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The Case for Insect Pest Management in Agroforestry Research

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SUMMARY

Insect pest problems in agroforestry are likely to arise from two sources: those problems associated with the importation of wild plants into intensively managed ecosystems and those related to some peculiar features of agroforestry. These problems become more prominent if the imported woody plants are taxonomically related to the food or commercial crops of a recipient country. In this paper, the insect pest complex of the leguminous genus Acacia, *with emphasis on* Acacia mollissima (=mearnsii), *is briefly reviewed to illustrate the potential insect pest problems to the exotic plants themselves and how, as companion crops, the exotic plants may compound the pest problems of food legume crops. There is presently a contention that agricultural insect pest management strategies are duplicatable in agroforestry systems. But the bio-ecological factors governing the population dynamics of the insect pests in the two systems are not necessarily the same. This is largely because agroforestry, with time, matures into a complex system of perennial woody plants whose ecology is temporarily interrupted by the cultural processes of crop husbandry and harvesting of these annual crops, while the modern, herbaceous-agricultural systems remain perpetually youthful as ripened crops are harvested and the unwanted vegetative parts ploughed down or removed off the fields. Because of this, the author has suggested that new sets of data are required for insect pest management in agroforestry systems. Data on insect pest behaviour as influenced by (i;) plant species diversity, (ii) perennial woody plants, (iii) age of the agroforestry system and (iv) the cropping pattern and relatedness of the companion crops, are considered paramount at this stage of agroforestry science.*

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INTRODUCTION

An old system of food production and land use management in the tropics has eventually been rejuvenated after it was summarily described as primitive, firstly, because of vested economic interest which pertained to monocultural strategy and secondly, because experts did not understand it (Trenbath, 1975). Monocultural strategy drove wedges between, and among, plant scientists of various specializations. Forestry was the domain of foresters and agriculture was seen as the preserve of agriculturalists plus the bulk (80%) of the tropical peoples who live in rural areas.

But now, forestry is being grafted onto agriculture, or vice versa, and several names have been coined for the new system—for example, agroforestry, agrisilviculture, silvipasture, etc (Stewart, 1981). This reunion was inevitable, though somewhat belated: globally, arable lands have become critically scarce and, especially in the tropics, the result is that these lands are now cropped continuously but with hardly any revitalizing inputs, which has, in turn, led to low crop yields that can no longer adequately feed tropical peoples. Agroforestry is primarily intended to redress this situation through the incorporation of soil revitalizing and stabilizing woody or herbaceous plant species into these cropping systems. Other technical and socio-economic reasons (Buck, 1981; de Bruijn, 1981; Raintree, 1983) are also propelling agroforestry towards the frontier of research in land use management. Although agroforestry is not new in the tropics, the practice was known in the past, under various names: *taungya* in south-east Asia and shifting cultivation in Africa and other parts of the world are good examples. The concept of agroforestry in the past century or so thus evolved (in most cases haphazardly) around the practice of growing food or cash crops in mixtures with trees or shrubs which were either planted or remnants of the natural vegetation of a particular locality. The majority of these traditional agroforestry systems, especially shifting cultivation, are breaking down—or have broken down—because they lacked supportive scientific principles and guidelines (also see below).

Thus, therefore, although the modern concept and/or definition of agroforestry varies with specific management objectives, there is one common inherent feature; that of detailed research on, and eventual re-introduction or introduction of, suitable and acceptable (Huxley, 1983*b*; Rachie, 1983) indigenous or exotic trees and shrubs into these

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impoverished lands to serve farmers or recipients in more than one way.

There are, however, four important points within this 'marriage' on which attention should be focused simultaneously in order to forge a firm base for agroforestry. These are: (i) scientific research in agriculture is more advanced compared with that in forestry (even in arboreal monocultures, excluding orchards); (ii) immaturity (van Emden & Williams, 1974; Matthews, 1976) is a common characteristic feature of agricultural, agroforestry and forestry systems in the early stages; (iii) ecological requirements for biomass production are not necessarily the same in all three systems with the passage of time and (iv) some of the time-tested agroforestry practices, especially shifting cultivation, cannot easily be revived.

The imbalance in research efforts existing among the three related disciplines (agriculture, forestry and agroforestry) and the realization that the ecological requirements of the three systems are different were fully recognized from the inception of agroforestry and a segment of scientists are now taking care of this (Huxley, 1983*a*). In other words, agroforestry is cautiously borrowing heavily from the plant research methodologies and ideas of agriculture, botany and, to a less extent, forestry, to enrich itself. The perfection of these research methods will assist in the design and establishment of agroforests, as well as in the revitalization of some of the traditional agroforestry systems. But it is also important to realize that revitalization is simply not possible in most cases. First, such systems, which were once stable farming systems, have broken down for two main reasons: (i) population pressure on arable lands and (ii) the introduction of commercial cash crops in some parts of the tropics (see above also); indeed, in some countries, indigenous woody plants have been wiped out of such lands. Secondly, the justifiably rigid criteria for the choice of woody plant components for agroforests (Huxley, 1983*b*; Rachie, 1983) do not favour a good many existing indigenous tree species of these needy tropical countries. Most of these trees are slow growers and offer little or no intermediate economic inducements except as sources of firewood and building materials. And, thirdly, the more orthodox view that very few useful plants have ever been found in secondary centres of origin of cultivated plants (Allard, 1960), suggests that few tropical countries, especially African, would serve as centres of origin of useful agroforestry plants.

Agroforestry will, therefore, be concerned mainly with the domestication, introduction and management of exotic woody plants grown in

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mixtures with agricultural crops and, in very isolated cases, the re-introduction of the few suitable indigenous woody plants into areas where they once flourished before man savaged them out of existence. In either case, there are production problems and these problems are different from those in agriculture, chiefly because of the production (i.e. planting-to-harvesting) cycle of agroforests and those associated with the first stages of the domestication of wild plants. Within agroforestry itself, these problems will again vary in magnitude as a result of management prescriptions. The success of agroforestry will therefore depend on systematic research activities, geared to resolve these production problems, by scientists engaged in this infantile science.

In this paper, the author is advocating research on insect pests of agroforests. The paper introduces and supports the institutionalization of agroforest entomology as a necessary discipline within agroforestry science and briefly outlines aspects of agroforestry systems where research can be undertaken immediately to augment the present knowledge acquired under both agriculture and forestry. Such information will greatly assist in the design, revitalization and establishment of agroforests.

THE NEED FOR INSECT PEST MANAGEMENT RESEARCH IN AGROFORESTRY

The basis for agroforest entomology

Present agricultural systems owe their existence to traditional agroforestry practices which formed the backbone of farming in Europe, Asia, Africa and the Americas soon after the era of Hunting and Food Gathering. It can therefore be argued that the concepts and practices of combating the insect pests that ravaged man's food crops evolved and developed under agroforestry systems until the advent of monocultural agriculture in each of these continents. Unfortunately, however, the woody plant components of these traditional agroforests offered little of economic value to peasant farmers and the 'agricultural entomology' of the time rightly ignored them. Neither the impacts of insects on them, nor their influences on the crop pest biology and ecology, were directly assessed. However, with the passage of time, indirect interests in

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agroforest entomology began to appear in the literature of agricultural entomology. Entomologists had inadvertently discovered that, in order to study and fully understand the biology and ecology of a good many serious agricultural insect pests, it is necessary to move out of the fields into adjoining woodlands or forests.

The discoveries that: (i) some aphid species can complete one to several generations on alternate wild woody host plants before migrating onto various field crops; (ii) the Bruchids, the seed pests of grain legume crops, in general also feed on the seeds of wild leguminous woody plants (Janzen, 1969); (iii) a deliberate incorporation of wild flowering plants into agricultural systems, or conserving such plants in the hedgerows as a source of nectar and pollen, enhances the effectiveness of parasitoids in biological control practices (van Emden, 1965; Weseloh, 1976); (iv) some non-food plants act as physical barriers and reduce the dispersal and searching ability of parasites (Price, 1970, 1971); (v) some plants act as diluting agents of the volatile cues emanating from host food plants to confuse the parasites which do rely on such volatile substances to locate their hosts (Vinson, 1976); and (vi) some crop pests find refuges in adjoining woodlands, hedgerows, forests, etc., when environmental conditions in the fields become unfavourable (Way, 1966; Callan, 1969), are a few of the many implicit references to agroforest entomology in modern literature. Implied in the above observations is the fact that agroforest entomology will seek to collect, synthesize and collate entomological information that integrates the behaviour patterns of insects which are common and/or specialist pests of woody plants and agricultural crops that can be grown in mixtures, on the one hand, while, on the other, it will attempt to elucidate the effects of agroforestry systems on the pests' natural enemy complexes.

Domestication of woody plants and insect pests

It is obvious, except for a few passing references (Huxley, 1983*b*; Rachie, 1983; and others) that agroforest entomology has had less representation in most international conferences on agroforestry. This is perhaps because, at this formative stage, most experts are pre-occupied with the idea of screening and domestication of woody plant components for agroforestry, the majority of which are less known and are forest or woodland species which have co-evolved with their pest complexes (Pimentel, 1961; Root, 1973; Murdoch, 1975; Price, 1975; Matthews,

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1976; Way, 1976; Strong, 1979; Smelyanets *et al.*, 1981). Thus, problems of insect pests do not feature much in their discussions.

However, as in agriculture and forestry, agroforestry involves a reduction in genetic diversity which results from rigorous selection of the parents that contribute progeny to the next generation, establishment of crop populations from small samples of wild plants and an inevitable element of inbreeding. All these erode viability and produce genetic structure in man-managed plant populations different from that in conspecific wild populations (Pickersgill, 1983). Besides, domestication, in most cases, dictates that certain intrinsic qualities, structures and/or organs of the wild plants, unacceptable to man or his domestic animals—the attributes which may actually, collectively or singly, be the basis of defence mechanisms against herbivores—are bred out, either to facilitate management and harvesting of the plant or to enhance the palatability of such plants to man (Allard, 1960). Agriculture—and, to some extent, forestry—have both learnt that breeding out some of the intrinsic defence traits is the basis of insect problems on crop plants. We can, therefore, envisage situations where these newly domesticated plants may be invaded by a more or less frequently disrupted set of insect species that, on average, must have had a relatively brief shared history (van Emden & Williams, 1974; Murdock, 1975). Furthermore, a typical characteristic feature of many agroforests is that a fully domesticated crop is combined with a crop which is only at the stage of incipient domestication (Pickersgill, 1983), a situation which again could be a source of serious insect pest problems.

Lessons from the past

The history of transcontinental developments of agriculture and forestry, plus published evidence, leaves very little room for present complacency. It is known that when transport facilities improved in the fifteenth century (barring the early Egyptian, Chinese, Mesopotamian, etc., travellers (Allard, 1960)), man embarked upon an extensive importation of domesticated and/or wild plants and animals; unfortunately, in some cases, to countries whose climatic and ecological conditions were inadequately known. The economic benefits of these enterprises are common knowledge (Allard, 1960), but some ended up disastrously. For example, the importation of scale-infested plants of *Acacia latifolia* from Australia which threatened the entire citrus industry along the Pacific

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coast (Martin, 1973), the prickly pear in the Australian pastures (Dodd, 1927) and the story of the black sage, *Cordia macrostachya* in Mauritius (Kirkpatrick, 1957), all remind scientists of the inherent dangers (van Emden & Williams, 1974) that attend the exercise of domestication and introduction of plant species into foreign environments before full evaluation has been carried out.

The widely accepted generalization that, whether insects are herbivores, parasitoids or predators, they share one common characteristic—namely, that they have a high degree of host-specificity as a result of co-evolution between eater and eaten (Matthews, 1976)—is deceptive. The herbivores in many instances break this natural law (see below): generalists or specialists may switch over from their native food plants to newly-introduced crops or ornamental plants, either with a minimum of genetic adjustment or because the new plants are taxonomically or chemically related to the indigenous host plants (Root, 1973).

Choice of woody plant components

The current biological criteria for choice of woody plants are largely dictated by the envisaged rôle of a particular agroforestry system. These criteria are less rigid and relaxed when weighed against the potential insect pest problems associated with such undertakings as mentioned above. There is therefore a need for a rigorous exercise in choosing woody plants for agroforestry. This exercise should preferably be based on the useful attributes of the woody plants which have been carefully weighed against the potential insect pests associated with the tree species. It is common sense that tree and shrub species which are taxonomically related to the major food or commercial crops grown in an area should be thoroughly screened before introduction. Thus, therefore, the current choice of leguminous tree and shrub crops (e.g. *Leucaena*, *Albizia*, *Acacia*, etc.) can be questioned in a number of tropical and subtropical countries where the major food crops are taxonomically related to these tree species.

From among the three promising leguminous genera, *Acacia* is useful for illustrating the magnitude of the potential entomological problems in agroforestry systems where they may be grown. The diversity of insect species feeding on, or associating with, *Acacia* is enormous. For example, sixty-three species which feed directly on *Acacia* trees and shrubs were

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reported in Australia (Froggatt, 1923) and it was rightly observed that these could only be a small fraction of the associated entomofauna (Matthews, 1976), considering that about sixty species of Cerambycidae alone were reported as pests or associates of this genus in Australia (Duffy, 1963) while another record shows nineteen families from which over forty-five species of insects are pests of *Acacia* spp. in East Africa (LePelly, 1959). Worldwide data indicate that fifty-six insect species from the orders Coleoptera, Hemiptera, Lepidoptera and Orthoptera are pests of this genus (Browne, 1968). This list has recently been expanded in Australia (Common & Waterhouse, 1972). It is within bounds, however, to guess that some of these insect pests are either polyphagous, oligophagous or monophagous. Again, one can speculate that their attacks are not in unison, but sequential; thus, from among them we can expect seed-eaters, defoliators at various vegetative growth and wood-borers. There are two deductions one can make from these observations. First, that any species selected from this genus can become a host plant to a number of native insects, especially if such a plant is grown in an intensively managed production system, and, secondly, that infested plant materials imported from such a species can be the source of pest problems in agroforestry and near-by production systems where legume food or commecial crops are grown.

The first argument can be illustrated using *Acacia mollissima* (= *mearnsii*) (a native of Australia) which is extensively grown in Kenya for tannin, but was occasionally grown in Uganda and Tanganyika for soil conservation on steep slopes. There are sixty-three insect species from twenty-five families attacking *A. mollissima* in Kenya compared with four species from four families and three species from three families attacking this plant in Uganda and Tanganyika, respectively (LePelly, 1959): the Tanganyikan species are all Coleopterans, whilst the Ugandan species are one Coleopteran, one Hemipteran and two Lepidopterans. Several facts emerge when the Kenyan insect pest species of *A. mollissima* (LePelly, 1959) are compared with the 'worldwide' data (Browne, 1968) (Table 1).

One point is evidently clear from these data. The insect pest species attacking *A. mollissima* in Kenya are remarkably different (only 15·8 % of the pest complex attack *A. mollissima* outside Kenya) and, for a small country like Kenya, with no physical barriers separating it from the neighbouring states, the pest burden is proportionately very high (88·7 %). On the basis of this evidence, it is reasonable to assert that the native insect species have switched over from their indigenous food plants

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TABLE 1

Acacia mollissima Insect Pest Complex in Kenya versus That of the Rest of the World and the Proportion of the Kenyan Pest Species Attacking *A. mollissima* in Other Parts of the World

Order	*Worldwide*	*Kenya*		*Kenyan pest species occurring outside*	
	Number	*Number*	%	*Number*	%
Coleoptera[a]	29	36	124·1	2	5·5
Hemiptera	15	15	100	4	26·6
Lepidoptera	27	12	44·4	4	33·3
Total	71	63	88·7	10	15·8

[a] It is doubtful whether Coleopteran data are comprehensive.

onto the highly concentrated food resource, *A. mollissima*. The switch-over trait is common in herbivory (see, for example, Tindale (1928)) who reported the switch-over of the genus *Chlenias*; Geometridae from *Acacia* to cultivated *Pinus* in South Australia). While the present *A. mollissima* pest complex might have switched over from the closely related (taxonomically and chemically) native *Acacia* spp. of Kenya, *Pinus* and *Acacia* are not taxonomically related. It would be interesting to know whether this switch-over was triggered by chemical relatedness of the two genera or whether the insects themselves underwent minor genetic adjustment, or a totally different phenomenon was at play.

That the negative and/or positive aspects of *A. mollissima* entomology up to now have not been realized in Kenya is because this crop has not been grown in a mix with the major food legumes. Analysis of the record (LePelly, 1959) (Table 2) indicates that only *Vigna unguiculata* and other *Vigna* species may be safe if grown together with *A. mollissima* in East Africa.

Cajanus cajan shares with *A. mollissima* six families of insect pests, two species being coccids which are sessile and therefore would benefit from the permanent refuge and food resource offered by *A. mollissima* grown together with this crop.

Controlling insect pests in agroforests

No evidence as yet exists to suggest that the pest picture in agroforests is more or less alarming than in agro-ecosystems. But information steadily

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TABLE 2
Analysis of Pests in Kenya

	Number of pests on			
	Phaseolus vulgaris	Pisum sativum	Vigna unguiculata	Cajanus cajan
Families	14	12	21	28
Species	37	24	34	77
	Number of common pests with A. mollissima			
Families	3	3	—	6
Genera	3	3	—	4
Species	1	—	—	2

accumulating from di- and poly-cultural systems of agriculture does indicate a lessening of severity (Trenbath, 1975; Baliddawa, 1983) and therefore can assist us to deduce that increased niche availability, due to diversity and complexity of plant species in agroforestry, may enhance, in various ways, the activity of biological control agents and thus cause a general reduction in pest populations more than in monoculturally cropped systems. Often, however, biocontrol agents and other control practices, when applied singly, may fail to achieve the desired results and, nowadays, the tendency is to integrate all suitable control techniques, including chemical control methods, to suppress insect pest populations to economically tolerable levels (van den Bosch *et al.*, 1971). In situations where we are forced to use a chemical, either to augment other control practices or as a last resort, we can be sure to receive a full dose of problems associated with this method, problems due to toxicity in effects on the non-target biota, on the one hand, and, on the other, problems uniquely agroforestry in nature. For example, the problem of adopting the modern technology of chemical control techniques, developed and perfected under generally immature monocultural systems of agriculture, for use in agroforestry systems whose configurations are temporally more diverse, and the problems related to the production cycles in agroforests, are very disturbing.

Woody plant components, in general, make pest control in agroforests more costly than in monocultures; these perennial plants tend, more than seasonal crops, to build up their insect problems as the years go by, thus making pest management more complex. Because of the need either to

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change or to devise new control tactics or to adjust present control strategy in order to combat new sets of pests, expensive equipment, pesticides and other essential inputs may be rendered valueless. Thus, the economics of insect pest control systems in agroforests has a very significant bearing on their design. Knowledge and control strategies for specified insect pests should be consulted right from the outset and relevant aspects appropiately incorporated in such designs to save the recipients from the heavy economic burdens that could result from such mistakes.

INSECT PEST MANAGEMENT RESEARCH FOR AGROFORESTRY SYSTEMS

Introduction

Agroforestry is a system whose productivity of plant biomass is governed by some, or all, the known ecological factors necessary for plant growth. The system is more or less different from natural plant production systems, but, to a large extent, is similar to agroecosystems in the early stages in that both are immature production systems. Nevertheless, it is partly wrong to contend that pest problems in both systems are similar. And the reasons for this difference are varied. For example, the plant components and the diversity of canopy strata in agroforestry are, in the main, different from those in polycultural systems of agriculture. It is also equally wrong to assume that, because ecological hypotheses about natural and agroforestry systems are more or less the same, insect behaviour in the two systems is therefore necessarily the same. The latter assumption, unfortunately, was generally believed to be true in polycultural or diverse and complex agricultural systems until detailed studies proved it wrong (Pollard, 1971; Root, 1973; Perrin, 1977).

As already mentioned above, it is wise, from the outset, to assess the woody and herbaceous plants for agroforestry, mindful that the potential insect pest problems are largely different from those in agricultural, forestry and other cropping systems. There is, as yet, no evidence to lead one to doubt that agroforestry systems may modify the behavioural attributes of the known insect pests of agricultural crops that will be grown together with these trees and shrubs.

Thus, the approach and strategy for insect pest management research

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in agroforestry lie in a cautious selection of research methods and techniques from agricultural, forestry and natural ecosystems with a biased emphasis on areas which are duplicatable in agroforestry. Such areas are briefly discussed below.

Crop diversity and complexity

It was implied earlier that agroforestry is a practice that aims at maximizing food, wood, etc., production on a given unit of land through crop diversity. With respect to insect pest management, this practice has both advantages and disadvantages. The management of insect pests in such a system can be greatly improved through conscious establishment of the right type of diversity and complexity which can only evolve from a well-planned programme of research. Undoubtedly, the creation of crop diversity (not necessarily complexity) in agroforestry will follow very closely the practice in agriculture. For example, in space, crop diversity could be achieved through strip cropping, inter-planting, mixed-row cropping or as cover crops, while in time, diversity could vary according to whether mixed crops are planted simultaneously or in sequence as rotational crops, relay cropping, ratoon cropping or whether crops are combined in a synchronous fashion or in a continuous or discontinuous planting sequence (Litsinger & Moody, 1976).

Many authorities argue that crop or plant diversity of various types (Way, 1970; van Emden & Williams, 1974) creates stability and therefore prevents insects from attaining epidemic populations (Watt, 1964, 1965; Price, 1975). But the equation, diversity = stability = decreased pest damage (Way, 1976), has, of late, been questioned with reference to various mixed-cropping agroecosystems. There is a school of thought which asserts that adding more species into a cropping system generally causes stability to decrease (van Emden & Williams, 1974; Murdoch, 1975) or that there are mechanisms as yet difficult to elucidate about stability in diverse habitats (Pollard, 1971). Nevertheless, evidence also exists that, in some systems, pest problems can be reduced (Trenbath, 1975; Perrin, 1977) either through the masking and camouflaging effects of the plants, the provision of alternative host plants, various biological space-and-time crop diversity (Way, 1970) or through resource concentration (Root, 1973; Baliddawa, 1983).

The ecological argument for or against the stability hypothesis has taken various forms, but one of them (Way, 1976) is elaborate and points

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to immediate research areas needed in agroforest entomology. This particular argument states that the concept of stability is untenable because:

(i) Diversity of plants is not necessarily related to stability.
(ii) Great plant diversity does not necessarily mean equivalent diversity of insects or other animals.
(iii) Great plant diversity does not necessarily mean the existence of a complex web system of stabilizing balances and checks.

Although the argument was based mainly on tropical forest ecosystems and some studies in agroecosystems (van Emden & Williams, 1974) have proved it right, the effect of plant species complexity on the behaviour of insects was never explicitly mentioned. Plant species complexity (van Emden & Williams, 1974; Strong, 1979) is one of the characteristic features that distinguishes agroforestry from most agricultural systems. It is therefore imperative to re-evaluate the validity of this argument in relation to some of the peculiar characteristics of agroforestry systems listed below.

Plant species diversity
This can range from dicultural to systems which more or less mimic natural ecosystems (Okigbo, 1983). It is to be noted that, with increase in plant species diversity, the animal species diversity also follows, thus, some emphasis should be placed in this area to map out insect behaviour in various agroforestry systems.

Woody plant components
Anatomy and morphology. Trees tend to have more anatomical and morphological diversity than do shrubs, which, in turn, have more than herbs. Morphological diversity might act to create niches for herbivore species as well as for their parasitic complex.

Permanence of crops. Many major pests of perennial crops have a limited tendency for dispersal and form a relatively 'closed' population together with their complex of natural enemies (Southwood & Way, 1970) and the longer the time available, the more species adapt to the resource (Price, 1975).

Microclimatic conditions. Tall vegetation often greatly alters and creates micro-environmental conditions for the shorter companion crop,

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which differs from the situation in pure culture. This different environment may affect host–pest or host–parasitoid relationships in subtle ways (Trenbath, 1975, Kayumbo, 1976).

Diversity pattern and relatedness of the companion crops
The diversity–stability–decreased insect damage concept can depend on the type of crop diversity created and to what extent the companion crops are related. For example, space–biological diversity and relatedness may, through differences in phenophase and through provision of refuges, oviposition, hibernating and pupation sites, maintain the entomofauna in the system for a relatively longer time than in the time–biological diversity system with unrelated or related crop companions.

Age of the system
Three different types of agroforestry system have been envisaged (Okigbo, 1983): (i) existing farming systems, (ii) production systems which mimic natural ecosystems and (iii) totally new, innovative production systems. The last two types of agroforestry system presuppose expansion into lands which are currently underutilized, such as forest reserves. This could result in a drastic disturbance of the environment of the local insect fauna and, in consequence, changes in its composition: the essential practical feature of these changes is a radical reconstruction of the injurious fauna of the useful plants (Uvarov, 1972).

The list, no doubt, is not exhaustive but is essentially reasonable at this critical stage of agroforestry science. There are obviously many areas where fresh data bases are also urgently required to deepen our knowledge of agroforest entomology. These include aspects such as the degree of browsing competition within and between insect and domestic mammalian herbivores, and the rôle of arthropods in the recycling of nutrients, especially in agroforestry lands whose woody perennials are non-leguminous, etc.

CONCLUSIONS

The development of agroforest entomology lagged behind that of agricultural entomology because the woody plant components of traditional agroforestry systems offered little of economic value to peasant farmers and hence only those insect species which caused vivid

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economic impacts on the yields of food crop components of the systems were studied and their populations suppressed. However, with rationalized agroforestry practices resulting from current research efforts and strategies, there is now a need to institutionalize agroforest entomology within agroforestry science to provide a base for insect pest management research in agroforestry systems. Traditional concepts of both agricultural and forest entomology are too rigid and therefore tend to leave out entomological data pertaining to the environmental dictates of the perennial woody–annual (seasonal) herbaceous crop 'interface' which is the basic characteristic feature of many agroforestry systems. Moreover, problems associated with controlling insect pests in agroforests, especially with chemicals, call for innovative or novel research strategies for their solutions.

It seems probable that the formulation of agroforest entomology would be based on relevant aspects of both agricultural and forest entomology. Thus, areas such as mixed-cropping entomology, tropical rain forest entomology and the bases of plant resistance to insect attacks, especially with regard to domestication and breeding programmes of wild woody plants, can, and will, assist in the formative stages of this discipline. Many benefits will accrue from agroforest entomology data. For example, the elucidation of defence mechanisms which have enabled wild plants and insects to co-evolve, using the current research techniques developed for agricultural entomology, will immediately guide plant breeders in decision-making as to what characteristics can be retained or discarded without predisposing the plants to serious pest attacks. All in all, however, agroforest entomology will contribute to our ability to give optimal entomological answers to the basic agroforestry design questions and crop husbandry in general.

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