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Research on Tropical Pest Control (**)

It is a humbling thought to find that 150 years of modern technology concentrated on exterminating insects of crucial health or economic importance, using all the technical ingenuity of man, have not achieved this stated goal in tropical Africa. True, these modern methods have given us some relief from the major disease vectors of tropical Africa during an emergency period (tsetse, malaria, livestock ticks, for instance), or when there is a widespread outbreak of a major crop and pasture pest (for example, locust plagues or armyworm invasions); but we have so far not succeeded in controlling these pestiferous insects on a long-range, sustainable basis.

We have only succeeded in three cases [1]. Firstly, the jigger (the flea larva) which was accidentally introduced from South America in the seventeenth century probably by the returning slave traffic. It spread like an epidemic throughout West and Central Africa, and decimated the indigenous population which was unfamiliar with and showed little resistance to this ectoparasite until they learnt a century later how to control it by simply mechanically removing the jiggers. Secondly, the coffee mealybug, *Planococcus kenyae*, became a devastating pest in the early history of the Kenya coffee industry East of the Rift Valley. Chemical control was unsuccessful in giving more than brief respite from this serious pest of the fruit-bearing branches. However, excellent control, which has now lasted for more than 40 years, was achieved by the introduction in 1939 of insect parasitoids from Uganda, where the coffee mealybug has never attained the status of a pest. The third example is the cotton leafhopper, *Empoasca fascialis*, which was a serious pest of cotton in the cotton-growing areas of tropical Africa until the early 1940's. Its infestation results in "hopper-

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burn", which often greatly reduces photosynthetic potential, blocks translocation of plant sap, may result in serious leaf shedding, and certainly reduces production of lint. The discovery that hairy cotton plants seem to be resistant to *Empoasca* led to a spate of plant breeding and entomological experimental work, which eventually revealed that these hairs prevented the gravid females from laying their eggs on the leaf surface, even though the hairs did not prevent them from feeding. Breeding for this hairiness factor has made the modern cotton varieties highly resistant to *Empoasca*, and has relegated it to a very minor role as a cotton pest.

The control of these three pests, among the 3,000 or so major pest species in tropical Africa, spanning a period of 150 years of scientific research and technological experimentation, is a miserable record of success by any standards. Perhaps, our pest management methodologies have not been as informed scientifically as they should be, and a reassessment is called for.

We could not do better in this reassessment than by starting with the question of how insects could have been so successful in competing for resources (host, prey, habitat, etc.) for more than 220 million years [2], in contrast to the rather brief evolutionary emergence of man only some 3 million years ago [3]. The orders Blattodea (among which are the cockroaches) and the Orthoptera (including the grasshoppers and locusts) emerged during the Upper Carboniferous Age (lasting about 30 million years); the Homoptera, among which are our most insidious crop and tree pests and efficient vectors of virus diseases, arose during the Permian Age (lasting about 50 million years); while the Mesozoic (lasting some 140 million years) saw the rise of many of the orders which contain the majority of our crop pests and vectors of human and livestock diseases — the Lepidoptera, Isoptera, Thysanoptera, and Diptera — as well as orders which contain some of man's friends, for instance, the Hymenoptera. The Cenozoic (lasting about 63 million years) saw the rise of the order Siphonaptera, which contains the fleas; the primitive termites, the Hodotermitidae; and the social wasps, the Vespidae. But, in terms of our major pests of crops and trees, it is the Cretaceous Period in the Mesozoic that holds the greatest interest. This span of 65 million years saw the rapid evolution of the flowering plants, which also saw the parallel evolution of the essentially modern insect fauna consisting of the Lepidoptera, Hymenoptera, Diptera, Thysanoptera, termites, as well as those of the older Orthoptera. It is not surprising then that one finds the emergence of societal organization in some of the insect groups at this time — for instance, the worker caste among ants in seen in Cretaceous amber for the first time. This socialization of insect life was intensified in the Cenozoic, with the emergence of true *Apis* (the genus containing the honey-bee) as well as the communal web-forming insect group, the Embioptera, in the Oligocene; and true *Bombus* a little later in the Miocene. The co-evolution of the flowering plants and their diverse insect fauna over the last 120 million years has given these two groups of living organisms plenty of time and opportunity to have evolved mutually sustainable mechanisms of tolerance and defence, and in occasional circumstances mechanisms of offence.

Plants have evolved an insurance scheme which allows insects to harvest a considerable proportion of the plant products without jeopardising the plant's own potential to grow, to exploit its environment for its own development, to mature, and to eventually reproduce itself. They have even invented and developed cues (flowers, nectaries, allelochemics, etc.) which attract insects to them so as to let the insects partake of these insurance products, while at the same time working for the plants themselves — cross-pollinating the species, carrying seeds to new habitats, and fertilizing newly matured ovaries. But plants have also evolved deterrent mechanisms (chemical, mechanical, etc.) which stop insects from predating on stages of growth or parts of plants which are critically vulnerable and need protection. On the other hand, insects have evolved behavioural mechanisms which tell them to migrate to new habitats or plant species when their usual host plants are no longer able to support them; and they have evolved chemical receivers which inform them when plants are injured severely, and they should decide what to do then, or that they are a good site for laying eggs. All these and other mechanisms, which have co-evolved in the plant-insect associations, have become mutually advantageous and have achieved a dynamic state of balance in different epochs of this evolutionary relationship.

Agriculture and forestry, by specially selecting certain production systems and by putting intense pressure on the plant to produce its selected products on time and in volume, put out of gear this naturally evolved balance of plant-insect associations. The short-term effect of this perturbation can be catastrophic, and may lead to the emergence of a pest situation where one did not have to exist. The question which faces us, then, is not how to eradicate this specific insect species, but rather how to manage its population so that, while it takes its assured harvest, it still leaves the human manipulator of the particular plant species with a handsome harvest to justify his effort in managing the original plant population. This is the problem facing the post-Green Revolution pest manager.

Status of Agricultural Production in Africa Today

Agricultural production has been declining steadily in Africa in the last 15 years; and this phenomenon, although most patently obvious in food production, is consistently clear as well among cash crops — with a few exceptions (e.g., coffee) in a few countries (e.g., Malawi and Côte d'Ivoire). This trend, intensified by recurrent drought, has resulted in large food deficits in Africa, and slowed down socio-economic as well as agricultural development.

It is not clear why this decline should be happening at this time, when in other areas of the tropical developing world — Asia and Latin America — agricultural production is very much on the increase, and these areas are in the middle of a "green revolution". One major factor seems to be the lack of innovative technology to support an agricultural production system which is very much dependent on the availability of water through natural rain [4]. It is, indeed, the consequence of the development of high-yielding crop varieties, their especially rapid response to irrigation, fertilizers and pesticides, and the adoption of intensive production strategies that first ushered in the green revolution in Asia and Latin America. Africa's dependence on rain-fed agriculture, its still prevalent strategy of emphasis on greater productivity through the expansion of the cultivated area, its low level of utilization of such agricultural inputs as fertilizers (chemical or otherwise), and its lack of a well articulated seed production and distribution system, are what militate against a transformation of Africa's agricultural production system. A second major factor seems to be the very dominant role crop pests (insects, weeds, and diseases) play in the socio-economic development of Africa — more so than in other tropical regions [5].

It is instructive to note that of the 17 recommendations advanced by the Future Actions Committee of the International Conference on Chemistry and World Food Supplies held in Manila, in The Philippines, in December 1982, 6 of them dealt with the management of pests (i.e., insects, diseases, weeds, etc.). Moreover, these recommendations were considered under the rubrics of "longer-range research at the forward edge" (1), and "near-term R & D (i.e., research and development) related to soils, crops, pests and animal production systems" (5 recommendations). The recommendations dealt with the assigning of high priority to R & D programmes in genetic engineering in relation to improved stress resistance in plants; the establishment of safety standards of pest-control agents in different environments, and the development of international agreements covering the registration, licensing, and patent procedures for pesticides and methods; the undertaking of multiple and interdisciplinary field studies in tropical countries to identify the factors limiting the current and optimum yield potentials; and the giving of some urgency to the development of new chemical and biological methods for the control of pests, especially under integrated pest management (IPM) strategies.

It is not usual, in a forum dealing with agricultural production, for pest management to play more than an incidental role, indeed an after-thought. But this departure was probably due to the circumstance that the Manila Conference was largely concerned with agricultural production problems of the tropical developing world, where it is recognized that losses due to pests could be as high as 35-50%, and where therefore pest control has a necessary part to play in increased overall production, particularly as agriculture becomes more intensified [6].

A special problem of Africa today is that a large proportion of its arable land is arid or semi-arid, and in many ways marginal in an agricultural production sense, particularly since irrigation is not a farming system that is widespread — either because of a lack of tradition in this agricultural practice, or because of insufficiency of resources to adopt it on a wide scale. Some of the conditions that have led to the current famine in much of the Sahelian zone and easternsouthern regions are the creeping desertification of the area; the fragility of the soil structure of this area which does not permit the implementation of intensive agriculture without particular steps being taken to continually regenerate the fertility of the soil (through agroforestry practices, mixed cropping, crop rotation, etc.); and the lack of a knowledge-base for the simple, low-cost solutions required by the resource-poor farmers who usually occupy such marginal lands. Indeed, such low-cost solutions can only be achieved by high-quality research being directed towards finding solutions to these difficult problems [4] largely unique to tropical Africa.

Under these circumstances, the farmer puts a premium on reliability of crop performance [7] rather than on high yields. In this respect, reliance has traditionally been given to natural selection to single out crop varieties that resist pest attacks. Such traditional cultivars have shown great stability in performance, as they are in overall balance with their total physical and biological environment [8]. The secret seems to lie in the fact that the relatives of the cultivated plants and their pests have co-evolved over millions of years, as we have already indicated — by the plants elaborating natural anti-pest defensive chemicals, by the genotypic response of pests to such secondary metabolic products, and by the establishment of a dynamic balanced co-existence as a consequence of this chemical-genetic interplay [9]. Since the traditional agricultural systems in tropical Africa — whether they be agroforestry systems or intercropping patterns — have a large number of species planted in space and time, and therefore have a structure closely simulating the natural ecosystems, they display plant-insect associations not unlike the natural associations. Consequently, their insect burden is much reduced, as compared to the pest level as a result of the severe shift from natural to specialised agricultural systems, represented by the monocrops, which disturb the ecological balance, and therefore create major problems of insect pests and crop diseases.

It has become clear that the starting point for agricultural production in tropical Africa must be the premise that the natural ecosystem comprises a rich and diverse fauna and flora, and that the most stable farming system should necessarily start from a diverse plant pattern, consisting of a mixture of trees or shrubs and annual plant species. This represents a radical change from the direction that scientific agriculture, in contrast to traditional agricultural practices which have evolved over thousands of years since agriculture was invented in the tropics and sub-tropics, has been taking over the last 150 years or so. In this time, temperate-climate agricultural methodology, based on the ecological fact of poverty of species, has dominated the thinking of agricultural scientists the world over. It is important that it be realised that this methodology is irrelevant and inapplicable in the tropics. As Ruttan [10] has so well put it:

> "Those countries that have attempted to rely primarily on borrowed agricultural technology have rarely developed the capacity to adopt and manage the borrowed technology in a manner capable of sustaining agricultural development".

Africa, and other tropical regions of the world, must build up their human resources and institutional capacity to know their priority problems and to conduct the necessary scientific research and technological development which will adequately address those problems. Temperate-climate technology cannot be transferred directly to the tropics with any degree of success: realisation of this fact came slowly, and it is still to penetrate to the science policy-designers and decision-makers in Africa.

Because of the dominant role of rain-fed agriculture in tropical Africa, the immense fragility of the soils there, and prevalence of intercropping and agroforestry farming stems in this region, early expectations that the Indian green revolution could be exported to Africa have remained unfulfilled, for the very reasons that have characterized African agriculture. A transformation of African agriculture cannot, therefore, rely on temperate-climate agriculture, nor the green revolution technologies with which we have become so familiar. Mission-oriented fundamental research in tropical Africa, which would lead to locale-specific, culturally-sensitive technological packages are therefore called for. A massive drive to train African agricultural scientists and technologists for reaching these goals is essential, because of a long tradition of neglect of agricultural sciences in Africa. In this regard, investment in the training of the traditional extension officers may well be misplaced. Firstly, it is becoming clear that the extension service in African agriculture has not worked productively, even though the number of extension officers involved is massive compared to that of any other region in the world (Table 1). Maybe Africa should re-examine the notion that the African scientist can probably talk more effectively with the peasant farmer if they do this face-to-face and work together shoulder-to-shoulder in a partnership of scientist and practitioner, without the intermediacy of the extension officer who neither fully grasps the science of agriculture nor fully understands or empathises with the tradition of farming. Secondly, it is now known that there is considerable leakage in information transfer between the science laboratory and the farmer in the process of utilising the extension mode [11]. Singh [12] has shown that in taking technological packages for the control of stem-borers of maize from the research laboratory to the farm nearly 60% of the technological information is lost by the time it percolates to the village level (Table 2).

Integrated Pest Management

A most attractive idea for the integrated pest management (IPM) of crop pests under African tropical agro-ecological conditions is to make three elements of IPM the basic tools for this control strategy:

— *Firstly*, Plant Tolerance to insect attack, which would include the chemical and physical basis of plant tolerance or resistance to insect predation, plant-insect avoidance of each other by behaviour and chemical means, and the production of substances which re-direct insects away from the vulnerable parts or phases of plant development. Such factors would be bred into plants which

TABLE 1 - Trends in the number of research scientists and extension workers with advanced degrees, 1959-1980 (after Ruttan [10]).

Region	Number of research scientists			Ratio of extension workers to research scientists		
	1959	1970	1980	1959	1970	1980
Africa	1,919	3,849	8,088	14.96	15.25	9.88
Asia	11,418	31,837	46,656	8.55	7.28	5.06
Latin America	1,425	4,880	8,534	2.35	2.21	2.68
North America	8,449	11,688	13,607	1.61	1.29	1.10
Eastern Europe and USSR	17,701	43,709	51,614	1.64	0.98	1.07
Western Europe	6,251	12,547	19,540	2.56	1.94	1.43

have other desirable agronomic characteristics, e.g., tolerance to heat and drought, acceptability to the users, ability to be intercropped with other crops or trees, early maturing, and disease-resistance. Once seeds with these characteristics have been produced, the farmer can be relied upon to propagate these new varieties — as they will have been shown to his satisfaction to be superior to what he already has.

— *Secondly*, pest population suppression through the utilization of favourable cropping patterns (intercropping, mixed cropping, agroforestry, crop rota-

TABLE 2 - Loss of information from research to extension system (abbreviated from Singh [12]).

Levels	Message: control of stem-borers in maize
Research System	
Original message	100
Extension System	
District level	70
Block level	62
Village-level worker's level	43

tion, etc.). We have now possessed increasing knowledge that one can rationalise these cropping patterns to produce low pest pressure, to conserve the top soil and gradually regenerate previously degraded soils, and to produce a higher yield per unit area than conventional monocrops and intensive cultivation with the same crop in the same area. These practices are often regarded as "cultural methods"; but this term does not adequately describe what these methodologies are. A new term, without cultural or racial imputations, is suggested: DIASTEMATIC METHODS OF INSECT CONTROL, from the Greek work "diastema" meaning space between, interval, or gap.

— *Thirdly*, pest control through methods constituting what are often called "biological control" methods. Most methods under IPM are biological: the term is therefore not clear or adequately descriptive. The term PREDARMATIC METHOD OF INSECT CONTROL is suggested for the control of pests using parasitoids and predators: it comes from the Latin words "preda" meaning prey or plunder; and "arma" meaning weapons. The term ANGINARMATIC METHOD OF INSECT CONTROL is being proposed for the control of pests by the use of insect pathogens: the term comes from the Latin works "angina" meaning distress; and "arma". Once predarmatic or anginarmatic agents are released effectively in the environment of the target pest, and if they become established, the agents do their work quietly without the necessity of the farmers' intervention in most cases.

All of these three approaches to pest control require a great deal of R & D, much more than required for insecticidal control. Indeed, insecticides captured pest management because of their simplicity, effectiveness (at least initially), the flexibility with which they can be used, and their relative cheapness (at least for the large-scale user). But the simplicity in the use of insecticides has, in the end, proved a mirage. On a global scale, we have used enormous quantities of insecticides over the last 40 years in an attempt to do almost the impossible, to exterminate crop pests and disease vectors: the cumulative production of DDT alone reached more than 2.7 billion kg by 1980, and of toxaphene more than 1.0 billion kg by the same time [13]. Yet, we are reminded by Picket [14] in these graphical words spoken nearly 40 years ago: "......while we can now control almost any specific pest [with insecticides] ..... nevertheless the problem of controlling pests is more acute than ever".

Pest resistance to insecticides is a principal reason why insecticides have not provided the final solution to insect pests. Genes for insecticide resistance have virtually limitless persistence in wild insect populations [13]. Moreover, the insecticide problem has been made worse by the fact that insecticides are often more damaging to the predatory insect species than they may be to the target pests themselves [15]: the predators may be poisoned when they feed on the poisoned prey, just as they may be directly hit during insecticidal application; the predators may be eliminated through the loss of their normal food, if the prey population becomes rare or depleted; or, because predator populations are usually less numerous than their target prey, they have less genetic material from which to develop resistance to the applied insecticide, and they take longer to regain their original population level after an insecticidal treatment has stopped being applied. Thus, it is clear that insecticides are not the most important answer to the pest management needs of the resource-poor farmer in tropical Africa, especially in the production of food staples, which traditionally and in the world market fetch low prices.

IPM may be described as "the selection, integration, and implementation of pest control based on predicted economic, ecological, and sociological consequences" [16]. In this light, insecticides can only be supplementary or complementary to methods which emanate from a comprehensive understanding of the biology of the target pests. Nevertheless, these biologically-oriented methods of pest control require a great deal of research, some of it opening new vistas for more effective and sustainable pest management methodologies.

A good illustration is in the field of anginarmatic control of crop borers using *Bacillus thuringiensis* toxin for systemic control of these internally feeding insects. As it happens, *B. thuringiensis* has been used commercially and in small-scale for the control of plant insect pests (as well as certain insect vectors of human disease, such as *Simulium* and mosquitoes) since the 1950's. The control is effected through the production of several toxins, which directly affect specific insect groups. An exciting new insect control possibility has recently been opened up by the isolation of the gene responsibile for protein toxin production in *B. thuringiensis* and cloning it into another bacterium, *Escherichia coli* [17]. This step could make it possible to transfer the toxin-producing gene into plants, and so enable us to test whether the latter can make the toxin *in situ* for direct insect control. Such a procedure would be an improvement on simply using the toxin, and applying it, as a biological pesticide.

The second illustration comes from the use of biotechnology to quicken the process of identifiying resistant plant cultivars in search for new germplasm to utilize as pest-resistant material for further breeding into a usable variety. The technique of tissue culture has recently inaugurated a new method of selecting for resistance against a variety of environmental factors (high or low temperature, high salinity, drought, herbicides, etc.) in an extremely rapid manner, accelerating the process several million times by providing the capacity to expose millions (or even billions) of single cells to these factors [18]. Thus, by employing this callus tissue culture procedure, and utilising selected cell cultures, plant breeders have been able to develop sugarcane cultivar resistant to *Helminthosporium sacchari*, *Sclerospora sacchari* and sugarcane mosaic virus, employing the ability of single cells being capable of regenerating into complete plants after selective screening of the single cells exposed to the factors under test [18]. Similarly, promising potato and tobacco plants resistant to *Phytophthora* have been selected within 2 years using this callus tissue culture method, in contrast to the 6 years which the conventional F_2 selection methodology carried out in greenhouses and on the field would normally have taken [18].

The last illustration to be given concerns the experimental use of viruses, particularly the highly insect-specific baculoviruses, for the control of lepidopterous insects, which contain a major group of the crop pests in the tropics. Baculoviruses are restricted largely to the Lepidoptera, Hymenoptera and Diptera; as they variously produce polyhedral and capsular inclusion bodies, they appear ideal biological pesticides; and their safety has been positively evaluated by the U.S. Environmental Protection Agency, a body which has established some of the most stringent standards of environmental impact assessment. The prospects for using baculoviruses for crop protection are therefore high [19]. Already, of the 300 baculoviruses known, 50 have been produced in amounts sufficient for field testing, and 6 of these are being produced by industry [19]: nuclear polyhedrosis viruses of 5 noctuid moths (*Autographa californica*, *Heliothis zea*, *Prodenia litura*, *Spodoptera exigua*, and *Trichoplusia ni*) and 1 sawfly forest pest (*Neodiprion sertifer*). For regular use to be assured, three problems need to be solved. Firstly, better persistence in the field needs to be guaranteed, perhaps through chemical protection or by genetic selection, as the virus particles are quickly inactivated by sunlight, especially ultraviolet radiation. Secondly, immediacy of impact on virus application is lacking: insect damage to crops is not immediately prevented in the first generation, although protection against future insect generations is usually good. Thirdly, multiple application of the virus is usually needed, simply because a single application is not adequate to trigger off an epizootic, nor to provoke a self-sustaining infection above the critical level needed for effective insect control.

The prospects are that increasingly sophisticated research and development will be undertaken in Africa and elsewhere to develop a spectrum of long-range, cost-effective, and sustainable management techniques to control the major pests and disease vectors of the tropics without disturbing too much the existing plant-insect associations which have been evolved over a long geological period of coexistence.

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