hutcheon, 1981). The challenge to the cocoa grower is to balance the asynchronous patterns of seasonal flowering with the population dynamics of pollinators in plantations. Typically a strong burst of intense flowering occurs at the end of the dry season (Alvim, 1984; Young, 1984c) in most regions, but pollinator populations are generally reduced at this time (Hewison and Ababio, 1930). Since midges require a generation time of about 20 days, a sizeable percentage of flowers will not be pollinated at this time. Young (1982; 1983a,b,c; 1984b,d) found that by placing piles of rotting banana trunk sections or cocoa pod husks in farms before the onset of the dry season, midges and other insects continued to breed in the dry season. There were, therefore, a greater number of midges available when the flower burst occurred at the end of dry season, and natural pollination during this critical period was increased.

The maintenance of an adequate ground cover of rotting organic materials is a simple means by which the population densities of pollinating midges can be enhanced. Rotting banana trunk sections support several genera and species of ceratopogonid midges, including some key pollinating species (Young 1982, 1983a) and distributing piles of banana trunk sections or piles of cocoa pod husks at three or four month intervals will augment the numbers of breeding sites for midges. Winder (1977c) noted the potential of this technique.

Cocoa farms with a thick layer of leaf litter and other dead plant matter tend to have higher rates of natural pollination than farms with little such cover and a high density of herbaceous cover (Young, unpubl.data). Cocoa with thinned jungle or shade as opposed to a planted shade species, appears to be entomologically more suited to pollinating insects (Young, 1983a,b).

Differences in cocoa farm habitat in the same cocoa-growing locality can have considerable impact on the rates of natural pollination, the species richness and seasonal abundance of cocoa-pollinating midges (Young, 1982; 1983a). The uniformity of the shade canopy, and the degree to which the cocoa trees are self-shading, will all influence the spatial distribution of midge breeding populations and the flight activity of adult midges and other floral visitors. The structural heterogeniety of vegetation within the farm habitat may account for the range of insect fauna present (Young, 1983b,c, 1984d). In one Costa Rican farm for example Young (1985c) found bees were more frequently associated with flowers in the sun while midges were shown to be more abundant in the shade.

The overall species richness of ceratopogonid midges in forest adjacent to cocoa plantations in eastern Costa Rica is as great as it is in the plantation habitat itself (Young, unpubl.data), both habitats appearing suitable for the maintenance of midge populations. At the periphery of a cocoa plantation sunlight may attract greater numbers of wild bees since (1) trees in sunlight often have more flowers thereby providing more attraction for bees, (2) bees may be nesting in adjacent forest, and (3) bees may incorporate cocoa trees in such places into a trapline foraging pattern (sensu Janzen, 1971) involving several other flowering tree species in the adjacent forest habitat. This suggests the importance of maintaining corridors of natural vegetation on the perimeters of farms whenever possible.

Wild bees of various taxa may be more prevalent in cocoa farms than was previously realised. Nearly two hundred euglossine bees have been collected in a Costa Rican cocoa farm. The frequency with which wild bees actually visit cocoa flowers requires intensive field study. The secretive nesting habits of euglossines (Young 1985d) and their extremely rapid movements mean that it is difficult to determine their exact role in cocoa pollination, but investigations in Costa Rica are presently in progress.

Another potentially significant source of spatial heterogeneity, is the varietal and clonal mix in any given field. There is no information on preference of pollinating agents for different varieties of cocoa. The evidence on floral pigmentation comparing natural pollination rates in a pigmentless variety such as Catongo with a highly pigmented clone, UF 613 for example, indicates little influence on pollination rates (Alvim, 1984; Soria et al., 1982). Little is known about the way plant breeding programmes in cocoa have altered other floral features which may be of great significance in the flower/pollinator interactions.

CURRENT AND FUTURE RESEARCH

The comprehensive understanding of cocoa pollination, requires two complementary research approaches. Firstly, there is a need for field assessment of pollinator populations through space and time, including the determination of the environmental requirements for the survival and continuous breeding of these insects in the cocoa farm. Secondly, there is a need for joint laboratory and field studies on those floral properties of cocoa that determine the mechanism by which the most effective pollinating agents act on cocoa. It is, however, necessary to know whether the small-bodied midges or the wild bees are the optimal pollinators and if the latter, how they could be integrated into a program of pollinator management in cocoa farms.

It is important to study allied species of Theobroma in terms of their floral properties and pollination systems as certain floral features, such as size and colour of the flowers, degree and type of floral fragrance, and floral visitors, differ greatly from T.cacao. Through these comparative studies, it is possible to gain insight into the nature of cocoa pollination.

It has been discovered that certain glandular hairs, in much greater evidence in species such as T. simiarum and T. speciosum relative to T. cacao, are the most likely primary source of the oily fragrance compounds which is responsible for attracting pollinating insects (Strand, 1984; Young et al., 1984; in preparation). These structures are different to those found in Herrania spp. and the chemical composition of the fragrance is also completely different (Young et al. in preparation). Diptera-attracting compounds are present in the Herrania fragrance, but not in that of Theobroma spp. The major fragrance components in Theobroma are indicative of a bee-pollination syndrome (Young et al., in preparation), though there is the possibility that these fragrance components are also very attractive to certopogonid and cecidomyiid midges.

Extensive research in the pollination of Central and South American orchids by euglossine bees (Bergstrom, 1978; Holman and Heimermann, 1973: Williams and Whitten, 1983) indicates a clear association of fragrance chemistry with pollinators, a pattern which may also exist in cocoa and other Theobroma spp. as the floral fragrance compounds of cocoa are somewhat similar to those of orchids (Young et al., in preparation).

Perhaps we should now be asking whether the structure of the cocoa flower originally evolved in association with a specific kind of wild bee as a pollinator. If so, then the evidence of this interaction should be found in wild stands of cocoa in South America. John Allen (pers.comm.) reports that wild T.cacao in Ecuador has very few flowers and that most of the flowers were found in the crown of the trees in marked contrast to the typically cauliflorous condition of cocoa trees in cultivated farms. Crown or canopy foraging by wild bees has been reported for cocoa trees in commercial plantations in Africa (Kaufmann, 1975c) and it would be interesting to determine if a similar pattern exists in the wild cocoa trees in South American tropical rain forest.

Studies of tropical bees indicate that some species exhibit a trap-line foraging pattern over long distances in tropical forests (Janzen, 1971). Such bees, the euglossines, visit various tree species for nectar or pollen in a single morning and this promotes outcrossing in tree species in which self-compatible individuals are scattered in the forest. This trap-lining pollinator strategy would fit well with the conservative reproductive system speculated for cocoa and its relatives: the adult tree produces relatively few flowers per unit of time and a small number of pods, more resources being allocated to vegetative growth functions.

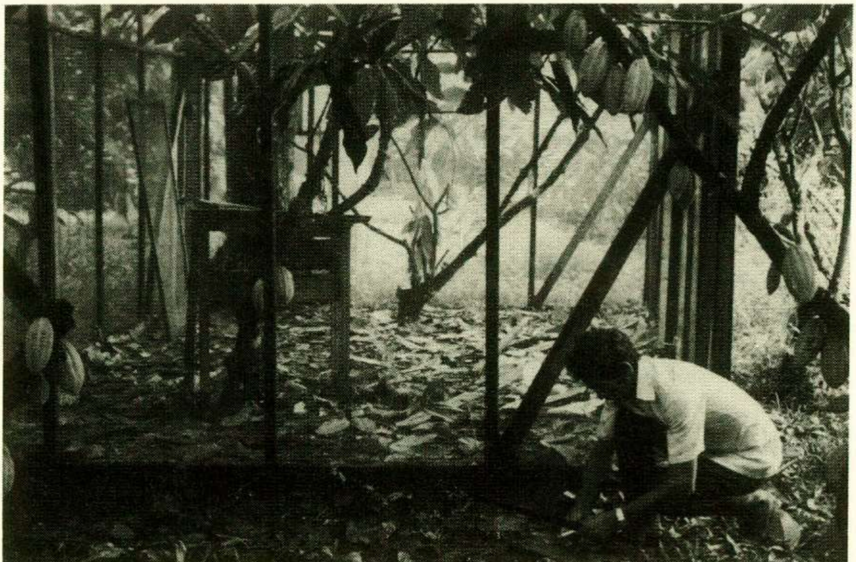

FIGURE 3: Experimental field studies of wild bees. Above: Field cage enclosing two cocoa trees (at Finca Experimental La Lola) and containing a colony of stingless bees (Trigona) in a bamboo tube suspended beneath the roof of the shelter, as protection against rain. Below: closeup view of bamboo tube containing nest of wild bees used in field studies.

Data on floral properties related to pollination (Young et al., 1984; in preparation) suggest that the bee pollination system is the primary system for Theobroma spp. evolved by interaction between flowers and pollinators. This would not necessarily rule out the role of midges as facultative pollinators of cocoa. Small-bodied midges may have ecologically replaced wild bees as the principal pollinators of cocoa in most cocoa-growing regions of the world, because these midges are found throughout the tropical wet regions of the world thriving in dense shade and exploiting cauliflorous flowers close to the ground. These are conditions largely unsuitable to sustained bee activity (Young, 1985c).

The degree to which cauliflory per se influences bee pollination in Theobroma may be a function of overall size of the tree. Wild cocoa trees and trees of other Theobroma species are much larger than cultivated cocoa trees having an approximate height range of 10-25m. Cauliflory is well developed in species such as T. speciosum and T. simiarum, and generally absent in others such as T. mammosum and T. bicolor, as well as in wild cocoa trees. The cultivation of cocoa has resulted in smaller trees, of height of 2-4m and with cauliflory juxtaposed upon the generally shaded conditions of the lower strata of cocoa farms. Such a condition may not be natural from the standpoint of how cauliflory originally adapted Theobroma species to natural pollination within the tropical rain forest habitat.

Adult midges may find some suitable resources in cocoa flowers, though it is not known whether midges actually feed on pollen and other substances in flowers (Downes, 1955). The shaded ground cover of farms provides suitable conditions for many species of ceratopogonid midges to breed and adults of these species are likely to be associated with cocoa flowers. However, the very low rate of natural pollination in most farms perhaps reflects the fact that midges may only be secondarily-adapted pollinating agents of cocoa, while the alleged principal or obligatory pollinators, (perhaps certain wild bees yet to be identified), are absent from these habitats. Alternatively, wild bees responsible for pollinating cocoa may be active at times of the day (or night) when few observations have been made. In Costa Rican cocoa farms, wild bees such as Dialictus and Trigona, visit the flowers of cocoa and other Theobroma species.

Experiments are now underway in Costa Rica to examine the behaviour of various species of endemic wild bees when induced to visit cocoa flowers on trees enclosed in large cages (Figure 3) and hence to explore the potential of wild bees as efficient, managed pollinators of cocoa.

We need to understand the degree to which cocoa flower fragrance profiles function as potent attractants to midges and bees and a field experiment has been planned to test the attractiveness of various ratios of the important components of cocoa flower fragrance to these insects. This will study the volatile components discovered through steam distillation of essential oils from fresh cocoa flowers (Young et al., in preparation).

Though cocoa flowers possess nectaries (Stejskal, 1969; Young et al., 1984), there is no evidence that Theobroma flowers normally produce sufficient quantities of nectar to provide a floral reward to pollinators. Examination of Theobroma flowers by electron microscopy combined with fragrance studies (Young et al., 1984; in preparation) indicates that they offer floral reward in the form of an oily secretion. Such secretions might be of nutritive value to pollinators, or might be used as nest construction or are perhaps pheromone materials. Preliminary studies (Young et al., 1984; in preparation; unpublished data) indicate that glandular trichomes and specialised cells found on the ovary, sepals, and in the 'basal ring' between the petals and sepals, are the primary sites for the release of oily volatiles responsible for floral fragrances in Theobroma species, including cocoa. The basal ring structure (see Figure 2) is far more prominent in some other Theobroma species than in cocoa (Young et al., 1984; Strand, 1984) and this may account for the pronounced fragrance in other Theobroma species.

Bees in the tropics often exhibit regular, predictable floral-visitation patterns (Janzen, 1971) as a result of their requirements to obtain nutrient-rich resources for the rearing of brood, a need absent in most, if not all, Diptera. There is therefore the possibility that wild bees in the tropics could be managed agronomically as cocoa pollinators. Many tropical bees, could be reared in artificial nests, replicated within a plantation habitat, once their nesting habits and general biology has been established. We are presently studying the floral biology of cocoa and making field observations on the species of wild bees visiting the flowers to see if any species could be useful to the grower for pollination.

In the La Lola cocoa plantation in Costa Rica, the large euglossine bee Eulaema meriana visits both cocoa flowers and those of T.simiarum . These early morning visits (0500 to 0700 hours) involved this large-bodied bee simply bumping into the flowers, which suggests that large bees may actually pollinate cocoa. In other plants, large-bodied bees quite often jostle small flowers sufficiently to cause pollination. Both small-bodied and large-bodied bees carry larger pollen loads on their bodies than small midges, increasing the chance for large quantitites of pollen being deposited on the stigma and style during floral visitations. Much more information on the association of wild bees with cocoa flowers is needed before species can be installed, as colonies, in cocoa plantations for pollination purposes.

One important avenue of future research on cocoa pollination is the reconstruction of the original pollinator-flower association in the wild for cocoa and its near relatives in the genus Theobroma, because this could identify the insect species which are the most efficient cocoa pollinators. This would involve laboratory studies of floral fragrance and its influence on pollinator behaviour of midges and bees, field studies of cultivated and wild cocoa to document floral visitors by day and night and field assays to test floral fragrance components at different times of the day and night as lures for effective, natural pollinating agents. It is also necessary to view midges as the most prevalent facultative pollinators of cocoa and to examine the environmental parameters promoting their activity in cocoa farms. It would, for example, be useful to compare levels of natural pollination by midges and resulting levels of fruit-set, in optimally maintained cocoa and sub-optimally maintained cocoa in the same location. In this context optimal maintenance would be defined as doing everything agronomically possible to maintain healthy cocoa trees, with a regular, consistent programme of pest and disease control, fertilizer application and maintenance of an appropriate level of shade cover. The proposed experiment would be to assess whether healthier cocoa trees are intrinsically more attractive to pollinators than less healthy trees under the same general climatic conditions. Attractiveness of cocoa trees to pollinating agents involves parameters such as increased number of flowers per tree per unit time, more fragrant flowers, adequate ground-cover litter beneath the trees, fewer floral herbivores, adequate shade to protect midges from drying out and undoubtedly many other factors. Healthy cocoa trees could have an enhanced capacity to attract pollinators and successfully set fruit and thus mature more pods per harvest. Natural pollination per se could become less of a limiting factor under optimal agronomic conditions. Under such conditions, the ecological capacity of the cocoa tree to yield mature pods approximates to the physiological capacity of the tree to reproduce itself. Such an experiment, if run over several successive years could demonstrate whether natural pollination is more of a limiting factor in cocoa plantations with less than optimal agronomic practices.

The techniques and discoveries presently being made on cocoa flower fragrance and other floral properties influencing insect behaviour (such as patterns of absorption/reflectance of ultra-violet light) during our studies in Costa Rica will provide a useful diagnostic tool for evaluating the effectiveness of the same floral properties on the attraction of pollinating insects for many different cocoa cultivars throughout the world. These techniques will allow us to assess the intrinsic 'potential' for natural pollination in different cultivars, since we anticipate that the selective breeding of cocoa for traits other than those related to floral properties, as done over many years, has essentially ignored how such breeding influences natural pollination.

IMPLICATIONS FOR COCOA FARM MANAGEMENT

Research on cocoa pollination could provide a solid basis for advising the cocoa grower how to enhance levels of natural pollination in cocoa. A number of key concepts are emerging from the increased understanding of cocoa pollination. Amongst them are the following (not in order of importance):

1. Cocoa farms with borders or corridors of natural forest, or those using thinned natural forest shade have an increased likelihood that potential pollinators will be available throughout the year;

2. Adequate shade with a well developed ground-cover of leaf litter enhances the breeding of pollinating midges;

3. The precise feeding habits of adult midges remains largely unknown, but healthy cocoa flowers produce a complex of essential oils not uniformly present at all times of the day and

night. These volatiles may be involved in attracting midges and other insects to cocoa flowers and may or may not be a nutritive source for pollinators. Such substances may be most effective in healthy cocoa trees not under stress;

4. Planting a mixture of varieties within a farm is an appropriate strategy for enhancing the flow of viable pollen between self-compatible and self-incompatible cocoa types;

5. Occasional plantings of other species of Theobroma in cocoa farms may enhance environmental signals which attract flying insects particularly wild bees to the vicinity of cocoa trees. Theobroma simiarum and T.speciosum have exceptionally strong floral fragrances and showy floral colours as well. If scattered within plantations such trees may lure potential pollinators into cocoa farms;

6. Insecticides and fungicides should be targeted specifically to certain trees or areas where the pest or disease prevails, thereby lowering the risk of reducing pollinator populations;

7. The addition of piles of rotting banana trunk sections and cocoa pod husks at every fourth tree within a row at 3-4 month intervals may increase the number of cocoa pollinating midges. In cocoa-growing regions with marginal rainfall the placing of such materials should be carried out in the month preceding the onset of the dry season and it is most effective under conditions of adequate shade cover.

8. Whenever time and resources allow, cocoa growers could perhaps enhance levels of natural pollination by optimising the healthiness of their cocoa trees, through regular, consistent agronomic programmes. This contention is based upon the prediction (likely to be confirmed experimentally) that healthy cocoa trees are more attractive to agents of natural pollination;

9. Cocoa growers should avoid destroying nests of wild bees within and near their plantations;

10. The development and maintenance of an evergreen shade cover where cocoa is grown under marginal rainfall conditions is a very effective means of maintaining adequate pollinator midge populations throughout the year;

11. The possible use of inexpensive time-release lures to attract pollinating insects to the vicinity of cocoa trees without interfering with the orientation of these insects with cocoa flowers offers considerable promise for the future.

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THE BIOLOGY AND APPLICATION NEEDS OF PHYTOPHTHORA POD ROT OF COCOA

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INTRODUCTION

The cocoa tree (Theobroma cacao) is susceptible to a variety of diseases of the pods, foliage and wood but only Phytophthora pod rot warrants regular spraying on a worldwide scale. The disease and its control pose an interesting situation of contrasts. Higher yields through improved breeding, agronomy and management are needed to make chemical control economically viable while the epidemiology of these pathogens requires further elucidation and clarification before current control methods can be used to maximum benefit. In spite of these constraints the biology of Phytophthora pod rot of cocoa is such that future needs can probably be best met by the continued use of high volume knapsack sprayers and copper fungicide within an integrated programme of disease management.

The habitat and morphology of the cocoa tree combine to provide conditions of wetness and humidity in which the pathogens responsible for Phytophthora pod rot can thrive. For many years Phytophthora palmivora was considered to be solely responsible for Phytophthora pod rot in cocoa, but in 1979 Brasier and Griffin proposed two additional species (P.megakarya and P.capsici) as causal agents while more recently P.citrophthora has been identified as a pathogen of cocoa (Kellam and Zentmyer, 1982). The geographical distribution and relative importance of these four species throughout the cocoa-growing areas of the world are described in Wood and Lass (1985).

These pathogens belong to a group of fungi called the Oomycetes which have a versatile pattern of reproduction heavily dependent on the presence of free water and high relative humidity. The major mode of disease spread is by asexual spores called sporangia which have the capacity to produce and liberate motile zoospores. Thick-walled chlamydospores play an important role in pathogen continuity during periods of dry weather while the production of sexually produced oospores has only been observed on laboratory cultures. The role of water, whether in the liquid or gaseous phase, in the success of these pathogens is all pervading because it provides the conditions necessary for sporangia production and the medium through which zoospores move, aids the dispersal of spores through drips, splashes, mists and rivulets, and is the most important factor preventing the maintenance of residual fungicide coverage on the crop surface.

The importance of the role of water can be seen from a comparison of Phytophthora pod rot levels in different locations. Although global losses have been estimated at 20 to 30 per cent of the cocoa crop (Opeke and Gorenz, 1974) and the disease is present in all cocoa-growing areas, differences in the amount and pattern of rainfall and the extent of cloud cover combine to give sharply contrasting levels. The incidence of infected pods can vary from less than 5 per cent in a dry year in Papua New Guinea (Hicks, 1967) to 95 per cent in Cameroon (Tollenaar, 1958). These differences are reflected in the differing needs for chemical control which is usually unnecessary in Ghana and drier parts of Ivory Coast but is used to the extent of 10 to 12 applications/year in Nigeria and the wettest parts of Ivory Coast (Wood and Lass, 1985).

The pathogens infect and sporulate on pods at all stages of development, on flower cushions and in the woody stem as cankers. Foliar infection causing chupon wilt and necrosis of young leaves occurs in some areas and may be the source for the start of an epiphytotic in parts of Central America such as Costa Rica (Manco, 1966). Phytophthora palmivora was identified as a pathogen of cocoa roots prior to the discovery of the additional species (Turner and Asomaning, 1962) one of which, P.megakarya is primarily a root pathogen on Nigerian cocoa (Ward and Griffin, 1981), although its greatest effect is in pod disease (Gregory et al., 1984). Inoculum from all of these potential sources may be spread by direct contact, impacting raindrops, aerosol droplets, drips, rivulets, pests and harvesting tools. At first sight such a combination of infection sources, modes and routes of spread appears to present a situation insurmountable by any coherent control strategy. The position is presented schematically in Figure 1. On closer examination, however, there are clearly definable patterns of disease spread and clear cut boundaries of infection which allow one to formulate control methods by manipulating the timing and placement of the spray and as well as the choice of spraying machine and its mode of operation.

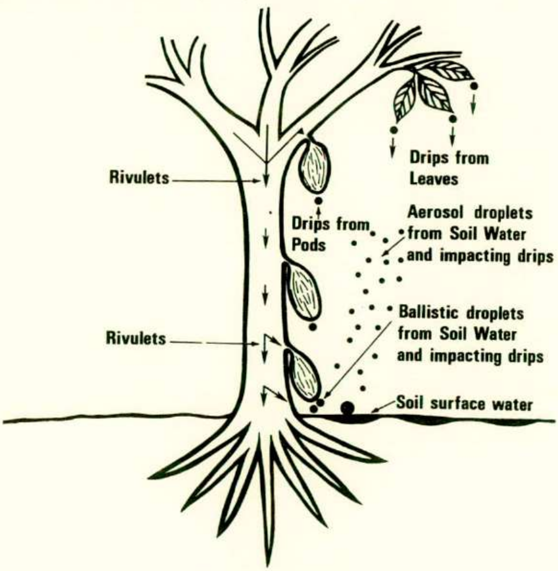

FIGURE 1: Dual Movement of spores and copper ions in various modes of water transport.

APPLICATION AND BIOLOGY

Spray Placement

The biological characteristics of a crop such as height, shape and density largely determine the type of spray machine that can be usefully employed and its mode of operation. The parts of the cocoa tree which are prone to infection and act as reservoirs of inoculum are the pods and flower cushions. These in turn may be the site of cankers. Only certain parts of the tree are vulnerable to infection and they are sufficiently distinct and accessible to be sprayed in isolation and therefore the requirements for spot application are fulfilled.

Low volume (LV) mistblowers have been used in cocoa for a number of years (Tollenaar, 1958; Hislop, 1963) and offer definite advantages where labour is in short supply and water has to be carried for long distances, but the mist cannot be spot applicated along the pod-bearing trunk and branches and thus much of the spray misses the target and is wasted (Wood, 1975). Therefore, the high volume (HV) knapsack sprayer appears to offer the best choice for spot application on the pod-bearing trunk and branches. The lance ensures the coverage of the whole circumference of the trunk, and permits application to those particularly vulnerable localities between the pod and trunk, without the operator having to move through a complete 360° turn. High volume knapsack sprayers are relatively cheap to purchase, are easier to maintain and have a wider range of uses than low volume mistblowers (Mabbett and Phelps, 1983a). Their simple construction offers more immediate possibilities for manufacture or assembly in those countries where cocoa is grown. Ultra low volume (ULV) application methods suffer from the same disadvantages as LV mistblowing techniques. There is no doubt that lower volume application could give improved cost effectiveness through reductions in both volume and dosage but similar savings can be achieved by careful selection of nozzles for high volume knapsack sprayers (Jollands and Jollands, 1984).

Spray Timing

Protectant copper fungicides such as Bordeaux Mixture and other copper compounds (cuprous oxide, copper oxychloride and cupric hydroxide) have formed the mainstay for Phytophthora pod rot control ever since chemical control measures were initiated on cocoa some seventy years ago in Cameroon (Wood, 1975). The fungicide must be deposited on the pod surface before sporangia or zoospores germinate. It must be retained there but at the same time be susceptible to some redistribution to compensate for pod growth. When this system ceases to maintain effective levels of fungicide repeat applications have to be made.

Spray schedules have been determined by the need to protect the pods, particularly those towards the base of the tree, in advance of inoculum splashed up from sporulating mycelium on soil debris. Repeat applications were made to stop or slow down the progress of the disease up the tree, the frequency being determined by levels of surface wetness and relative humidity and the loss of initial deposit through weathering and growth. Spray schedules are therefore dependent on the onset and pattern of rainfall and will vary between areas. Good sanitation and spray schedules combined should give adequate control, because the epiphytotics build up stepwise along a continuous vertical gradient from the primary source of inoculum in soil debris. In practice Phytophthora pod rot has never been controlled to a satisfactory degree and recent interpretative work from Nigeria may indicate why (Gregory et al., 1984).

Phytophthora megakarya, which is the principal pathogen causing Phytophthora pod rot in Nigeria (Brasier and Griffin, 1979), is primarily a pathogen of the roots where it sporulates freely (Ward and Griffin, 1981). Evidence suggests that the vertical infection gradient is not continuous but is sequential with infection gradients starting from initiators at various points up the tree. Ballistic droplets (large droplets originating from soil splash) and ant tents follow a single gradient pattern, but sequences can begin at any time and position in the tree being initiated by spore-laden aerosol droplets which are carried up from the soil and through the canopy by convection currents. The infective agents would most likely be the smaller and more numerous zoospores (Gregory et al., 1984), which have been shown to swim upwards against gravity (Cameron and Carlile, 1977). They probably accumulate at the soil surface during heavy rain and are projected upwards ballistically in large droplets or carried in convection currents in small ones. The ability of P.megakarya to invade and sporulate on living roots will ensure a continuous stream of spores irrespective of the level of sanitation. This reinterpretation of Phytophthora pod rot may help to explain the difficulty in control of the disease (Gregory et al., 1984), in spite of pod removal up to a height of 0.8 metres (Adebayo, 1983).

An infected tree presents a series of inoculum reservoirs which lie in a vertical plane and within a relatively narrow spectrum of width from the soil and roots up through the trunk and fan branches. With favourable weather conditions inoculum is produced and may be carried upwards or downwards along the central axis of the tree, mainly by water but also by ants, other insects and rodents. Continued protection by frequent application or efficient redistribution is required. The economics of spraying rule out the former but detailed studies in Brazil (Pereira and Lellis, 1985; Pereira, 1984) have shown that control can be achieved with a single well-timed application provided that it is not accompanied by a reduction in dosage. Thus a single spray of 16 g Cu^{++}/tree gave the same level of control as was achieved by 4 applications at 4g Cu^{++}/tree spaced at 30-day intervals. A single spray provides a reservoir of fungicide which can be redistributed down through the canopy to maintain levels depleted by weathering and pod expansion. The fungicide will eventually be washed off into the soil where it may make further contributions in the depression of inoculum levels, particularly if the Phytophthora species concerned are important root pathogens. Integrated within such a system could be the application of fungicide to the soil (Okaisabor, 1972), particularly the sparingly soluble oxides, oxychlorides and hydroxides of copper formulated as powders (Gregory et al., 1984) which could provide for the slow release of Cu^{++} to prevent sporulation on the roots, kill zoospores in the soil water or accompany them up the gradient within ballistic or aerosol droplets.

PROTECTANT FUNGICIDES - WHY COPPER?

Many protectant fungicides including triphenyl tin compounds (Wood, 1975) captafol and chlorothalonil (Lellis et al., 1983) have been evaluated for control of Phytophthora pod rot, but fungicides based on copper have remained the most popular and widely-used since spraying began on a large scale in the 1950s. Copper fungicides have been chosen for their availability, economy and efficacy, but there are many more reasons why copper fungicides are the ideal choice.

TABLE 1. Effect of long term weathering on copper deposits on citrus foliage (1) in Trinidad

	$\mu g\ Cu^{++}/cm^2$		
Leaf surface	1 day	2 months	4 months
Upper	1.82	0.98	0.51
Per cent (2)	-	54	28
Lower	2.48	1.92	0.87
Per cent (2)	-	77	35
Upper and lower	2.15	1.45	0.69
Per cent (2)	-	68	32

(1) sprayed with cupric hydroxide by LV mistblower. 425 mm of rainfall were recorded over the 4 month period;
(2) per cent of deposit recorded one day after application;

The properties of copper such as the particle size, shape and molecular behaviour are ideally suited to the intensely wet conditions under which cocoa thrives and the single application strategy which promises to maintain control while reducing labour costs. For such a strategy to work, the fungicide used must have a degree of tenacity which prevents large losses with the first good shower of rain but allows for the gradual solubilization of material to produce active copper ions for protection in the immediate vicinity of the deposit or elsewhere through redistribution. The reservoir of copper should ideally be maintained during the four to five months it takes for pods to grow to maturity which is also the duration of the wet season in many cocoa-growing areas. Longevity from studies carried out on other tropical tree crops grown under similar conditions have shown that the tenacity of copper deposits is such that this can be achieved (Mabbett and Phelps, 1983b). Reservoirs of copper from low volume water-based applications of cupric hydroxide were maintained on citrus foliage over four to five month periods in the wet tropical climate of Trinidad (Table 1). The potentially weak point in the longevity of deposits in the wet tropics is the timing of sprays in relation to any substantial rainfall. All chemical deposits are vulnerable to being washed off while they are still wet on the leaves but, given about one hour to dry, deposits of cupric hydroxide are fairly resistant to large drops of intensely applied rainfall (Table 2) and deposits on cocoa trees are largely sheltered from the direct effects of rainfall. The sparingly-soluble nature of these copper fungicides means that copper ions will pass into solution gradually and be redistributed by splashes and rivulets together with Phytophthora spores. The redistribution of fungicide and dissemination of spores in the same drops or rivulets of water is thought to play an important role in the control of coffee berry disease and coffee rust (Rayner, 1962; Pereira and Mapother, 1972). The success of the single application strategy using copper fungicide, in spite of the many sites of spore production and modes of dissemination may well be due to the fact that these are matched by reservoirs of fungicide and equivalent routes of redistribution (See Figure 1).

TABLE 2. The tenacity of copper deposits on citrus under intense artificial rainfall

Intensity of Artificial Rainfall (mm/min)*	Copper retained on leaf surface	
	µg Cu^{++}/cm	percentage
CONTROL	10.49	100.0
25	5.97	57.0
125	3.91	37.0
250	2.33	22.0

* Drop size 6 mm for each treatment; application of Cupric hydroxide by LV mistblower.

Copper fungicides are relatively safe to use which is an important consideration in the tropics where the wearing of protective clothing is difficult to impose. Phytophthora pod rot is the only disease of cocoa that warrants regular spraying but there are other diseases such as pink disease, thread blight, mealy pod disease, Botryodiplodia pod rot and Ceratostomella wilt which are susceptible to copper. The characteristic colour exhibited by copper deposits enables farmers, overseers and managers to see at a glance that an area has been sprayed. These bright colours also play an important safety role during the storage of fungicides. Many small farming families are forced to store fungicide alongside provisions but any contamination of food stocks will be immediately apparent.

Phytophthora spp. can manifest themselves as a canker of the trunk and branches, a symptom which is particularly prevalent in Malaysia. Copper compounds can be formulated on the estate into brightly coloured canker paints using stickers where necessary.

IS THERE A ROLE FOR SYSTEMICS?

Systemic fungicides with specific activity against Oomycete pathogens have appeared on the market during the last decade. Two notable examples are metalaxyl and fosetyl aluminium. Both have been evaluated for control of Phytophthora pod rot of cocoa either singly or in mixtures with copper fungicide (Figuereido et al., 1985;

McGregor, 1983; Djiekpor and Davous, 1985). Metalaxyl has been used commercially in Cameroon and Ivory Coast for several years while label recommendations have been established for fosetyl aluminium in Thailand and Malaysia. The use of metalaxyl in a mixture with cuprous oxide is recommended for Phytophthora pod rot control in Papua New Guinea (McGregor, 1983).

Fosetyl aluminium presents some entirely different problems because it appears to act, at least in part, through the metabolism of the crop by inducing the formation of anti-fungal compounds (Bompeix, 1982; Dekker, 1983). This homeopathic property is reflected in an activity spectrum which has consistently failed to provide control in some crop disease situations (e.g. late blight of potato) while proving most efficacious in others (e.g. downy mildew of vine) and thus activity is dependent on both the crop and the pathogen. This type of specificity poses two immediate questions in relation to the control of Phytophthora pod rot of cocoa. Firstly, does the specificity of action extend to differences between species of Phytophthora on the same crop and secondly, what is the plant organ in which the anti-fungal compounds are made, because it would be pointless to spray the pods and bark if the chemical is primarily produced in the leaves. By virtue of its mode of action fosetyl aluminium is unlikely to induce resistance readily and its ability to be carried downwards as well as upwards within the plant tissues (Williams et al., 1977) increases the application options compared with other systemics.

Systemic fungicides will have protectant action as long as they remain on or in the plant surface but for maximum benefit the material must enter the plant rapidly and in great quantities. With foliar application this can only be achieved if the target (i.e. the canopy) is sufficiently large and young enough to facilitate rapid entry. Sprays timed to coincide with foliar flushing would appear useful for cocoa but the newly-emerged leaves hang limp from the petiole and are therefore difficult to cover. In addition deposits on the leaves are exposed to the full force of weathering. The most efficient use of systemics in cocoa may require farmers to spray the whole tree which will be more expensive than spot application of protectant copper fungicide.

Entry through the roots is another possibility but the presence of a thick leaf litter and low growing weeds, both of which reduce the splash of spores from the soil onto low hanging pods (Braudeau, 1962; Gregory et al., 1984), might also intercept and take up much of the material destined for cocoa roots.

Systemic fungicides may be used to eradicate established infections of the cushions, bark and roots, and may arrest the development of lesions on the pod thus minimising the loss of beans within an infected pod (Figuereido et al., 1985). The translocation of fungicide into the pod or beans could cause taint problems for the chocolate manufacturing industry where flavour is so important. The residues of systemic fungicides must therefore be carefully examined.

DISEASE MANAGEMENT - INTEGRATION AND SIMPLICITY

The versatility of these pathogens in sites of sporulation, modes of dissemination and compatability with the climate required for the healthy growth and high production of cocoa has made Phytophthora pod rot of cocoa one of the most difficult diseases to manage in the tropics. Without some measure of clonal resistance, good sanitation and crop management practices which discourage disease spread and development, any chemical control measures will always be fighting an uphill battle. Much of the world's cocoa is grown in regions where farmers operate on small budgets and have limited access to new methods and technical advice. In these situations a simple, cheap method of control which the farmer operates with a minimum of technical assistance is desirable. The use of high volume knapsack sprayers employing water based sprays of copper fungicide fulfils these requirements and is completely compatible with the biology of the crop and its disease. Reliance on spray adjuvants adds unwelcome complications for the farmer and recent work in Brazil has thrown doubt on the usefulness of stickers (Pereira and Lellis, 1985). The use of systemics appears to offer an optional means of control but many imponderables including fungicide resistance, which is most likely to occur through imprudent use, and possible effects on flavour combine to make them a less attractive proposition. Furthermore systemic fungicides are often significantly more expensive than the equivalent dose of copper.

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A REASSESSMENT OF MONILIOPHTHORA (MONILIA) POD ROT OF COCOA

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INTRODUCTION

Until relatively recently Moniliophthora pod rot of cocoa was geographically isolated, being confined to north-west South America, and therefore of interest only to countries of that region. Its appearance in Panama in the 1950's caused little concern since cocoa cultivation is of minor importance and the area affected was close to the border with Colombia where the disease is endemic. However, its more recent spread to Costa Rica has had greater repercussions because this is traditionally a cocoa growing country and the crop plays an important part in its economy. Is the pathogen breaking out of its seemingly narrow geographic confines?

It is now considered appropriate to reassess the causal agent and to examine the threat it poses to those cocoagrowing areas where the disease is absent. Although much of the information in the present article is taken from a recent monograph on the fungus (Evans, 1981a), the latter publication is not readily available to cocoa growers and is couched in a format more suitable for scientists, where hard facts tend to be obscured by data. These facts are sifted out and presented in a form which, hopefully, will give the layman a better idea of the symptoms and disease cycle of the pathogen.

The disease can cause a high level of losses as shown in Table 1 and no economic control method can presently be proposed.

TABLE 1. Disease losses in the principal cocoa zones of western Ecuador, 1972-73 (Modified from Aragundi, 1974)

Zone	Yield [1]	Percentage Pods Diseased: Moniliophthora infected	Percentage Pods Diseased: Total diseased [2]	Rainfall (mm)
Viche	306.6	40.5	51.2	2135
Chone	190.5	40.4	67.8	1175
Quevedo	586.1	21.6	35.9	2057
Montalvo	211.8	43.6	65.6	-
Milagro	722.1	20.3	26.5	1076
Machala	1034.6	30.1	32.3	389

(1) kgs dry cocoa per hectare
(2) Witches' broom disease (Crinipellis perniciosa) probably accounts for the major part of the remaining pod losses

THE CAUSAL AGENT

Name changes proposed by laboratory-bound mycologists are often more of a hindrance than a help to plant pathologists, and to field workers in general, who become confused by nomenclatural niceties and annoyed by having to learn new and often complex names for a familiar foe. Nevertheless taxonomy is a dynamic science and as more specimens and new techniques become available such changes are inevitable. Whenever feasible, old and recognised names should be conserved but, as with the present pathogen, this is not always possible.

The fungus was first studied scientifically by J B Rorer in Ecuador (1917-1925) and samples were forwarded to the USA for identification. Expert opinion at the time agreed that the cocoa pathogen was similar to species of the genus *Monilia*; well-documented fruit rot fungi of temperate zones. No further taxonomic work was carried out until E Parodi sent Ecuadorian material to R Ciferri in Italy who considered it to represent a new species of *Monilia* and described it as *M. roreri* in honour of Rorer (Ciferri & Parodi, 1933). It is perhaps not surprising that this taxonomic conclusion was never questioned because the fungus is superficially similar to several *Monilia* species both in macroscopic and microscopic appearance. It should also be emphasied that none of the mycological authorities had actually observed the fungus in the field but were working with dried specimens. More recently however, several characters were recognised which did not conform to the concept of the genus *Monilia* or its relatives and which, when taken together with the behaviour of the pathogen in the host, suggested that a more highly evolved parasite was involved. Detailed analyses, using both scanning and transmission electron microscopy, showed this to be the case since the asexual spores (conidia) are not formed in 'monilioid' chains (with the youngest spore at the tip) but in exactly the reverse manner. Further confirmation was obtained when the internal structure of the mycelium (fungal threads or hyphae) was found to be more typical of the mushroom group (Basidiomycetes) rather than the Ascomycetes to which *Monilia* species belong (Evans *et al*., 1978). Thus the cocoa pathogen was now identifiable as the asexual state of an unknown Basidiomycete fungus and a new genus had to be described in order to accommodate its novel method of spore formation. *Moniliophthora* was chosen as it was felt that the name was not too unlike the previous one and could be similarly abbreviated.

This, of course, has created further problems regarding the common name for the disease, often referred to as Monilia pod rot or Moniliasis of cocoa. Technically, the names are incorrect and in the past have only served to mislead since workers have tended to compare the cocoa pathogen with temperate *Monilia* species, whose biology is totally different, and to draw analogies which simply do not exist. Other names such as Quevedo disease, watery pod rot ('podredumbre acuosa') have been widely used but the latter should be avoided since this is not a unique symptom (Evans, 1981b). Several of the local Spanish names used by farmers in Colombia and Ecuador describe the powdery, whitish or frosted appearance of diseased pods which readily distinguishes them from pods attacked by the other important cocoa pathogens. Thus, frosty pod rot has been proposed as an alternative or common name to describe the disease (Evans, 1981a).

THE DISEASE

Moniliophthora roreri is a serious pathogen of cocoa pods, of longstanding, in both Colombia and Ecuador (Jorgensen, 1970), where it ranges from sea level to over 1000 metres and from very dry (irrigated) to very humid zones (Table 1). Estimates of disease incidence in Ecuador are highly variable and should be treated with caution but Rorer (1918; 1926) has quoted examples of over 90% crop loss and the total abandonment of cocoa cultivation due to the ravages of the Monilia disease. (Table 2). Colombian losses are probably more reliable and are put at 30-40% or a net loss of 21 million dollars annual revenue (Barros, 1981). Some recent data from Costa Rica show that losses there may be as high as 60-90% (Enriquez et al., 1981). In Venezuela, it is not regarded as a major disease because it is restricted to the western Andean region where relatively little cocoa is grown (Capriles, 1979). In its economic impact, therefore, M. roreri ranks with any of the other major pod pathogens.

In the field, M. roreri invades only young or expanding pod tissues but in laboratory and greenhouse experiments where abnormally high numbers of spores are used for inoculation, infection can be elicited in seedlings and flushes (Evans, 1981a). However, the fungus fails to sporulate on such tissues and this should be regarded as purely artificial infection, not relevant to field conditions. It is sufficient therefore to consider here only those aspects relating to pod infection.

Pods are usually most susceptible to infection during the initial three months of development and the first obvious symptom is the appearance of chocolate to dark brown, irregular lesions which rapidly coalesce to cover the whole pod surface. Some 3-8 days later, a white mycelial mat envelops the pod and gradually assumes cream, grey to brownish hues as the spore bloom develops. It is difficult to mistake this stage of infection with that of any other pod pathogen - the frosted pod covered by a powdery layer of easily dislodged spores - which together with the disorganised often watery internal contents, typically completely necrotic and valueless, constitute the classic symptoms of Moniliophthora pod rot. However, symptom expression is modified by a number of factors including pod age and host genetics. Certain varieties readily develop green swellings or distortions on the pod surface several weeks prior to lesion appearance, which is often preceded by premature ripening. It is frequently stated that pod swellings are diagnostic of M. roreri but similar growth abnormalities also occur on pods infected with witches' broom disease (Evans, 1981b). Hence care should be exercised in separating these two diseases in the field in the absence of sporulation. A useful test is to cut the newly necrotic pod in half and leave for several days. It is often difficult to cut an infected pod as the beans may be compacted together and to the inner pod wall due to the proliferation of extra tissues making the pod considerably heavier than a comparable healthy one. With both diseases a dense white mycelial skin (frequently with a mushroom odour) rapidly forms, but with M. roreri this is accompanied by the characteristic spore bloom. Conversely, the witches' broom mycelium never sporulates.

In pods infected at a later stage, external lesions are usually restricted in size and internal necrosis may be confined to the inner wall with little destruction of the bean mass. M. roreri attacks a range of Theobroma and Herrania species and significantly sporulation is most abundant within the bean chamber, particularly in those species with woody pods.

THE DISEASE CYCLE

The disease cycle is illustrated schematically in Figure 1.

The talcum powder-like qualities of the spore bloom mean that the dry (non-wettable) conidia are readily dislodged from the pod surface by any air or tree movement or rain, being immediately carried away by convection currents: a fact easily verifiable by simply blowing on or touching a freshly-sporulating pod and watching the resultant spore cloud swirl upwards into the canopy. Earlier reports of insects as major vectors, transporting spores to wounded pods, owed a lot to fanciful comparisons with true Monilia diseases and the initial failures to prove pathogenicity by conventional inoculation techniques. Unlike most pod pathogens, but in common with witches' broom disease, M. roreri penetrates the young pod without provoking an antagonistic reaction, and subsequently develops with it, growing between the host cells and often stimulating cambial activity which results in external swellings and the internal compaction of embryonic tissues. There, is thus, is a highly evolved parasitic phase during which the host does not recognise the fungus as an intruder and continues to develop, albeit abnormally. When growth begins to slow down, the fungus invades the cells of the tissues which it had previously colonised intercellularly. Internal necrosis and external lesion formation are, therefore, extremely rapid and this explains why it is impossible to salvage anything from such pods even though they may appear healthy because the damage had already been done over the prolonged colonisation period. The time span from the spore landing on the pod to visible necrosis varies from 45-90 days (Evans, 1981a). This unusual disease cycle hampered initial investigations into the real identity of the causal agent and resulted in erroneous conclusions as to its mode of dispersal and infection. Needless to say, inoculation experiments cannot be conducted in the laboratory nor on fully grown or mature pods in the field. This further hampers the study of the pathogen.

Freshly produced spores are relatively thin-walled and pale (hyaline) in colour, with time the wall thickens and the conidia assume a darker colouration which accounts for the variable colour of the spore bloom on the pod surface. Spores which are released during the first few days may be less resistant to physical damage (irradiation, desiccation) than older spores but generally conidia can remain viable for up to 9 months on or in hanging pods and retain a high infectivity. Those spores which fall into the soil, or remain on pods in the soil, survive for much shorter periods and infectivity tails-off after one month (Evans, 1981a). Infected pods quickly lose moisture, probably due to rapid uptake of water by the sporulating mycelium, becoming woody or mummified, and remain on the tree for up to several years. The spore bloom is gradually eroded by weathering and ultimately only the white mycelial skin persists. The fungus, therefore, has a mechanism for survival between crops or during unfavourable conditions, sufficient to 'oversummer' even through the extended 5-6 month dry season experienced in coastal Ecuador. Because rain or external humidity play no vital part in spore dispersal and pod colonisation and subsequent fungal sporulation, M. roreri is not restricted to wet environments or seasons. Pods infected at the end of the rains are able to sporulate 2-3 months later, in the middle of the dry season. Humidity is, of course, essential, for pod penetration and prolific sporulation but there would seem to be sufficient internal pod moisture to promote satisfactory spore production independent of external conditions. The pathogen can function therefore throughout the year, assuming that susceptible pods are available, and is less dependent on climatic factors than any other pod pathogen of cocoa.

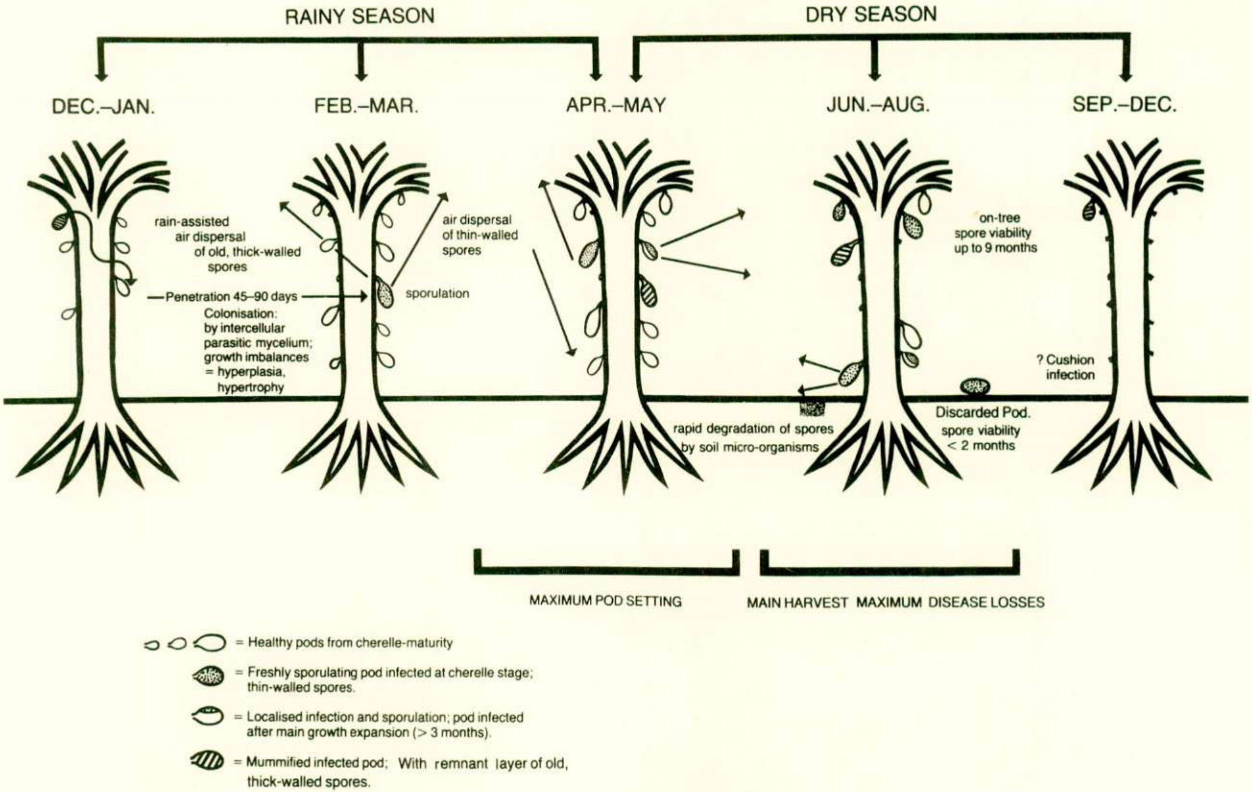
In western Ecuador, the cropping pattern is fairly rigid, by virtue of the well-defined dry season, so M. roreri survives between crops on mummified pods usually left in the canopy after the final harvest. The initial heavy rains probably serve to dislodge or wash the more persistent conidia from the mummified pods which then infect the few available cherelles. These sporulate approximately 2 months later, during the period of maximum flowering and pod setting. After a further 2 months, there is therefore an abundance of inoculum to infect the developing pods of the major crop. The cycle is completed.

DISEASE CONTROL

Good crop sanitation would appear to be the most logical and simple method of disrupting the disease cycle, thereby preventing the intercrop or interseason survival of the fungus. This is feasible in areas where the cocoa has a regular cropping pattern but is more difficult in irregular cropping cocoa because susceptible tissues are always available. Indeed, it only needs several out-of-season trees harbouring infection to invalidate or reduce the effectiveness of cultural control, since the symptomless systemic phase would go undetected during sanitary harvesting. Infected pods may be left on the soil without further treatment, although covering them may be advantageous if wet conditions prevail, though it is considered that the soil as an inoculum source is of minor importance. (Evans, 1981a; Cubillos, 1981).

As with witches' broom disease, chemical control of M. roreri has never given satisfactory results because the pathogen attacks rapidly-expanding, vigorously-growing tissues and it is difficult to maintain an adequate coverage on pods during the 3-month critical period. It has, however, been shown that protectant, copper-based fungicides can give economic control of Moniliophthora pod rot in Ecuador when applied to heavily-bearing trees (Cronshaw, 1979). More recently, Gonzalez et al. (1983) reported that similar products were uneconomic under Costa Rican conditions; disease incidence was

Figure 1. Schematic representation of disease cycle of *M. roreri* in a cocoa farm in western Ecuador



reduced only slightly even though there was a significant increase in yield. Once M. roreri has penetrated the pod, most fungicides are useless and the fungus can only be reached using erradicant systemic fungicides. No fungicide has so far been developed which functions within cocoa tissues against Basidiomycetes. The use of antisporulants is worthy of investigation but, because the fungus can mobilise the whole pod as a food source to promote extremely rapid and vigorous sporulation, this will be difficult to implement.

At the present time, therefore, cultural measures offer the brightest prospects for control of M. roreri and most work on this aspect of control has been carried out in Colombia. Significant reductions in disease incidence have been achieved using a range of agronomic recommendations, including weekly harvesting (Barros, 1981) and this has since been demonstrated in Costa Rica (Gonzalez et al., 1983). This 'cultural package' may be suitable for plantation systems but not for the typical Ecuadorian smallholder who harvests as few times as possible during the year. In these cases, losses may be reduced to an acceptable level by harvesting all pods towards the latter part of the dry season, thereby eliminating seasonal carryover both as mummified and living, systemically-infected pods. In the unfortunate situation in Ecuador, however, pods saved from potential Moniliophthora pod rot may only fall victim to witches' broom disease.

There is some circumstantial evidence to suggest that M. roreri can grow back into the flower cushion through the peduncle of a diseased pod and remain in a viable condition, subsequently infecting any pods borne on that cushion. This facet of pathogen behaviour remains to be proven but obviously it would complicate cultural control.

PAST AND PRESENT DISTRIBUTION

The disease may have evolved in the forests which cover the slopes of the western Andean cordillera of Colombia; a zone rich in Herrania and Theobroma species (Thorold, 1975). In such habitats, where typically there is a paucity of pods, internal sporulation may have been important in the life cycle of M. roreri, there being a steady liberation of conidia over a prolonged period as the pod walls gradually break open or crumble. As is shown later, internal spore production has serious implications for long distance dispersal of the fungus. M. roreri was probably disseminated aerially from this Andean centre of origin, throughout the western regions of both Colombia and Ecuador, wherever cocoa was cultivated. The pathogen is well-adapted to airborne dispersal having dry, powdery, thick-walled spores. Its rapid spread throughout Costa Rica, where the cocoa-growing areas are scattered, would seem to endorse this ability.

The much quoted example of the effect on cocoa yield of Moniliophthora pod rot in Ecuador is worth repeating (see Table 2). It shows the real decline in annual cocoa production of a large plantation from the first appearance of the disease in epidemic proportions in 1918 until cocoa cultivation was abandoned in 1920 and the land planted with bananas.

TABLE 2. Annual production of a plantation of 35,000 Trinitario cocoa trees in Ecuador (after Rorer, 1926)

Year	Tonnes	Observations
1916	29.923	'Monilia' not present
1917	32.685	'Monilia' not present
1918	10.404	'Monilia' appeared
1919	1.657	'Monilia' continued
1920	Nil	Cocoa cultivation abandoned

The arrival of M. roreri in Costa Rica may have been by airborne inoculum from Panama although it is more likely to have been introduced accidentally by man. This was the considered method of entry of the fungus into Panama (Orellana, 1956). M. roreri is admirably suited to this indirect method of dissemination. The long period of pod colonisation prior to the manifestation of visible symptoms demonstrates how an apparently healthy, systemically infected pod can be selected and transported for use as a source of planting material or, more dangerously, for trade or demonstration purposes to friends or family where no selection operates. As the pod ages and the mucilage contracts from the inner wall, a suitable environment is created for abundant internal sporulation with little or no external evidence of infection. A dramatic example was encountered recently at Kew when part of the bean chamber of a selected 'healthy' pod from Ecuador was found to be covered with sporulating mycelium of M. roreri. Almost certainly the pod had been infected towards the end of its growth cycle and consequently fungal colonisation had been restricted to a small section of the outer and inner walls.

Cocoa-collecting expeditions in the eastern or Amazonian region of Ecuador had never recorded the presence of M. roreri on cocoa until recently. The development of an oil pipeline during the last decade opened-up this previously remote area to colonists and 'improved' cocoa hybrids were introduced via pods from the other side of the Andes. The subsequent arrival of M. roreri was inevitable and entirely predictable (Evans, 1981a).

POTENTIAL DISTRIBUTION

Now that M. roreri is well established in the Napo region of Ecuador it must surely be only a matter of time before the pathogen reaches the more extensive plantings in the Brazilian Amazon. Its natural progress may be slow, since wild and planted cocoa has a scattered distribution along the headwaters of the Amazon, but Indian farmers or traders could hasten the process in the quest for better cocoa material or new markets. There are earlier erroneous 'citings' of M. roreri in Brazil (Wellman, 1972) and there was a recent scare in the Bahian region when a white, Monilia-like growth was observed on pods at the main experimental station. The latter fungus, however, turned out to be parasitic and was a secondary pod pathogen

(Botryodiplodia) which had invaded over-mature, unharvested pods.

A similar incident occurred more recently in Rondonia, a rapidly expanding cocoa-growing zone in the Brazilian Amazon, when suspected samples of M. roreri arrived at the Commonwealth Mycological Institute for identification. These, however, were found to be Geotrichum candidum, a cosmopolitan fungus and a known wound parasite of citrus fruits and vegetables. This is a new pathogen for cocoa, gaining entry into pods via insect wounds (Andebrhan et al., 1981), but cannot be regarded as a primary or obligate parasite and is unlikely to be a serious problem. Apart from the spores being produced in chains and its whitish appearance on the pod surface, G. candidum shares no other similarities with M. roreri.

Moniliophthora pod rot has not been identified as yet in Bolivia, the serious pod losses previously ascribed to this disease were found to be due almost entirely to witches' broom (Evans, 1981a), whilst its presence in Peru requires confirmation.

The chances of natural spread to Bahia and further afield seem remote because, although M. roreri is aerially dispersed, the geographic barriers are considerable (Evans, 1981b) and there is evidence to indicate that relatively high numbers of conidia are necessary for successful pod infection (Evans, 1981a). There remains, of course, the very real threat of long-distance dissemination by man. Two methods are possible: in or on pods, although these are unlikely to be moved inter-continentally; or on budwood or similar material. The powdery spores would readily adhere to such tissues and remain viable in this situation for many months. However, fungicide treatment would certainly reduce the inoculum and considerably reduce the chances of an unwanted introduction. As the fungus can only sporulate on pods the risk of spread is virtually eliminated when an intermediate quarantine station is involved, because the pathogen cannot proliferate and survive in the absence of mature cocoa trees. There is the remote possibility of contamination of budwood by systemic mycelium but, once again, the fungus would be unable to sporulate even supposing that it could be transferred successfully to a recipient plant.

In conclusion, therefore, Moniliophthora roreri invades only actively-growing cocoa pods and is a highly sophisticated, obligate parasite in sharp contrast to true Monilia species which generally are facultative parasites of wounded or predisposed tissues. It is a serious pathogen of cocoa causing considerable pod losses in north-west South America. It had been confined to the latter region until its recent incursion into the Central American isthmus. The fungus is well-adapted to air dispersal and long-distance movement via wind is a possibility, nevertheless, this is much more likely to be brought about by man's intervention. At present there is no satisfactory economic method of control which can be recommended.

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COCOA ABSTRACTS

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Management of coconuts and cocoa on acid sulphate soils.
CHEW POH SOON, KEE KHAN KIANG and OOI LING HOAK Highlands Research Unit, Klang, Selangor, Malaysia - Planter (Malaysia) 60 483-500; Nov 1984.
A unique characteristic of the cacao industry in Malaysia is the emphasis on the cacao-coconut system. The yield performances of underplanted cacao and a mixture of dwarf and hybrid coconuts in field on acid sulphate and non-acid sulphate areas in 3 coastal estates were compared. The cacao yields under the heavy shade of coconuts were about 365 to 465 kg per ha per year in the acid sulphate areas against 732 kg per ha per year in comparable non-acid sulphate areas. Coconut yields were 1762 to 2095 kg copra per ha per year against 2439 kg copra per ha per year respectively. Liming from pH 3.9 to pH 4.5 in the topsoil, increased copra content per nut and copra yields by 10 per cent and nearly doubled cacao yields. Management practices including fertilizer applications, leaf and soil analytical data and water management are also described and discussed.

Analysis of nesting boundaries of some dominant ants in cocoa trees in Nigeria.
ADEDEJI, F.O. Department of Biological Sciences, University of Ife, Ife, Nigeria - Cafe, Cacao, The (France) 28 (1) 43-46; Jan 1984.
This paper describes the preferred nesting territories (base, trunk or canopy) of four ant species living in cacao trees in Nigeria, i.e. Camponotus acyapimensis, Myrimicaria striata, Pheidole megacephala and Crematogaster despressa when present alone or in competition with other species.

Flower and fruit-setting patterns of cocoa trees (Theobroma cacao L) at three localities in Costa Rica.
YOUNG, A.M. Invertebrate Zoology Section, Milwaukee Public Museum, Milwaukee, Wisconsin, USA - Turrialba (IICA) 34 (2) 129-142; Apr 1984.
In Costa Rica monthly patterns of flowering and fruit-set were studied for large samples of cocoa trees at 3 localities. At all 3 localities, and regardless of shade cover, there was a marked decline in flowering near the end of the rainy season when rainfall was very high. When shade cover was thinned through leaf drop by the late dry season, fluctuations in flower production varied greatly in the following rainy season. At 2 localities in particular, there was a large peak in fruit-set coinciding with the burst of flowering in the first half of the rainy season. Multiple peaks of flowering and fruit-set occurred at all localities. Differences in levels of fruit-set depend upon the effects of climatic factors upon populations of pollinating insects at different localities. The incidence of the fruit disease Monilia increased during periods of high fruit-set and disappeared at other times of the year.

The feasibility of growing certain crops in Sabah.
MONTGOMERY, P.J. - Planter (Malaysia) 60 390-399; Sep 1984.
This paper gives some information on the feasibility of growing rubber, oilpalm, coconut, timber, cacao, coffee, tea, sugar-cane, tobacco and banana in Sabah. It is concluded that Malaysian plantations are attractive to investors because of the consistent massive appreciation of land values, which shows no signs of abating. This is applicable even with land on relatively short (33 years) leasehold. At the same time, depreciation of plant etc is minor compared to that of the chemical and manufacturing industries. As plantations are essentially very long-term investments, extreme caution must be exercised in the manner in which investment appraisal is undertaken. The discounted cash flow method is very suitable for investment of the depreciating type for making comparisons between investments. The three essential factors of production involving plantation inputs, viz. capital, land and labour are also discussed.

OCTOBER 1985

[Comparative study of the influence of two methods of management on the yield factors of a cacao farm] Etude comparative de l'influence de deux modes de conduite sur les facteurs du rendement d'une cacaoyere.
LACHENAUD, P.H., and MOSSU, G. Institut de Recherches du Cafe et du Cacao (IRCC), Abidjan, Ivory Coast -

Cafe, Cacao, The (France) 29 (1) p.21-30; Jan 1985.

In a study on the effect of the removal of shade on yield components of cacao in Ivory Coast, it was found that in the absence of shade the yield of healthy pods increased by a factor 2.47 because of more abundant flowering with, and greater losses without shade. No conclusion could be drawn on the possible effect of KP fertilizers on yield factors.

NOVEMBER 1985

[Influence of shade and management on the moisture content retention in an Oxisol with cacao] Influencia do sombreamento e manejo na retencao de umidade em um Oxisol cultivado com cacau.
LEAO, A.C. Divisao de Geociencias, Centro de Pesquisas do Cacau (CEPEC) Itabuna, Bahia, Brazil - Revista Theobroma (Brazil) 14 (2) 159-166; Apr 1984.
The annual variation of the moisture content of an Oxisol (Typic Haplorthox) in which cacao was grown under two types of shade and management was determined. Samples were collected bi-weekly for 11 months, from 3 different topographical positions, on 2 different slopes, at 0-20, 20-40, 40-60 and 60-80 cm depths. The moisture content was different under the types of management studied and between the 0-20 cm layer and the other layers. There was no difference in moisture content of the soils at the different topographical positions.

Cocoa drying and storage using charcoal and solar heated rocks.
BARYEH, E. Department of Mechanical Engineering University of Nairobi, Kenya - Agricultural Mechanisation in Asia, Africa and Latin America (Japan) 16 (1) 23-28 1985.
An effective cacao dryer cum-storage bin using as much local material as possible has been constructed. The dryer is durable and simple in construction. It does not use fossil fuel as a heat source but charcoal and the sun. Temperature rise of up to 100°C was possible. Testing temperatures were 50°C, 75°C and 100°C. After drying the cacao, the same equipment may be used to store the product for up to 5 months.

An assessment of pathological research on cocoa in Jamaica from 1950 to 1980 and current research priorities.
FAGAN, H.J. Cocoa Research Unit, University of West Indies, Mona, Kingston, Jamaica - Tropical Pest Management (UK) 30(4) p.430-439; Dec 1984.
Pathological research on cacao in Jamaica has been confined to black pod disease (Phytophthora palmivora) which is the main disease of cacao in the island and a major limiting factor to production. Experimental control of this disease with copper hydroxide has been obtained but the recommended programme is of doubtful economic benefit at the present productivity levels. Non-chemical control of black pod by more extensive use of locally available disease disease-resistant clones such as ICS1 and by newly introduced materials is being attempted. Priorities are outlined for future research on chemical control, fertilizer experiments for raising productivity levels and taxonomic studies of local Phytophthora strains.

[Dynamics and incidence of Forcipomyia spp. and pollination of cacao (Theobroma cacao) in Palmira, Valle] Dinamica e incidencia de Forcipomyia spp. (Diptera, Ceratopogonidae) en la polinzacion del cacao (Theobroma cacao) en Palmira, Valle.
FIGUEROAC, M.A. and CRUZ L.,J DE LA Universidad Nacional de Colombia, Palmira, Colombia - Acta Agronomica (Colombia) 34 (2) 42-52; Apr 1984.
The effect of rainfall and pruning on the population density of Forcipomyia spp. was determined and its pollinating activity in 5 cacao clones was studied. Pruning reduced populations of Forcipomyia spp. The pollinating activity was enhanced by rainfall as it maintainted the level of the humidity required for the development of the insect. Clone ICS-78 gave the highest number of flowers and clone SPA-9 showed the highest number of fruits and strongest activity of Forcipomyia spp. indicating a possible scarcity of pollinating insects.

Yield prediction of cocoa based on soil survey and land evaluation in Sabah on sedimentary soils : a case study.
LEE CHAI HAI Sabah Softwoods Sdn. Bhd., Tawau, Sabah, Malaysia - Planter (Malaysia) 60 533-538; Dec 1984.
The success of yield prediction based on soil surveys should be fully exploited to reduce investment risks. Agromanagement is important for improving yield in a particular soil situation. An appraisal of available experimental results within and outside

Malaysia can serve as guide for manufacturing policy, especially when the important pedological properties are understood. Soil maps at various scales to serve specific objectives are presented for the cacao growing area of Sabah.

[Seasonal abundance of phytophagous Coleoptera on cacao trees in Southern Bahia and Espirito Santo] Abundancia estacional dos coleopteros fitofagos do cacaueiro no Sul da Bahia e no Espirito Santo.
BENTON, F.P. Divisao de Zoologia, Centro de Pesquisas do Cacau (CEPEC), Itabuna, Bahia, Brazil - Revista Theobroma (Brazil) 14 (2) 85-102; Apr 1984.
The seasonal fluctuations of some Coleoptera populations belonging to the families Chrysomelidae and Curculionidae were investigated in cacao plantations. Monthly samples of insects were taken using the 12% BHC knockdown effect. In Southern Bahia *Colaspis ornata* occurred uniformly throughout the year. In the case of *Nodonota theobromae* there was a marked population peak in September-October, coinciding with the period of maximum leaf flushing of the cacao tree. The fluctuations of other insects, including *Conotrachelus curvicostatus*, *Lordrops aurosa* and *Lasiopus cilipes* were also investigated.

[Insecticides suggested as substitutes for BHC in pest control in cacao in Bahia, Brazil : a case study] Insecticidas sugeridos para substituir o BHC no controle das pragas do cacaueiro na Bahia, Brasil: um estudo de caso.
SORIA, S. DE J., CRUZ, P.F.N. and ABREU, J.M. Divisao de Zoologia Agricola, Centro de Pesquisas do Cacau (CEPEC), Itabuna, Bahia, Brazil - Revista Theobroma (Brazil) 14 (2) 103-114; Apr 1984.
A study was made to evaluate some insecticides as substitutes for BHC. The application of insecticides in the form of powders, is still the general practice, in contrast with fungicides, which are sprayed. A distinction is made between persistent and knockdown pesticides. In the category of persistent insecticides, the following compounds, in increasing order of cost price/ha could be recommended, viz. endosulfan 3%, carbaryl 5%, lindane 1.5% and carbaryl 7.5%. The less persistent insecticides, which could be recommended, comprised trichlorphon 2.5% and malathion 2%. The methods of application are also discussed.

[Relationship between climatic variables and cacao production on the Unit Farm at the Cacao Research Center, Bahia, Brazil] Algumas relacoes entre variaveis climaticas e a producao de cacau de Fazenda Unitaria do Centro de Pesquisas de Cacau, Bahia, Brazil.
HOEPPNER Z., M.M. and NICOLELLA, G. Divisao de Metodos Quantitativos, Centro de Pesquisas do Cacau (CEPEC), Itabuna, Bahia, Brazil - Revista Theobroma (Brazil) 14 (2) 143-147; Apr 1984.
The cacao production-weather relationship was studied during 11 years (1970/71 to 1980/1). Initially, linear correlations between the monthly cacao production and different climatic factors were studied. In addition, linear correlations between the cacao crop and the monthly climatic factors of a year earlier were studied. A set of 8 climatic variables represented by climatic factors, or linear combinations of these, was chosen by maximum correlation. Afterwards the best subset of these variables in regression was selected. The criteria for determining the best subset regression were the maximum determination coefficient, maximum adjusted coefficient and the C_p statistics of Mallows.

[Incompatability in cacao clones EEG 13 and EEG 65] Incompatibilidade em cacaueiro clones EEG 13 e EEG 65.
YAMADA, M.M. and BARTLEY, B.G.D. Divisao de Genetica, Centro de Pesquisas do Cacau (CEPEC), Itabuna, Bahia, Brazil - Revista Theobroma (Brazil) 14 (2) 167-169; Apr 1984.
Self-incompatibility was shown to occur in the clones EEG 13 and EEG 65. This is the first report of the phenomenon in clones selected in the original cacao population of Bahia and Espirito Santo, Brazil. These clones are inter-incompatible. Various hypotheses are proposed to explain the appearance of self-incompatibility in these clones.

[Toxicity of insectides to Diptera, Hymenoptera and Arachnids of cacao plantations in Bahia, Brazil] Toxicidade de inseticidas para dipteros, himenopteros e aracnideos associados aos cacuais de Bahia, Brasil.
CRUZ, P.F.N. DA and SORIA, S. DE J. Divisao de Zoologia, Centro de Pesquisas do Cacau (CEPEC), Itabuna, Bahia, Brazil - Revista Theobroma (Brazil) 14(2) 171-173; Apr 1984.
Five insecticides were evaluated for their effects on parasites and/or

cation vegetative du cacaoyer: note sur une methode d'obtention de boutures a enracinement orthotrope.
AMEFIA, Y.K., CILAS, C. and DJIEKPOR, E.K. Groupe de Recherches sur le Swollen Shoot du Cacaoyer, Institut de Recherches du Cafe, du Cacao et Autres Plantes Stimulantes (IRCC), Kpalime, Togo - Cafe, Cacao, The (France) 29 (2) 83-88; Apr 1985.
A cacao tree vegetative propogation trial trial by cuttings of orthotropic suckers, induced by bending on subjects derived from seeds, has shown that it is possible to obtain the formation of taproots. Naphylacetic acid used at a concentration of 10^{-5} g/ml and exuberone used as rhizogenesis promoters gave the best rooting rates. Bending plagiotropic cuttings causes the formation of an orthotropic sucker at their base. The plants obtained from these orthotropic axis cuttings had a vertical habit when planted out, and seemed to form their crown early.

[Long-term effects of insecticide treatments on pollination conditions and cacao production in Ivory Coast] L'action a long terme des triatements insecticides sur les conditions de pollinisation et sur la production du cacaoyer en Cote d'Ivoire.
DECAZY, B., COULIBALY, N. and MOSSU, G. Centre de Recherches de Bingerville, Institut de Recherches du Cafe, du Cacao et Autres Plantes Stimulantes (IRCC), Bingerville, Ivory Coast - Cafe, Cacao, The (France) 29 (2) 99-106; Apr 1985.
The long-term effect of the insecticide quinalphos on pollination and flowering conditions and cacao production of 2 hybrids (UPA 402 x UF 676 and UPA 603 x UF 667) in Ivory Coast was studied over 2 consecutive years. Quinalphos was applied at a rate of 480 g/L per ha, either every month or 4 times a year. Treatments had no effect on flower production or pollinating insect fauna. An increasing treatment frequency increased cacao yields. The effect on fructfication hazards was significant.

[Research Report 1983] Informe de Gerencia 1983.
MONCAYO, F.G. Instituto Colombiano Agropecuario (ICA), Ministerio de Agricultura, Bogota, Colombia - 225 p. 1984.
The research activities in the agricultural and livestock husbandry fields in 1983 are reviewed. The release of new varieties, such as predators of cacao pests. The compounds were applied as powders and included carbaryl 7.5% at 1200 g a.i//ha, isoprocarb 4% at 640 g a.i./ha, BHC 1.5% at 240 g/ha, trichlorphon 2.5% at 400 g/ha and fenitrothion 1.5% at 240 g/ha. The results showed mortality rates in decreasing order, viz. carbarl 60.4%, fenitrothion 43.4%, BHC 43.0%, isoprocarb 34.0% and trichlophon 21.0%.

DECEMBER 1985

[Effect of fermentation on the peroxidase and polyphenoloxidase activities in cacao beans] Effet de la fermentation sur les activites peroxyidases et polyphenoloxyidases de la feve de cacao.
VILLENEUVE F., CROS, E. and MACHEIX, J. Laboratoire de Chimie et de Technologie, Institut de Recherches du Cafe, du Cacao et Autres Plantes Stimulantes (IRCC), Montpellier, France - Cafe, Cacao, The (France) v. 29 (2) 113-120; Apr 1985.
The rate of peroxidase and polyphenoloxidase activity in cacao beans during 1, 2, 3, 4 or 5 days of fermentation was determined resp. with a spectrophotometer and with an oxygraphe. Both enzymatic activities were mainly located in the cotyledons and both activities decreased after 2 days. Loss of peroxidase activity probably results from changes in pH and temperature during fermentation. Loss of phenolic compounds, observed between the 2nd and 3rd days, is therefore not explained by enzymatic oxidation.

Effect of Helicotylenchus dihystera on growth of cocoa seedlings.
YUEN PAK MUN Crop Protection Branch, Malaysian Agricultural Research and Development Inst. (MARDI), Serdang, Selangor, Malaysia - MARDI Research Bulletin (Malaysia) 11(3) 305-308; Dec 1983.
An initial inoculum level of 2800, 3500 and 4200 Helicotylenchus dihystera did not significantly depress growth of Upper Amazon seedlings after 4 and a half months in the following variables: dry weight of leaves, stem and roots, total dry weight, leaf number and plant height. Fine soil population of nematodes exceeded numbers encountered in cocoa plantings.

[Vegetative propagation of cacao: note on a method for obtaining cuttings with orthotropic rooting] La multiplicotton var. Gossica P-11 (resistant to Pseudomonas malvacearum) and Gossica N-23 (with excellent fibre quality), maize like cv. JCA H213, resistant to lodging, and JCA V304 (for the high altitudes), wheat like JCA, Susuta, sesame cv. Sesica-M11, soya bean, forage legumes and sorghum varieties, is discussed. Research on oil crops, including oil palm, fruit crops, cattle, pigs (artificial insemination) mechanization and rural development activities, covering 56, 415 families is reviewed. In addition the activities in the fields of agriculture plant protection measures against coffee rust and zootechnical fields are reviewed.

JANUARY 1986

A comparison of soil test methods for estimating available soil boron in cocoa growing areas of Southwestern Nigeria.
CHUDE, V.O. and OBIGBESAN, G.O. Department of Agronomy, University of Ibadan, Nigeria - Beitrage zur Tropishchen Landwirtschaft und Veterinarmedizin (Germany D.R.) 22 (3) 245-254.
The extractable B was determined in 46 soil samples (surface and sub-surface) from 23 cacao growing areas in Southwestern Nigeria. The methods used were: (1) hot water extraction; (2) extraction by means of 0.1% $CaC1_2$ solution; and (3) extraction in ammonium acetate (normal, pH 4.8). The mean extracted amount of B decreased in the order hot water > $CaC1_2$ > NH_4-acetate. There is no significant correlation between the extracted B amounts. The amount of B taken up by tobacco plants comprised only 3.2% in NH_4 acetate 4.7% in $CaC1_2$ and 22.6% in hot water, out of the total B amounts extracted. The deficiency range for boron in cacao was found to be 0.44 to 0.88 ppm with hot water extraction, 0.56 to 1.12 ppm with $CaC1_2$ extraction and 0.03 to 0.44 ppm with ammonium acetate extraction, respectively.

FEBRUARY 1986

Approaches to the control of diseases of cocoa in Papua New Guinea.
PRIOR, C. Cocoa Industry Company, Rabaul, Papua New Guinea - Planter (Malaysia) 61 306-315; Jul 1985.
Papua New Guinea's cacao is produced by plantations, both privately and company owned, and by smallholders on land owned by themselves or their village or by blockholders on land leased by the government. The hybrid cacao currently recommended for planting in Papua New Guinea has resistance to vascular-streak dieback (VSD) but is susceptible to Phytophthora stem canker. The diseases, control options and the use of them, research on disease control and future consequences are discussed. Both VSD and canker can be managed adequately by chemical or cultural means or by resistance. Once blackpod is established an expensive spray programme is required to maintain yields. Since spraying is not carried out by smallholders or some plantations there is a strong argument for large-scale exploitation of a very limited range of black pod resistant material. To achieve more knowledge about races or variability in the fungi concerned, resistance must be identified and checked, therefore it is recommended to develop routine screening procedures. Resistance is the best solution for pest and disease problems of the growers.

MARCH 1986

Biochemical and physiological aspects of leaf development in cocoa (Theobroma cacao) Water relations and abscisic acid in the control of leaf development.
ABO HAMED, S., COLIN, H.A. and HARDWICK, K. Department of Botany, University of Liverpool, Liverpool UK - Cafe, Cacao, The (France) 29 (3) 155-162; Jul 1985.
The present study investigates the possible relation between cacao leaf water status as measured by leaf water potential, relative leaf water content and stomatal diffusion resistance, and ABA (abscisic acid) levels. It was found that in well-watered plants ABA decreased in the same period whereas in dry plants both free and bound ABA decreased to a considerable extent. The period of apical dormancy was extended in the dry plants but was broken before rewatering. The relations between leaf water status, apical dormancy and ABA levels may have implications for the interaction between nutrients, carbohydrate levels and ABA synthesis, a subject which is currently under investigation.

Cocoa production and processing in Ghana.
AWUA, P.K. and AGBLEZE, G.K. - 36p.
This study briefly describes the history of the cacao industry in the world and in Ghana, and reviews the

literature on its production, pest and diseases, harvesting, fermentation and subsequent processing, and the chemical changes which take place during the latter operations. This paper was presented at the Seminar on agro-based industrialisation, held in Lagos in Nigeria, from November 4th to December 3rd 1983.

Trial shipment of coffee and cocoa from Papua New Guinea to evaluate (a) in-container CO_2 disinfestation and (b) techniques to prevent condensation damage: CoCof 79.
SHARP, A.K. and GREVE, J. VAN Division of Food Research, CSIRO, North Ryde, New South Wales, Australia - Technical Paper - CSIRO Division of Food Research (Australia) no. 47, 39p. 1985.
Steel containers loaded with coffee were treated with CO_2 for disinfection purposes. After 18 days the Co_2 concentration had dropped from an initial 90% to 5%. A few Sitophilus spp. but no Tribolium castaneum survived this treatment. In a second experiment with improved slow release of Co_2 final CO_2 concentration was 36% while no insects survived. In an experiment comparing cacao quality after transport in either unmodified general-purpose steel containers or containers with 8 large vents and a plywood ceiling lining or smaller vents, respectively, only the larger vents were found to be effective in preventing the development of heavy container sweat.

Annual Report 1984. International Board for Plant Genetic Resources (IBPGR), Consultative Group on International Agricultural Research (CGIAR), Rome, Italy - 135p; Mar 1985.
Activities conducted in the field of germplasm of cereals, food legumes, roots and tubers, vegetables, fruit and tree nuts, industrial crops, including cocoa forages and trees are reported as well as regional activities in Africa, East Asia and the Pacific, Europe, Mediterranean, Latin America, South Asia, Southeast Asia and Southwest and Central Asia. Aspects such as conservation, information and data management, training and administration are separately treated.

The effects of cocoa cultivation on some physical properties of soil in south-western Nigeria.
EKANDE, O. Department of Geography, University of Ife, Ife, Nigeria - International Tree Crops Journal (UK) 3(2-3) 113-124 1985.
Bulk density, total porosity and particle size distribution (percentages sand, clay and silt) of soil under cacao in a part of the main cacao growing region of south-western Nigeria, were studied and compared with the properties of adjacent forest soils. This study revealed highly significant differences in bulk density and total porosity, which means that if tropical rainforest is opened to cacao, soil compaction will take place over the years. Under cacao plantation, percentage of sand content increases and percentage of clay decreases, both in topsoils and subsoils. This poses a serious threat to soil fertility. This degradation of soil physical properties may have hindered the success of rehabilitation efforts of cacao plots in most parts of south-western Nigeria. It is suggested that natural, rather than artificial soil improvement techniques shuld be adopted to maintain the physical properties of soil under cacao plantations.

[Survey on insecticide tolerance of cacao tree mirids in Cameroon] Enquete sur la tolerance des mirides du cacaoyer aux insecticides au Cameroun.

BRUNEAU DE MIRE, P. Institut de Recherches du Cafe, du Cacao et Autres Plantes Stimulantes (IRCC), Montpellier, France - Cafe, Cacao, The (France) 29 (3) 183-196; Jul 1985.
LC 50 values of mirids were compared using one population which had been sprayed regularly and one population which had not been sprayed for 3 years. The effects of 3 pesticides were investigated. It was found that isoprocarb had not induced resistance or tolerance. Resistance to lindane had developed in an isolated spot submitted to heavy insecticide exposure. Resistance to diazinon (disulfoton) never reached a critical level but had become rather general and to an extent which warrants close supervision. Resistance to insecticides was favoured by their application in a mixture with a fungicide; this practice should, therefore, be abolished. Tolerance to insecticides disappeared after 3 years without treatment. It is strongly recommended to alternate the utilisation of insecticides belonging to different groups regularly and monitor their efficiency systematically.

Growth response of mycorrhiza cocoa seedlings in soil; POME mixture
Azizah Chulan, Aini, A. and Omar, M. Soil Science Dept., University Pertanian Malaysia, Serdang, Selangor, Malaysia - Planter (Malaysia) v. 61 (714) p. 409-416. Sep. 1985.

The ability of the mycorrhizal fungus Gigaspora calospora to improve growth in cacao seedlings was tested in 2 soil series, viz. Serdang and Mungchong. The soils were fertilised with palm oil mill effluent (POME), at rates of 0, 25, 50, 150, 250 or 400 g/3 kg of soil, or with NPK at 60-60-60 kg/ha (0.13-0.13-01 g/3 kg of soil. Seedlings responded well to POME and mycorrhizal treatments. Plants in the POME-Mungchong soil mixture gave a better response to mycorrhizal inoculation than plants in POME-Serdang soil. Application of 150g POME to 3 kg of soil was found to be equivalent to NPK application at 60-60-60- kg/ha.

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