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Pest control in Malaysia's perennial crops: A half century perspective tracking the pathway to integrated pest management

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Abstract

Leaf eating insect outbreaks of unprecedented severity occurred on oil palms and cocoa in what became Malaysia, from the late 1950s to early 1960s. Growers faced two crucial questions, what to do about the attacks, and what caused them. The tropical climate generally continues suitable for phytophagous insects to realise their large increase capacity, a factor emphasised in the stable agroecosystem of perennial tree crops. Parasitic and predatory natural enemy insects are equally favoured and maintain control. It became increasingly evident that the prime cause of outbreak was disruption of this balance by the introduction of broad spectrum, long residual contact insecticides (bslrcs), with various contributory factors. Patchy pesticide residues would continue to eliminate inherently exploratory parasitic and predatory insects, something worsened by uneven initial application. In these conditions, there is a complete overlap of generations of both pests and enemies, with no evolution of synchronised or otherwise coordinated life cycles ('continuous generation mode' – CGM). In outbreaks the pests tend to be at a similar lifecycle stage ('discrete generation mode' – DGM), so that at times a high proportion of an enemy population that may be building up cannot find a suitable host stage.

Simply stopping application was often enough to end the vicious circle of treatment and reoutbreak, but also, commonly, there was heavy damage in the meantime. Selective application was developed, involving inherent pesticide characteristics or method of use opposite in at least one aspect to bslrc (i.e. narrow spectrum, short residue life, or non-contact). Large areas were treated, e.g., from the air. Infestations mostly disappeared with only one or a few applications. In that era of the 1960s, chemical application compatible with biological control was known as 'integrated control'.

The bslrcs had been introduced to control other regularly occurring pests ('key' pests), limited localised build up of the target pests e.g., from climatic fluctuations ('occasional' pest), or as a 'precaution'. Some species only appeared after disruption started ('potential' pest). Development of selective chemical control continued to be for key and occasional pests, aiming at effective kill once decided upon. Census monitoring ensured application only when justified economically, with timing to the most vulnerable stage in the pest lifecycle.

Among non-chemical approaches, cultural methods include provision of suitable flora in the ground vegetation for food sources for adult parasitic insects. Reasonably dense ground vegetation cover is grown to suppress rhinoceros beetle damage in oil palm replantings. Other possibilities include dissemination of insect diseases, traps and attractants, and resistant plant types. This fitted 'pest management' which by the mid-1970s came to encompass selective chemical use, as 'integrated pest management (IPM)'.

There were similar developments in other parts of the world, and in other perennial tree crops, extended also to short term crops (e.g., rice and vegetables). IPM is not an esoteric methodology awaiting 'complete knowledge'. It can be applied on the basis of principle and existing knowledge for the most reliable economic control, targetted to encompass any aspect, such as toxicology and environmental effects.

Introduction

The cultivation of tree crops in plantations in the humid tropics has grown up over recent centuries in parallel with international trade. In South East Asia at the middle of the 20th century, rubber was the predominant tree crop, reaching about two million ha in Malaysia alone. Oil palm (*Elaies guineensis*) plantations had been developed from about 1920 (some decades earlier in Sumatra), and by the mid-1950s had reached about 45,000 ha in large estate blocks distributed over various parts of the peninsula. Cocoa was grown in pilot plots in various regions, including what became Sabah, a Malaysian state in north Borneo, from around 1950. Defoliating pests were known to infest all of these, and other tree crops. Accounts of the identities and habits of some of the commoner ones are given in texts of that era e.g., Dammerman (1929), Corbett & Miller (1933), and Kalshoven (1950–1951), but none had ever been considered a major constraint to growing the crops.

In the mid-1950s, severe attacks of defoliating caterpillars, mainly but not entirely bagworms (Psychidae) and nettle caterpillars (Limacodidae), occurred in several separated localities. Some became widespread and recurrent, and the loss of leaf was inevitably followed by serious crop loss for a prolonged period. At much the same time, the pilot projects of cocoa in Sabah became inundated with pests, mainly defoliators, of a range of groups, including caterpillars and others.

With an apparently increasing risk of outbreak, crop loss, and control expense, the growers faced two key questions – one, how best to halt an infestation, and two, what were the reasons for the change, that is, the cause of the outbreaks. Most growers, with practical and economic interests at stake, naturally saw the first as the most urgent, but those who had the job of finding and recommending effective control measures, recognised the crucial significance of the second question. It became apparent that the measures being applied could worsen the situation, and indeed were implicated in causing outbreaks. The recognition of the ecological principles in this was the basis for the integrated pest management (IPM) procedures developed for those crops over succeeding decades, with implication for other tropical tree crops in the region, and further extension into other regions and crops. This experience is the theme of this review.

The early days

Oil palms

Caterpillar outbreaks of an extent and intensity not previously experienced began to occur from about 1956. The bagworms reaching outbreak proportions on occasions were *Metisa plana*, *Cremastopsyche pendula* and *Mahasena corbetti*, and nettle caterpillars, *Setora nitens* and *Darna trima*. A description of the attacks, their biology in relation to oil palms, and a listing of other species that became common but not necessarily in outbreak proportions, is given in Wood (1968).

A preliminary study noted huge upsurges of insects of various groups, and recommended a more thorough investigation (Rao 1962). An entomologist was recruited in 1962, the first in the world specifically to deal with oil palm pests (Pearson 1968). An early step was a review of the history of the outbreaks and measures taken to date, in the context of experience building up globally, including personal exposure (e.g., Wood 1963). This clearly, albeit circumstantially, implicated the application of broad spectrum long residual contact insecticides (bslrcs) as a precursor to the original outbreaks, and a cause of recurrence, often after a period of 'control'. The underlying cause is the disruption of the balance between pests and their natural enemies, which is elaborated below (see also Wood 1965, 1968, 1971a, b, 1976a; Conway & Wood 1964; Conway 1968, 1972). At that time the insecticide groups most likely to contain chemicals with the characteristics to cause this disruption were organochlorines and organophosphates. As an aside at this point, many are now proscribed for toxicological reasons. Even so, the lessons about insect pest/natural enemy balance remain, and some modern toxicologically more acceptable pesticides have equal capacity to cause disruption to natural balance. In the oil palms, endrin had been widely used, and DDT and dieldrin to a lesser extent.

These chemicals kill insects, and have a high risk of removing insect natural enemies more thoroughly than the target pests. Application against an outbreak might well achieve the intended effect of elimination, but it set the scene for reoutbreak, often more intensive and widespread than that treated. In some localities, recurrent spraying was being practised with apparent necessity, with periods of varying length of 'remission'. If the sprays caused the outbreaks, why were they done in the first place? These bslrcs were relatively new chemicals in those days, and as they became available, they tended to replace any that might have been used before that lacked the disruptive effect (see *Integrated chemical control* and *Chemical characteristics for blanket spraying*). Then, minor upsurges were treated, of the pests that themselves later became serious or of others such as leaf-eating cockchafers. Warnings circulated of 'new pest threats', and growers, especially if there were problems in the vicinity, might do 'precautionary' sprays against minor increases, prophylactic inclusion of an insecticide in a fungicide spray, and so on.

Cocoa

Pilot projects were established in Sabah in the 1950s, and commercial plantations were established from 1956, expanding to about 2500 ha within 10 years. It was planted mostly where natural forest had been felled for timber, with some non-commercial trees retained as cocoa shade. In a government R&D planting, in the period 1958–1960, problems with caterpillars, the ring bark borer (*Endoclita hoseii*; Hepialidae) and branch borers (*Zeuzera* spp.; Cossidae), occurred. From about 1961, these were tackled with bslrcs (particularly DDT and dieldrin). The problems did not improve, and attacks by defoliators began to occur (Conway 1971, 1972). These new attacks were of a severity not previously experienced in the crop, and included some species that had not until then been recorded at all. With recurrent spraying, increasingly well applied, some pests declined, but others became more common leading to frequent defoliation. As in oil palms, bagworms (Psychidae) were a particular problem at this time. Other plantations followed the lead of the R&D centre, and a similar cycle of events occurred, whilst those who did not use these chemicals had at most only limited problems with the pests that had earlier led to initiation of chemical application.

Evidence of the role of pesticides

The circumstances

Broad spectrum implies a wide range of insects killed (physiological susceptibility) including groups containing natural enemies as well as pests; long residual implies that insects may be killed for some time after the immediate application; and contact implies kill of insects touched by the chemicals, including deposits on plant surfaces. The basic chemistry of pesticides therefore governs the likelihood that particular natural enemies will be strongly affected. Susceptible natural enemies may be killed by residual deposits upon entering after application, probably more so than pests because their activities characteristically are exploratory, to find hosts. Even if the spray largely eliminates the pest, the latter may thus resurge before natural enemies can build up. Poorly applied sprays can exaggerate this chance since uneven deposits remove and continue to exclude enemies, but leave patches for pest survivors to commence reincrease. This was no doubt a factor in both of these crops. Oil palm has a large crown (diameter 10 m or more at maturity, from about the 5th year in the field), which gets progressively higher (roughly 0.3 m height gain per year). Systematic coverage with powered knapsack sprayers, the only equipment available that could be taken into most of the terrain at that time, was very difficult. The cocoa mostly was still young, but becoming dense, which presented similar problems for efficient coverage.

The evidence to date was circumstantial, involving regular finding of outbreak where the chemicals had been introduced, but very little incidence where they had not. Alternative explanations were put forward. A special susceptibility of extensive monocultures undoubtedly is a factor in the rapid spread of infestation once it gets going, but severe attacks also affected small plantings, especially of cocoa (oil palm is rarely grown in small patches). Potential pests suddenly finding a conducive environment can also be suggested, but is difficult to justify where several different species 'explode' and decline at the same time, in situations usually free of incidence. Subtle changes in crop or physical environment could be excluded on much the same grounds.

In a global context, unease about the use of chemical pesticides on grounds of killing insect natural enemies had existed for some time for theoretical reasons, e.g., Wigglesworth (1945) soon after the introduction of DDT etc. to agriculture, and from early practical cases, e.g., Ripper (1956). Other cases of pesticidally induced outbreaks were occurring in tropical tree crops, including cotton in

Peru and tea in (then) Ceylon, reviewed together with the present cases by Wood (1971a).

Insecticidal check

A variation of the insecticidal check technique was tried with oil palm bagworms. The technique was devised for citrus scale insects, showing huge increase in numbers on individual trees given low dosage DDT sprays (DeBach 1955; Wood 1963). Caterpillars seemed less suitable for the test with more mobile pests on interconnecting crowns, but it was tried in an area of oil palm with an active but not then severely damaging bagworm incidence. A c 0.8 ha patch was recurrently sprayed with endrin. The bagworm clearly built up there whilst declining in the area at large. The boundary of the treated area was not so clearly delimited as in the citrus cases due to gradual spread outwards of the pests, but numbers clearly were much higher in and around the sprayed patch in succeeding generations (Wood 1971a).

Action taken

The context

The key questions, cause of outbreaks and what to do about them, existed in parallel. Whether growers accepted the explanation of cause at that time or not, their first priority was to terminate the outbreak. Crop volume and even the trees themselves were (or could appear to be) under severe threat. An obvious step, with realisation of the cause, was just to stop spraying, but that was not always followed by immediate restoration of the largely pest free status, for reasons gradually becoming clearer (see *Ecological principles in the global context*). Spraying could be effective in terminating outbreak in the short term, if done properly, even if it might lead to a cycle of control and reoutbreak. Some growers were ready to contemplate that as a regular feature, emphasising the need to find chemicals and methods to most effectively kill the pests. The best solution though, lay in finding active measures to reduce pests whilst allowing best chance for natural enemy populations to restore. In other words, selective measures. This was generally achieved, and the principles came quite quickly to be accepted and acted on in these crops.

Stopping spraying

In the oil palms, the recommendation to stop the spraying of bslrcs was made from the end of 1962. Residual populations of bagworms and nettle caterpillars continued to flare up, sometimes to damaging numbers. Mostly though, they just disappeared, or fluctuated for a time, but within 'tolerable' levels. Where observations were possible, a range of parasites and predators attacked the caterpillars (see *Background or silent natural control*). Thus some estates significantly affected earlier, had no further serious build up, but in others, the pests increased to the point where clearly severe damage was being done, with apparent risk of spread.

In cocoa, spraying of bslrcs was stopped in most properties from late 1961. There was then a period of evident pest activity, but within a year most were rapidly declining, clearly in association with build up of insect predator and parasite numbers. In some cases, some species remained at damaging levels and others increased to that.

Releasing natural enemies

This was contemplated, but not much was known about the relative importance of particular enemy species at various population levels, nor was there any evident way to create a source of them. Occasionally, a clearly parasitised stage could be collected and kept to allow enemies but not pests to re-enter the crop, e.g., cocoons of nettle caterpillars from as early as the 1920s – see Cock (1987) for review. There is little information on effectiveness, and probably there is usually not much advantage since enemies if potentially effective, would rapidly build up unaided.

Integrated chemical control

At that time, the term 'pest management' was not current. 'Integrated control' was going through a transition in meaning, from implying suitable use of chemicals together with manipulated biological control (Stern *et al.* 1959), to covering any specific control measures compatible with sustaining environmental control, particularly natural enemy activity (Smith 1968). In the present case, the term was used to cover chemical application to reduce damaging infestations whilst allowing continuing restoration of self-sustaining biological control, referring to the broad approach as 'ecological' (Wood 1971b). Suitability of chemicals for this might lie in their intrinsic characteristics, or the way of use. Predisposing characteristics are the opposite to those causing upsets. That is a narrow spectrum of toxicity, more against the pest insects than their enemies, and fugitive (short lived) contact residues, or no contact action e.g., stomach poisons. This is not an exhaustive list but it covers the main general features, particularly those accessible for the early situation (see Bartlett 1963, 1964; Conway & Wood 1964; Wood 1973, 1976a).

Trials in oil palms had shown that lead arsenate, a stomach poison was moderately effective directly against the caterpillars, though less so immediately than the bslrcs. For example, one oil palm block had a history of outbreak of the nettle caterpillar, *Darna trima* (Limacodidae), going up to 3–400 caterpillars per frond, alternating with endrin sprays, up to mid-1962. When spraying then ceased, the pest was common but did not threaten serious loss until in 1964, it flared up to numbers over 800 per palm frond. Lead arsenate was applied, which was followed by a rapid decline of the pest, and no further incidence. Similarly with a previous bagworm 'outbreak area' (*Metisa plana* mainly) where spraying had ceased, after apparent restoration of balance, a crop threatening outbreak built up through 1964–1965. About 400 ha was aerially sprayed with lead arsenate. Pest numbers declined quite gradually, and no further treatment had to be considered. Despite its enormous increase potential, only isolated individuals continued to be found (Wood 1973).

In Sabah cocoa, trichlorfon (Dipterex), which claimed some insect group selectivity with short life contact residues, was tested and it proved effective against many of the chewing insects. It brought down the bagworms that had continued to infest the cocoa after use of bslrcs was stopped, a process observed to be accompanied by intensive activity of parasitic insects (Conway 1972).

The same chemical proved effective against some of the more conspicuous oil palm insects, and was used against bagworms in reverberations from previous incidence or the few new outbreaks (of occasional pests – see *Ecological aspects of pest incidence and control*), for several years. Generally, one spray was enough to terminate build up without subsequent recurrence (Wood 1971a).

Ecological principles in the global context

The agroecosystem

During this period, the integrated control approach was developing globally, defined by Smith (1968) as application of control techniques in as compatible a manner as possible. He propounded two fundamental precepts, *viz* consider the agroecosystem, and utilise economic damage levels. The first had immediate obvious relevance to the Malaysian situations, initially by unwittingly ignoring it, and then the rectification by some comprehension of it, a comprehension building up in parallel with action chosen as the most appropriate available at the time. The key agroecosystem characteristic was the existence of numerous species of defoliators with a very large and rapid reproductive potential (often hundreds- or thousands-fold, in a generation time of a few weeks at most), in an environment physically continuously suitable to its realisation. Usually however, they were constrained to very low numbers by insect natural enemies, whose reproduction was equally favoured by these conditions. Anything disrupting the control exercised by those enemies was liable to unleash severe pest upsurgences. The next limit to increase can be total destruction of the food source.

Further aspects of the agroecosystem are summarised e.g., by Wood (1971a, 1973, 1988). An important point is the tendency of outbreak to continue once set off. Where the natural balance prevails, rare pests are controlled by rare natural enemies (DeBach 1964). Once the pest explodes there is a time lag before the enemies can 'catch up'. In the wild vegetation where these pests and their enemies have evolved, there has been no pressure to lifecycle coordination, such as often characterises plant feeding host insects and their insect enemies in more seasonal conditions. The hosts exhibit complete spread of generations, so natural enemies that infect particular stages have an equal chance of finding a suitable host whenever they emerge. In upsurges, there is usually a cohort of pests at a similar stage of development. These two can be defined as continuous generation mode (CGM) and discrete generation mode (DGM) (Godfray *et al.* 1987), also 'multiphase' and 'single phase' (e.g., Wood 1976b). The leaf eaters in the more serious outbreaks in the oil palms were noted to be in DGM, with various implications. First it is a reason why outbreaks may resurge – a predominant cohort may persist in numbers reduced but not eliminated for some generations, and then have opportunity for a fuller realisation of the reproductive potential, e.g., see Wood (1987a). The enemies themselves by being more numerous (in proportion to host numbers) between these main generations can actually reinforce DGM, something that may be involved in occasional pest flare ups not provoked by any control action. Chemical control too may reinforce DGM by being more effective against some phases in the lifecycle than others. This, on the other hand, also emphasises the need for good timing to get the best from selective applications.

Economic damage levels

The recognition of economic damage levels in the early stages lay simply in the supposition that leaf loss led to crop loss. This was ultimately shown to be so, with crop in the year following total defoliation falling by 40% or more from expectation, both in estate practice and in controlled trials (Wood 1977; Wood *et al.* 1973). Details built up as events proceeded, but census systems were used in oil palms from an early stage (Wood 1968), to assess the need for application, its timing, and its effectiveness. Action levels were proposed for some pests. These inevitably are somewhat arbitrary in respect of cost of control measures against loss otherwise sustained, due to the complex relationships. Decisions at given pest numbers in any case require assessment of whether current numbers represent a risk of upsurge, a decline (with natural enemy build up), or ongoing fluctuation within tolerable limits. In the former, treatment might be best done when timing is appropriate even before numbers reach 'critical' levels, but in the latter can be delayed even if they are above the level.

Ecological aspects of pest incidence and control

The recurrence and interpretation of outbreaks led to the development of what later came to be known as IPM in these tropical plantation crops. After the crisis of the early 1960s, it became apparent that injudicious chemical application was not the sole cause of significant insect pest incidence. Certainly some of the initial outbreaks arose from prophylactic or precautionary sprays, but upsurges can occur due to 'natural' disturbances. Further, not all pest species are sharply controlled below damaging levels by natural enemies. In the oil palms, the incidence of leaf eating cockchafers, against which some early applications were made, seems more related to availability of suitable conditions for larval development, and they rarely become very serious anyway (Wood 1974, 1976b, 1976c). In the Sabah cocoa, the early troublesome ring bark borer, *E. hoseii*, came from one of the secondary jungle trees, *Trema cannabina*, and the evidence is that sprays against that set off the whole train of devastating infestations. Elimination of that tree then solved the problem. When spraying had stopped, mirid bugs appeared in numbers that caused economic damage in the absence of any form of control interventions, necessitating finding programs of regular integrated spraying.

The 'ecological' classification of pests devised by Smith & Reynolds (1966) has proved a useful framework for interpreting pest status. Most of the pests in the outbreaks were *potential pests* i.e. they would not be a problem in the usual growing conditions without prior disturbance to their natural balance by pesticide application. *Occasional pests* may flare up sometimes as particular conditions favour disruption to their natural balance. *Key pests* would pose a continuing problem under prevailing agronomic conditions, irrespective of pesticide interventions. The relationship of this to the foregoing paragraph is self-evident. Most of the problems were from potential or occasional pests generated or worsened by pesticide use (which can be categorised together as *induced pests*). The risk that one or more of these could have become a regular feature in growing the affected crop (vicious circle of reoutbreak, spray, some control, reoutbreak, again respray) has been mentioned. Whilst this might be tolerable for some time, the onset of resistance can lead to devastation as infestation continues uncontrollably (Smith 1968; Wood 1973). Evidently key pests do require control as do occasional ones when there is incidence, but in such a way that repercussions in other aspects of the agroecosystem are minimised. This forms the basis for the further refinement of IPM in these crops. It should also be clear that cultural measures to change the agronomic conditions (as in removal of *Trema cannabina*) are an important part of the approach.

Further development of IPM in plantation crops

The induced outbreaks were in one sense an isolated event, and with the causes recognised and the situation restored, were over. In a broader sense, they led to a greater appreciation of pest ecology, and for development of measures that added to or at least did not disrupt natural suppression. This of course is the basis for the IPM approach in these crops (Wood 1985).

Selectivity of chemicals – further considerations

Chemical characteristics for blanket spraying
Crucially this requires chemical approaches that relatively favour natural enemies over their pest hosts. The key word is relative. Even a moderate kill of the pests with a chemical that allows enemy activity to continue is preferable to one that gives complete elimination of both. In oil palms, lead arsenate in plot trials gave nowhere near such a good kill as e.g., dieldrin, but its use was followed by continuing decline of the caterpillar populations. Best of all is to get a good pest kill with selective chemicals, especially if their selectivity lies in allowing early return of natural enemies after initial kill, e.g., short term residues.

The agroecosystem of tropical tree crops tends to stability. Regular marked weather changes are absent, and the crop environment itself is not subject to disruption, as at planting and harvesting of short term ('annual') crops. Often chemicals not apparently very suitable for selectivity in many circumstances can be used in these crops without disrupting natural balance. Whilst *a priori* considerations can suggest likelihood, field evidence, ultimately full scale use on a number of occasions, is necessary for confident evaluation. A wide range of chemicals has been tested against nettle caterpillars, for example, without any evident induced resurgence (Wood *et al.* 1977; Wood 1987a). Both BHC and endosulphan, organochlorines with broad spectrum but relatively fast fading contact residues, have been regularly used to control the cocoa mirid bugs, without repercussion (Conway 1972; Chung & Wood 1989).

Apart from the characters of the chemical itself, best kill is ensured by good coverage and timing. This should be the objective, once a chemical intervention is decided upon, whether an isolated treatment of an occasional pest, or a regular one for a key pest.

Application and coverage
The difficulties posed in the dense and often high canopies and rough terrain of both crops have been mentioned. Spray tracer trials have helped to develop satisfactory procedures. Hand carried high pressure high volume pumps have added to the early capability, but height and time for large areas, pose limits. Tractor drawn air blast sprayers can be effective in cocoa and younger palm areas, providing the terrain is suitable for tractor progress. For a review of ground spray machinery use, see Wood (1968, 1976a, 1987a), Chung & Wood (1989) and Wood & Chung (1989). On large areas of oil palm, aerial sprays have given effective coverage and successful control without resurgence (Mariau *et al.* 1973; Wood *et al.* 1973). An important development in oil palms has been trunk injection. A systemic insecticide is poured into a small hole bored in the stem, which spreads to all parts of the crown (but not into the fruit). Virtually all leaf feeders are susceptible, and with suitable equipment, very large areas can be rapidly treated (Wood *et al.* 1974; Mariau *et al.* 1981; Sarjit 1986; Wood 1987a). There is no general environmental distribution of the chemical, and toxicity risks are minimised.

Decisions on application and timing
This covers decisions on whether to apply or not, and the appropriate stage in the infestation to do it. Census monitoring methods have continued to develop from the early procedures (Wood, 1968 – see *Economic damage levels*). They comprise scoring the number of pests or their damage, by sampling, for example on a grid or transect system. Summary reviews are given for oil palms by Wood (1976b), and for specific cocoa pests by Wood & Chung (1989). For key pests, census may have to be continued regularly, but for occasional (or induced) pests, a two stage system is appropriate (e.g., Syed & Speldewinde 1974). In this, general alert is continually maintained, with counting initiated if there are signs of increase, until such time as the incidence declines again. By including the stage of the pests in counts when appropriate, sprays can be applied at the most susceptible time, e.g., for bagworms as soon as all caterpillars have emerged from the eggs (which are

contained within the case of the mother insect until the young caterpillars hatch and emerge) (see also *Chemical characteristics for blanket spraying*); or counting on the plant part most susceptible e.g., for cocoa mirids, as soon as damage becomes noticeable on new stem growth (Wood & Chung 1989).

Control techniques other than synthetic pesticides

A range of alternative control techniques were investigated. During that period, such approaches were being termed pest management, and by the mid-1970s by incorporation, became consolidated as integrated pest management (Mathys 1977).

Semiochemicals, lures etc.
Attracting the pest to a lethal chemical or trap can minimise risk of side effects. Practical developments in these crops have been limited, but there are cases e.g., poison baits for mole crickets in oil palm nurseries. The sex pheromones of the introduced cocoa pod borer (*Conopomorpha cramerella*), have been isolated and tested extensively to trap populations out (Ho *et al.* 1987), or at least for census.

Biological control
'*Background*' or '*silent*' *biological control*. This is the central factor in the IPM approach in tropical perennial crops. The more information that is accumulated on natural enemy biology in relation to the crop environment and their pest hosts, the better. In the oil palms, early studies showed numerous parasitic and predatory insects on the leaf eating caterpillars (Wood 1968, 1971a). These included expected groups, ichneumonids, braconids, etc. (these strictly are parasitoids, but the generic term parasites is used in this general account), as well as predacious bugs and beetles.

Importation and manipulation (classical biological control). Supplementation of the range of natural enemies by establishing imported species can sometimes give control. It is mainly effective with pests that cause regular problems, although they belong to a group that is normally subject to strong natural enemy suppression, in an environment apparently suitable for biological balance. Often, they are accidental imports, scarce where they originated, but tending to 'explode' where their natural enemies are absent. There have been no cases in the plantation crops in Malaysia, but it has been the source of parasites exported to deal with such problems elsewhere e.g., the parasitic tachinid fly *Bessa remota* against the zygaenid moth caterpillar, *Levuana iridescens*, that halted coconut production in parts of Fiji in the 1920s, but virtually disappeared after the importation (Tothill *et al.* 1930). See also Wood (1973) for a review of this and other cases in coconuts. The approach has been considered particularly for cocoa pod borer (Ooi 1987), but never implemented.

Mass rearing and release to boost numbers of an already existing natural enemy has had some attention, e.g., collecting nettle caterpillar cocoons and allowing escape of the emerging parasites (see *Releasing natural enemies*). There was an intensive program of mass rearing and release of an egg parasite of cocoa pod borer in Sabah during the 1980s (Lim & Chong 1987).

Biological pesticides. Insects can be subject to lethal disease. This can cause near-extinction when transmission becomes easy, in dense populations. It is sometimes possible to cause this before it happens naturally, by artificial infection. There have been several successes by spraying broths derived from field collected infected nettle caterpillars in oil palms (Entwhistle 1987; Desmier de Chenon *et al.* 1988).

Enhancing environmental suitability. There may be opportunities to improve the environment for natural enemy activity (apart from the question of selective chemical use, stressed throughout this chapter). During the mid-1960s, both bagworm and nettle caterpillar outbreaks occurred on newly established oil palm plantings in Sabah, sometimes extending over some hundreds of ha. Prior use of bslrcs could not always be blamed, but the indications were of disruption to natural balance. In most cases, following experience in the peninsula, a single application of trichlorfon terminated the outbreak, aerially applied in several cases (Wood & Nesbitt 1969). This was the most promising selective option then available, but some nettle caterpillar outbreaks were less well controlled, apparently in part due to variable effectiveness against this group (Wood 1987a). The frequency of the attacks was greater than expected, attributed to various possible causes, e.g., some disruptive effect of a rapid transition from separated individual palms to a widespread interconnected canopy over huge areas. Syed & Shah (1977) later recognised that an agronomic policy often existed of keeping the ground bare in early mature plantations. The absence of flora whose nectar would be the food of adult parasitic insects probably limited their activities. The frequency of serious outbreak declined over subsequent years, and the possible risk from extensive bare ground continued to be recognised and investigated (Tiong 1982).

Cultural control

Agronomic conditions can often be modified to reduce opportunities for pest build up or attack. Some key pests particularly have been approached in this way. The removal of the wild host of the cocoa ring bark borer, *E. hoseii* (see *Ecological aspects of pest incidence and control*) is a case in point. A difference was noticed in the frequency of attack by rhinoceros beetles (*Oryctes rhinoceros*) on young oil palms according to the amount of vegetation growing on the ground. It related to the vegetative barrier effect observed in mature coconuts (Owen 1959), and led to the investigation of the 'ground cover effect' (Wood 1969). Evidently a reasonably dense cover of plants (planted legume or self-established vegetation) reduces both utilisation of potential breeding sites within the planting, specifically rotting trunks of a former palm stand, and (equally or more important) it protects the growing palms themselves from attack, usually below economic levels. Cocoa pod borer has proved resistant to most control approaches attempted, including blanket spraying. It develops in the ripening pods, where its generation time is long enough to exceed the time between practicable harvesting intervals. A control measure that may be effective is regular complete harvesting. It is difficult to achieve because many pods are difficult to find in dense canopies, but if done properly, gives good control, and also enhances crop recovered (Wood *et al.* 1992).

Where a cultural approach is effective against a pest, still any negative effect on productivity would have to be taken into account. In fact, in all the above, the agronomic treatment is neutral or beneficial to productivity.

Recent and associated developments

The experiences in Malaysia have been paralleled in other parts of the humid tropics. The IPM approach developed in perennial crops has continued to be the basis for plantation practice, with research aimed at further refinement within that framework.

Oil palm

Malaysia

In oil palms, the central role of natural balance in the control of leaf-eating insects continues to be recognised and investigated, with emphasis on selective control measures applied only on response to census counts. In a review of IPM developments, Ho & Teh (1997) describe improving knowledge of technical aspects of the response system, and the relationship of known natural enemies to their flower food plants. They refer to further incidences of outbreak and cyclic reoutbreak induced by synthetic pyrethroids, against nettle caterpillars, in the early 1990s in 6–7 year old palms, in the Malaysian state of Sabah. This was eventually overcome by a switch to the selective *Bacillus thuringiensis* insecticides and virus applications. Chung & Sharma (1999) similarly stress IPM, and cover recent developments in optimising application systems for selective chemicals. In a recent volume on oil palm research, Basri & Norman (2000) likewise stress the crucial importance of IPM. Ongoing work investigates the biology and population dynamics of leaf-eating caterpillars and their natural enemies, identifies important parasitic insects, elucidates their lifecycles, and shows more precisely the role of individual species (e.g., Basri 1995; Basri *et al.* 1995). Newer studies are revealing the relative suitability of specific flowers for parasite feeding activity (Basri *et al.* 2001) and investigating fungal pathogens as possible biopesticides (Ramle *et al.* 1993).

From survey of incidence in a comprehensive sample of responding estates, Basri *et al.* (1996) recorded a total over the 10 years to 1985 of 3.2% of the area having severe bagworm damage, whilst Norman & Basri (1992) found a similar low total incidence of limacodids through the 1980s. There are no reports of any marked change in this general level of incidence since. Overall insecticide use remains very low, with no more than 5% of the total area of oil palms receiving application in any one year (Wood & Corley 1993).

Other regions
In nearby Indonesia, developments have been similar (Wood 1974, 1976c; Desmier de Chenon *et al.* 1990; Syed & Saleh 1993), and IPM continues to be the basic approach, equally stressing the central role of natural enemies, with selective control techniques where necessary (Chiu *et al.* 2000). The situation is similar in Thailand (Wood 1987b). In Papua New Guinea, outbreaks of *Segestes* spp. ('Sexava') (Orthoptera, Tettigoniidae), have posed problems similar to those from leaf-eating caterpillars in the other locations. Success has followed use of selective measures permitting re-establishment of natural enemy control (Prior 1988), and this continues to be the focus (Prior & Sar 1992; Caudwell 2000).

Further afield, in West Africa the leaf-mining hispid beetle, *Coelaenomenodera minuta*, is an occasional pest that can sometimes build up to cause severe damage over large areas. Major outbreaks have been induced by non-selective insecticides. A detailed study of the relationship between the lifecycle of the pest and its enemies, clearly showed how the desynchronisation in DGM (see *Ecological principles in the global context – The agroecosystem*) (Mariau 1976), contributed to the continuation of outbreaks, once they had started. Selective methods continue to be developed, including trunk injection (Philippe *et al.* 1999). This can deal rapidly with large areas where the techniques developed in Malaysia (see *Selectivity in chemicals – further considerations, application and coverage*) are applied. The IPM approach for pest problems continues to be stressed, recognising the key role of natural control, with response application of selective measures (Mariau 1999). In South and Central America, similar problems with leaf-eating pests have arisen, but generally after periods of intense and frequently recurrent incidence, natural factors have resumed control when bslrcs are discontinued, often after some application of selective compounds (Genty 1982; Mexzón & Chinchilla 1993). This continued to be the approach through the 1990s (Mariau 1999) although increasing incidence of a key pest, the tissue dwelling nematode that causes red ring disease, posed an intensifying threat. The nematode is transmitted by the red stripe weevil, *Rhyncophorus palmarum,* and lately, control of that, with traps baited with semiochemicals, is proving effective (Giblin-Davis 2001).

Rhinoceros beetles
The 'ground cover effect' that limits rhinoceros beetle damage in replantings (both by restricting breeding site use and protecting the young palms from attack) in Malaysia (see *Cultural control*), has also been demonstrated in West Africa (against *O. monoceros*) and shown to be of value also in coconuts although these are more attractive targets for the pest (Julia & Mariau 1976). It remains generally the recommended and successful practice, but during the 1990s, there have been some cases of severe attack in Malaysia. Various reasons have been put forward for this, including a reversion to the practice of leaving the stems of old palms (whose tissues offer a medium for larval development) unburned for environmental reasons (Ho & Teh 1997), new areas being replanted as the 1970s expansion of plantings reaches the end of the first palm generation (Liau & Ahmad 1993; Norman & Basri 1995), stems piled in heaps around areas cleared for nurseries (Chung *et al.* 1993), and palms killed but left standing upright (Samsudin *et al.* 1993).

Such incidence tends to remain sporadic and localised. This seems to rule out any general build up of breeding sites (increased area or non-destruction of the old stems) as a major factor. Ho (1996) and Desmier de Chenon *et al.* (1998) attribute cases to poor timing or other restriction in ground cover establishment. B.J. Wood (unpublished) noted that in most cases of significant attack observed, there had been some clear deficiency in ground vegetation establishment or maintenance. Another possibility concerns the empty fruit bunches (EFB) from the factory, which are now often returned to the field to provide useful nutritional mulch to the young palms. Fresh EFB is not a very satisfactory medium for *Oryctes* larvae (Norman *et al.* 2001), but if it is left heaped some time before application, then larvae can develop (Chung *et al.* 1999). In fact, the application itself may disturb the ground vegetation, so permitting some attack on palms and greater breeding site utilisation.

Economic studies do show that where attack is heavy and repeated, there are marked losses in yield and set back to palms (Liau & Ahmad 1993; Samsudin *et al.* 1993; Desmier *et al.* 1998; Chung *et al.* 1999). Additional control measures resorted to include trapping of adults with an aggregation pheromone (Chung 1997; Desmier *et al.* 1998; Morin *et al.* 1999; Norman *et al.* 1999), distribution of inoculation sources of the diseases caused by the entomofungus, *Metarrizhium*, and the virus, *Bacculovirus oryctes* (Ho 1996; Ramle *et al.* 2002). Chemical control with synthetic pyrethroids offers protection (Chung *et al.* 1993) and whilst usually without side effects, can sometimes set off a cycle of insecticide dependence (see *Recent developments – Oil palm, Malaysia*). Some caution evidently is needed about expenditure on these additional methods, particularly those with risk of side effects, before paying attention to ensuring best growth of ground vegetation.

Cocoa

Most of the Malaysian cocoa plantings of the 1970s and 1980s have been uprooted due to poor economic prospects, but on what remains, and on cocoa elsewhere in the world, there is generally a requirement for chemical application against key pests. Effort is towards doing this within an IPM framework (see *Chemical characteristics for blanket spraying*), and to search for non-chemical methods (e.g., Wood & Chung 1989; Philippe *et al.* 1999). Mirids generally pose the most persistent problems, but blanket sprays of some chemicals, in particular BHC, endosulfan and propoxur, remain unassociated with induced outbreaks, unlike those organochlorines that induced upsurges of caterpillars etc in Sabah (see *The early days – cocoa*) and West Africa (Philippe *et al.* 1999). One possible alternative is the establishment of an ant, *Dolichoderus bituberculatus*, that inhibits *Helopeltis theobromae* (Khoo & Muhamad 1986). Dealing with it by selection of suitable planting materials also is under investigation (Mariau *et al.* 1999). Some evidence that this might have potential for this very difficult group of pests comes from tea in Assam state in NE India. There *H. theivora* can damage most tea, but it only builds up to do severe damage on one or two clones. There appears to be a difference between susceptibility to feeding and support of the full life cycle (Sidhu & Saikia 1999).

The cocoa pod borer remains a threat to cocoa growing throughout the SEA region, and control is often attempted with synthetic pyrethroids (with attendant risks), although regular complete harvesting remains effective if done properly, a practice which also regulates other pests that depend on continuing availability of ripe pods to complete their life cycles (Mumford, Matlick, Hamzah & Leach 2001).

Other tropical tree crops

Except for the disruptions that caused outbreaks in the 1950s and 1960s in particular, some of the principles behind the IPM approach might have remained less evident. Rubber was a more widespread and longer established plantation crop then, but no such problems arose. This was sometimes thought to be due to some deterrent quality of its leaves, but the evidence is of the existence of caterpillars that can complete a life-cycle for successive generations, and these could have led to similar cycles had disruptions occurred. Similar induced outbreaks have occurred in other tropical tree crops in other regions, e.g., tea and coconuts (see Wood (1971a) for review of earlier cases). Awareness of the ecological principles, particularly the general stability in tropical perennial (tree) crops, has facilitated avoidance of serious problems in Malaysia. The upsurge of occasional pests still may pose intermittent problems, whilst availability of a selective technique, can aid restoration of the pest free situation, e.g., a widespread and increasing incidence of a leaf-eating caterpillar that can sometimes build up to damaging levels on Malaysian coconuts, was halted by trunk injection similar to that developed for oil palm (Ooi *et al.* 1975).

This situation has continued through the 1980s and 1990s in SEA, and the IPM approach is increasingly adopted in tropical perennial crops in general (see e.g., Mariau 1999). For example, in tea regions of India, extensive areas were subject to several rounds of spraying per year with bslrcs against mite damage on leaves, with continual risk of upsurge that could not be treated for one reason or another. During the mid-1990s, a programme of restriction to selective chemicals on response reduced applications to 1 or 2 per year on average, evidently with less ongoing risk of severe flare up (B.J. Wood unpublished).

Relevance to more seasonal crops

Short term crops progress rapidly through distinct stages of susceptibility to given pests. They are often termed annual, but that can be misleading in the tropics, where the growth succession does not necessarily relate closely to times in the calendar year. The progress of growth stages mean fluctuations in agroecosystem characteristics that themselves can disrupt natural balance, with periods of scarcity or absence of susceptible plant stages alternating with opportunity for pest abundance. Still, there is some natural balance that has potential for exploitation, and serious consequences may occur from bslrcs with induced incidence in which regular spray programs *appear* to be essential. Outbreak of occasional pests may be more frequent, but the situation can be greatly worsened by long term destruction of natural enemy populations, e.g., in rice (Ooi *et al.* 1978) and vegetables (Ooi & Sudderrudin 1978). Some warning of the risks from bslrcs and of the means to escape from the 'vicious circle' in these crops was derived from experiences in the perennial tree crops (Wood 1971a, 1973, 1979). IPM has continued to be developed in these crops in recent years, of crucial significance in rice (Kenmore 1996), and vegetables (Ooi 2000a). With crops of this type, education of farmers to appreciate the basis of IPM is important (Ooi 2000b), something generally needing less focus in large scale plantation crops with a hierarchical management structure implementing operational policy.

Several flower growing projects across tropical Africa were subject to intensive pest pressure with recurrent applications of bslrcs, that similarly risked severe flare up of target or other pests. In the 1990s, it was often demonstrated that these were induced problems, and better and more reliable control could be achieved with selective chemicals applied on response. An interesting example was in a pilot project to grow Chrysanthemums in Gambia. Large plots were very soon inundated with a strain of *Aphis gossypii* that was resistant to most organo-synthetic compounds available, but with a wide range of natural enemies that kept it in check if no insecticides or only selective ones were used (Wood 1997a).

Conclusion

IPM principles and implementation

Even now, it may be heard that IPM is not possible until knowledge of the particular agroecosystem is complete. The experience in these crops shows that in fact an appreciation of basic ecological principles is enough for a starting base to commence IPM, whilst refinement comes as experience accumulates. There is no such thing as an IPM technique in its own right. A central precept is 'Consider the agroecosystem'. A measure that fits into it in one circumstance can be part of IPM in that circumstance, but where it causes unacceptable and unavoidable side effects, it cannot. Use of BHC, propoxur and endosulfan for cocoa mirids is a case in point. In another crop environment these chemicals may well have disruptive side effects e.g., endosulfan in rice (Ooi 2000b). Obviously some types of measure are more likely to fit the requirement than others, but the final proof is in actual use. It is important to remember that 'integrate' means 'to make whole', not 'to combine'. In the agroecosystems here, the crucial aspect of the agroecosystem is that conditions continually favour the reproduction of a range of potentially devastating pests, but they also favour the biotic suppressors of that potential. Applying no specific control measures *advisedly* is just as much IPM as is a variety of actions.

IPM commonly is taken to be in contrast to 'the chemical (or some term of similar implication) approach', with reliance only on regular application. However, it is also in contrast to doing no direct pest control except what can be done by hand – which can be termed the 'primitive approach'. This is more common than often is realised in 'village agriculture' (Wood 1997b), and serious losses can occur to pests that would be susceptible to selective control measures. A sudden availability of non-selective chemicals in such circumstances has often been the beginning of a 'vicious circle'.

IPM is shown to be capable of being target orientated, that is to say targets can be set, and IPM procedures developed to suit them. For example, the level of freedom of the harvested crop product from signs of pests can be pre-determined – total absence does not have to imply heavy use of bslrcs – it is just as easy to develop programmes that use selective inputs. Similarly IPM is not necessarily an 'organic' approach, but it can be targeted to be so. It should be the most economic method in any term other than possibly dealing with an immediate outbreak, provided that some expenditure on research and monitoring is as acceptable as it is on purchase and application of chemicals.

Economics

Economic damage levels have played their part in these developments, though they have received less focus in this account. The need often to take an indirect line from pest numbers to need of control (e.g., through some assessment of likely impending natural enemy build up and its effect) has been noted. The economics of damage have been investigated in some detail in oil palm, including the relationship of pest numbers to damage, and of that to crop loss (Wood *et al.* 1973; Wood 1977). This has not been done in many crops as yet. Often educated guesses at losses are the best that can be done, and consciously attempted, are better than nothing. However the actual crop loss in relation to given amounts of damage can be counter-intuitive, and the relationship needs to be established objectively whenever possible, by direct comparison of yield under given levels of incidence, or from simulated damage. The productivity and resilience of tropical tree crops often is such that a certain amount of damage can be tolerated before there is any detectable loss of crop, but it is important to confirm this in specific cases. It is not to imply that IPM has to tolerate more damage than other approaches. It may be that a certain level of loss has a better economic optimum than application of any known control measure, but this needs to be quantified. The objective of IPM in terms of damage tolerated and control cost must be set as much (or more than) in any other approach. The aim is to optimise economic production within constraints accepted, with the implication that it is cheapest in the longer term.

Toxicity and environmental aspects

Sometimes, increasingly perhaps, IPM is taken to cover toxicity and general environmental aspects, as well as sustainable pest control. Most of the approaches here have not had those aspects primarily in mind, although most in fact happen to suit these requirements, and can be incorporated into targets. A high proportion of suitable (selective) chemicals are of low toxicity, and further, their use is minimised. There is no detailed recorded collation of records, but pesticide inputs are minimised, e.g., in oil palm (see *Recent developments, Oil palm, Malaysia*), where chemical application would average perhaps once in a planting generation (around 25 years), most of which would be by trunk injection. Remaining cocoa needs regular spraying against mirids (see *Ongoing developments*), but usage is minimised by regular census (Chung & Wood 1989).

Worker protection and residue tolerance becomes increasingly emphasised (see e.g., Chung & Sharma 1999). This can limit the measures that are available, but the IPM techniques and approaches developed can well adapt to the situation.

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