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CHAPTER 11

Groundnut pests

J.A. Wightman and G.V. Ranga Rao

11.1 INTRODUCTION

There have been four major reviews of the literature discussing the insects living on groundnut plants since 1973 (Feakin, 1973; Smith and Barfield, 1982; Wightman *et al.*, 1990; Gahukar, 1992). There are also several more concise accounts dealing with pest problems in general (e.g. Wightman and Amin, 1988; Wightman *et al.*, 1989; Lynch and Douce, 1992), specific topics, such as host plant resistance (Lynch, 1990), and discrete geographical zones such as India (Amin, 1988), developed countries (Biddle *et al.*, 1992) and southern Africa (Wightman, 1988a; 1989; Sohati and Sithanantham, 1990; Sithanantham *et al.*, 1990). Feakin (1973), Redlinger and Davis (1982), Dick (1987a,b) and Wightman *et al.* (1990) provide details of the insect pest problems associated with stored groundnut and their management in developed and developing countries. There is little more to add to what has already been recorded about the post-harvest pests of groundnut – the limited coverage given to them in this chapter should not be taken as an indication that they lack importance. Thus, although the general literature up to 20 years ago was somewhat sparse (despite the publication of a large body of information in primary sources), there have since been attempts to redress the situation.

Smith and Barfield (1982) extended Feakin's (1973) pioneer work by providing an invaluable list of the pest species associated with the crop. There is not yet enough verified or verifiable data to distinguish between those insects that merely live on, under or around groundnut stands without causing appreciable damage, and those that are capable of causing significant or economic reductions in crop yields when their populations reach a particular intensity. We call the latter **pests**, restricting the term to mean 'insects' as opposed to all biotic constraints. For the sake of simplification, we include all yield-reducing arthropods (in particular, myriapods and arachnids) with the insects. The term **intensity** is adopted to indicate that yield loss can be influenced by pest density, the duration of the

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general move away from complete reliance on synthetic insecticides for managing (i.e. killing) insects that may have a detrimental effect on crop yields. There may also be a case for suggesting changes to the management of the many farms that grow groundnut without insecticide application. The alternatives are combinations of:

- the provision of crop varieties that are in some way resistant to the most important pest(s);
- sowing crops in combinations or patterns that result in pest outbreaks being diminished in intensity and frequency: such modifications may involve the physical environment, and/or
- changes in the farm environment that encourage the natural enemies of potential pests to aggregate within the cropping system;
- enhancing natural control processes by releasing biological agents such as specific insect pathogens, parasites or predators in the farm environment;
- applying natural or synthetic insecticides only when they are needed and in such a way that the impact of predators and parasites is not diminished.

A common feature of these intertwined alternatives is the emphasis on the prevention of pest outbreaks. It is also clear that they are not necessarily crop specific, and not always even farm specific. There can be good reasons for IPM being the business of the community.

These concepts are the basis of the IPM tool box and involve making management decisions beyond the traditional or conventional gamut of what has been known as pest management. The people who are going to make these decisions are the farmers. The role of the scientists (of several disciplines) and extension workers is to evaluate procedures that may not have occurred to farmers and to demonstrate alternative approaches to procedures that the advisors see as being detrimental. Farmers in developing countries can rarely employ specialists (soil analysts, IPM scouts, disease forecasters, etc.) to help them make decisions. Thus, although a team of scientists can and should ensure that IPM procedures 'fit' particular sets of environments, it is the farmer who has to make the day-to-day and season-by-season decisions according to his or her own perceptions of the resource base of the farm or family, its requirements and aspirations.

Once they have their initial data sets, scientists genuinely interested in IPM should probably consider the need for interaction between the laboratory and the land, the farmer, the advisor and the researcher. General principles can be worked out on research stations but do not gain relevance until they are established as being viable on a number of farmers' fields. However, IPM is knowledge intensive, and some of the available knowledge is presented below.

11.2 THE INSECTS

This section describes the insect taxa most likely to be associated with reduced groundnut production, together with an indication of their distribution and the kind of damage they cause. Further details of their biology and ecology are available in Wightman *et al.* (1990) and in the other publications indicated below.

11.2.1 Soil insects

The insects that live in the soil of groundnut fields are responsible for higher levels of yield loss than foliage feeders. They attack pods and roots, and the foliage via the roots. Anitha (1992) has constructed a key to the pod borers based on damage symptoms.

Soil insects are difficult to manage because farmers usually do not know that they are present until plants die or until the crop is harvested. The prophylactic application of insecticides at sowing is not generally a feasible proposition because of the non-availability of suitable products in many countries, their high cost, and the residue problems many create in the seed. The latter point refers specifically to the lipophilic but highly effective cyclodienes such as dieldrin, aldrin, endrin and heptachlor. The unacceptability of organochlorine residues in the environment in general, and in the oil of groundnut seeds in particular, has meant that farmers have lost access to the only persistent insecticides that give good control of soil insects at a low price. However, they did present a risk to the health of the applicators and of other non-target organisms. Progress is being made in other areas of soil pest management following international recognition that a widespread problem exists.

(a) Isoptera – termites

Termites are pests of groundnut throughout Africa, and in western and southern Asia. Several of the most troublesome species are distributed throughout this rather large region. Their attacks are usually associated with periods of drought and therefore tend to be most serious at the end of the growing season. They are less serious in Asia as a whole because they prefer sandy or at least light, well-drained soil. Their life style is thus not compatible with the lowland paddy systems that dominate much of the agricultural landscape of this continent. However, as Wood and Cowie (1988) list three of the termite genera mentioned below as being pests of upland rice in West Africa, it is apparent that the cultivation of this crop is not a complete barrier to termites. They are also rated as being a major groundnut pest in Nepal (personal observation) and are recognized as pests in southern Asia and Thailand (Wightman *et al.*,1990; Logan *et al.*, 1992).

The only species of ant known to be groundnut pests are *Dorylus orientalis* and *D. labitus* (doryline, blind or red ants). The ants hollow out the pods as they approach maturity, entering by regular holes 2–3 mm in diameter.

Both species have been known as pests of groundnut in India and Malaysia (Dammerman, 1929) for many years. Only in Thailand is the problem sufficiently serious for action to be taken to manage *Dorylus* spp. (poisoned coconut meat baits). It is recently believed to have been found in Philippine groundnut fields (ICRISAT, 1991a). There is thus a good case for a concerted search of groundnut fields in the countries between the Philippines and India to determine its range and perhaps the site characteristics that govern its presence or absence in Asia. Wightman and Wightman have found *Dorylus* sp. under groundnut in Malawi, Zambia and Zimbabwe and have detected pod damage in Malawi.

(e) Coleoptera

Buprestidae – jewel beetles The jewel beetle *Sphenoptera indica*, which is a root borer, has been known as a widespread resident of groundnut fields in India for many years (Rai, 1979). Information about its potential pest status has recently become available (Logan *et al*., in press). In a rain-fed field on the ICRISAT Research Farm 20 days before the 1986 rainy-season harvest, it was found that 23% of the groundnut plants had *S. indica* in their roots as larvae, pupae or adults. As the three larval instars tunnel through the parenchyma of the root, a high rate of mortality or severe wilting among the attacked plants was anticipated. On one side of the field, where 76% of the plants were attacked, 82% of the dead plants and 64% of the living plants were host to this species. A survey of groundnut plants growing in three irrigated fields on the ICRISAT farm in the 1986 rainy season revealed infestation rates of 0.4%, 9% and 14%. This indicates that irrigation does not eliminate the risk of attack by this species. Attacks in subsequent years have been sporadic, and spread across the 1300 ha farm; they have been sufficiently heavy to permit us to screen for resistance to this species among *Arachis* spp. A survey in Andhra Pradesh and Karnataka (southern India) in the rainy season of 1992 revealed that up to 10% of the plants growing on red soils (alfisols) had been killed by this species.

Scarabaeidae – white grubs (as larvae); cockchafers, May bugs or June beetles (as adults) The general importance of white grubs as pests of groundnut in India and in parts of southern Africa has been recognized only recently (Wightman *et al*., 1990). Since then, further research and discussion with experts from Asian countries has revealed that white grubs are associated with yield loss from India to China and the Philippines. They are also a problem in moister areas of West Africa, such as Senegal.

Appert (1956) noted that 'underground larvae' (i.e. white grubs, Table 11.1) can cause as much damage as millipedes,which are usually recognized as a major constraint to groundnut production in West Africa.

It has therefore been possible to extend the list of white grub species associated with groundnut (Table 11.1; cf. Table 5.10 in Wightman *et al*., 1990) to include further information from Asia and southern Queensland, Australia, where the identity of the main peanut pest species has been resolved and a key provided (Rogers *et al*., 1992).

It appears that there are some 70 named species (including subspecies) of white grub known to be associated with the groundnut crop. However, the current maximum exceeds 100 because of the number of undescribed species. This compares with *c*. 52 species of termites (Wightman *et al*., 1990) and more than 60 lepidopteran species (Smith and Barfield, 1982).

White grubs feed mainly on the taproots and/or the peripheral rootlets. Either way, the net effect is to restrict the growth of the plant. This is particularly marked in sandy soils in drought prone areas such as occur in groundnut fields of the Middle Veldt of Zimbabwe. Seedlings can be killed outright if the phenologies of the crop and pest result in large larvae and small plants occupying the field at the same time. In the Sudan, white grubs have been associated with aflatoxin contamination of groundnut left in the ground for 6 weeks after it should have been harvested (Ahmed *et al*., 1989).

Heteronyx piceus is the species most likely to cause damage in Queensland. It forms 90% of the scarab population under groundnut in the main growing area. It is unusual in that it attacks the pods but not the roots. Population densities of up to 30 larvae per metre of row nave been reported (Brier and Rogers, unpublished).

Kalshoven (1981) indicated that there are many species of *Anomala* in the Indonesian archipelago. Supriyatin (1991) reported that white grubs attack the roots of groundnut plants in upland crops in that country. As members of this genus are known to eat groundnut roots in other countries, it is likely that there may be an undefined white grub problem in East and/or West Java, the centres of groundnut production in Indonesia. Cadapan and Escano (1991) indicated that *Leucopholis irrorata* has recently been associated with the groundnut crop in the Philippines. This ties in with the major pest status awarded to this species in maize–rice systems (Litsinger *et al*., 1983).

A survey by Nath and Singh (1987) of cropped fields (mainly groundnut and sugar cane) in a relatively small area of eastern Uttar Pradesh, northern India, added 16 species to the list. They indicated that these species were common to all crops but were most numerous on groundnut and sugarcane. Several of these species were also found during a detailed tudy of white grubs many miles away in semi-arid Rajasthan, particularly around Jaipur (Yadav, 1981). However, Yadav did not associate them pecifically with the groundnut crop in his report, which concentrates on

TABLE 11.1 *Scarabaeidae associated with the groundnut crop in the larval (white grub) stage*

Species	Location	References
Adoretus cribrosus	Zimbabwe	Smith and Barfield, 1982
A. decanus	India	Nath and Singh, 1987
A. laisopygos	India	Nath and Singh, 1987
A. limbatus	India	Nath and Singh, 1987
A. umbrosus	'Africa'	Smith and Barfield, 1982
A. versutus	India	Nath and Singh, 1987
Adoretus spp. (up to 4 spp.)	Malawi, Zambia Zimbabwe	Wightman
Anomala antiqua	Burma	Smith and Barfield, 1982
A. atrovirens	Indonesia	Smith and Barfield, 1982
A. bengalensis	India	Nath and Singh, 1987
A. corpulenta	China (PR)	Xu, B.C., 1982
A. dorsalis	India	Yadav, 1981
A. dorsalis var. *fraterna*	India	Nath and Singh, 1987
A. plebeja	Senegal Burkina Faso	Appert, 1956 IRAT, 1976
A. punjabensis	India	Yadav, 1981
A. ruficapilla	India	Nath and Singh, 1987
A. rufocuprea	Korea (Rep)	Cho *et al.*, 1989
Anomala spp. (up to 11 spp. in southern Africa)	Botswana, India, Indonesia, Malawi, Zambia, Zimbabwe	Wightman; Yadav, 1981; Kalshoven, 1981
Anomala sp.	Burma	R. Milner, personal communication, not *A. antiqua*
Apogonia cribricollis	India	Nath and Singh, 1987
A. ferruginea	India	Nath and Singh, 1987
A. roucca	India	Nath and Singh, 1987
A. uniformis	India	Nath and Singh, 1987
Autoserica atratula	India	Nath and Singh, 1987
A. insanabilis	India	Nath and Singh, 1987
A. nathani	India	Nath and Singh, 1987
Dyscinetus trachipygus	India	Nath and Singh, 1987
Crator cuniculatus	Burkina Faso	IRAT, 1971
Eulepida mashona	'Africa'	Smith and Barfield, 1982
Heteroligus claudius	Nigeria	Smith and Barfield, 1982
Heteronyx brevicollis	Australia	Smith and Barfield, 1982
H. piceus	Australia	Rogers *et al.*, 1992
H. rugosipennis	Australia	Rogers *et al.*, 1992
H. sp. nr. *rugosipennis*	Australia Australia	Rogers *et al.*, 1992 Rogers *et al.*, 1992
H. diomphalia	China (PR) Korea (Rep)	Shang *et al.*, 1981 Cho *et al.*, 1989
Holotrichia consanguinea	India	Smith and Barfield, 1982
H. formosana	China (PR)	Lu *et al.*, 1987

TABLE 11.1 *Cont.*

Species	Location	References
H. morosa	Korea (Rep)	Cho *et al.*, 1989
H. oblita	China (PR)	Wang *et al.*, 1986
H. parallela	China (PR)	Wang *et al.*, 1986
H. sauteri	China (PR)	Huang and Lin, 1987
H. serrata	India	Smith and Barfield, 1982
Lachnosterna caudata[1]	Australia	Smith and Barfield, 1982
L. fissa	India	Smith and Barfield, 1982
Lepidiota sp.	Australia	Gough and Brown, 1988
L. crenita	Australia	D.J. Rogers and H.B. Briers, personal communication
Leucopholis irrorata	Philippines	Cadapan and Escano, 1991
Maladera orientalis	China (PR) Korea (Rep)	Wang *et al.*, 1986 Cho *et al.*, 1989
Maladera sp.	Thailand	Sathorn Sirisingh, personal communication
Neodon pecuarius (= *Trissodon puncticollis*)	Australia	Smith, 1946
Oxycetonia versicolor	India	Smith and Barfield, 1982
Pentodon idiota	USSR	Smith and Barfield, 1982
Phyllophaga ephilida	'Americas'	Smith and Barfield, 1982
P. armicans	'Americas'	Smith and Barfield, 1982
Podalgus (Crator) cuniculus	'Africa'	Smith and Barfield, 1982
Popillia japonica	China (PR), N. America	Smith and Barfield, 1982
Pseudoheteronyx basicollis	Australia	P.G. Allsopp, in Rogers *et al.*, 1992
Rhopaea magicornis	Australia	Smith and Barfield, 1982
Schizonycha africana	NE Africa Senegal	Smith and Barfield, 1982 Appert, 1956
S. fusca	Malawi	Wightman
S. ruficollis	India	Nath and Singh, 1987
S. straminea	Malawi	Wightman
Schizonycha spp. (up to 8)	Malawi	Wightman
Sericesthis ino	Australia	Rogers *et al.*, 1992
S. suturalis	Australia	Rogers *et al.*, 1992
Schizonycha spp. (up to 3)	Malawi	Wightman
Strigoderma arboricola	USA	Smith and Barfield, 1982
Trochalus pilula	Senegal	Appert, 1956
Trochalus sp.	Malawi	Wightman
Xylotrupes gideon	Burma	Smith and Barfield, 1982
Tribe: Sericini 8 indet. spp.	Malawi, Zambia, Zimbabwe	Wightman

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[1] not recognized in Australia, possibly *Lepidiota caudata*, see Gough and Brown (1988) (P.G. Allsopp, personal communication)

the predominant *Holotrichia consanguinea*. The predominant species in southern India is *H. serrata* (Veeresh, 1977).

Elateridae – Click beetle larvae or wireworms; Tenebrionidae – false wireworms Wireworms and false wireworms can be treated together because they have a similar morphology and the symptoms of their pod boring activities are indistinguishable: both make symmetrical holes, 2–3 mm in diameter, in the maturing and mature pods. Elaterid larvae have also been discovered eating the tissues of germinating seeds on the ICRISAT research farm in peninsular India. This activity could lead to diseased and malformed plants.

Appert (1956) indicated that wireworms ('taupins'), mentioning *Cardiophorus subspinosus* and *C. cognatus*, can be predators but, together with false wireworms, they can reduce the density of seedling stands by as much as 10%.

The survey carried out by Wightman in southern Africa in 1987 revealed a major problem with both of these taxa: the difficulty of identifying them to species from the larval stages and sometimes the adults. Table 11.2 shows species in the Elateridae and Tenebrionidae added by Wightman (with determinations by the British Museum of Natural History) to those listed by Smith and Barfield (1982).

Chrysomelidae Members of this large family will almost certainly be found tasting the foliage of groundnut wherever it is grown, but they probably cause little damage. The same cannot be said for members of the genus *Diabrotica*, especially *D. undecimpunctata howardi*, the spotted cucumber beetle, in the southern states of the USA. The adults cause relatively minor damage to the terminal leaves but the subterranean larvae can cause major injury to the pods and pegs. As such, it has been recognized as a major pest of this crop throughout this century (Smith and Barfield, 1982).

Curculionidae – Weevils The only species of weevil that has had a high profile as a pest of groundnut is the white fringed weevil, *Graphognathus leucoloma* (Feakin, 1973), especially in the Americas and, more recently, in Australia. The larvae eat the roots and cause stunting of the stems and plant death. The adults (parthenogenetic females) eat the foliage. Each can lay 1000–2000 eggs, hence the high damage potential of this species.

Adult weevils of other species are often numerous in groundnut crops and can often be seen eating the edges of the leaflets. In southern Asia, the ash grey or grey cotton weevil *Myllocerus undecimpustulatus maculosus* is often found at densities of up to 10 per plant. *Systates* spp., *Mesoleurus dentipes* and *Diaecoderus* sp. can reach even higher densities in southern Africa (Jepson, 1948; Rose, 1962; Broad, 1966). Jepson (1948) associated *S. articollis* with the 'yellowing and failure' of a young plantation. This is a significant observation because it is likely that the larval stages of weevils caused the yellowing (by attacking the nodules, cf. *Sitona* spp.) and crop failure by eating the lateral roots. The importance of weevil larvae as subterranean groundnut pests is worthy of further consideration.

TABLE 11.2 *Additions to species lists (Smith and Barfield, 1982) in Elataridae and Tenebrionidae*

Species	Locations
Elataridae (two previously listed)	
Agrypninae, Agrypnini (larvae) indet.	Mtopwa, Tanzania
Agrypninae, Monocrepidiini (larvae) indet.	Mawengo, Zimbabwe
Elaterina (larvae) possibly 6 spp. indet.	Malawi and Zambia
Tenebrionidae (five previously listed)	
Pimeliinae (larvae) possibly 13 spp.	From 20 locations in Malawi, Zambia and Zimbabwe
Tenebrioninae (larvae) possibly 3 spp.	Malawi and Zimbabwe
Zophosis sp. (adults)	Malawi
Gonocephalum nr *simplex* (adults)	Malawi
Anchophthalamus plicipennis (adults)	Malawi
Drosochrus sp. (adults)	Malawi

(f) Lepidoptera

The caterpillars of several lepidopteran species that live at the soil surface damage groundnut plants – *Agrotis* spp. and *Feltia* spp. feed at the crown, *Spodoptera litura* (in India) and *S. littoralis* (in southern Africa) are pod borers. In Australia, the larvae of *Etiella behrii*, the lucerne seed web moth, penetrate the pods and feed on the seed (Brier, personal communication).

The only true soil-dwelling lepidopteran to cause major damage to groundnut is *Elasmopalpus lignosellus*, the lesser corn stalk borer, which is restricted to the New World (Smith and Barfield, 1982). This species is regarded as a major pest of groundnut and other crops. Larvae feed at or close to the soil surface in the first two instars, paying particular attention to the flower and vegetative buds. The older stages feed on the underground parts of the plant, and often scarify the pods. This results in a high risk of seed contamination with aflatoxin (Lynch and Wilson, 1991).

(g) Myriapoda – millipedes

Millipedes, often more than 30 cm long, are the most important pests of groundnut in the drier areas of West Africa, where they attack the pods, nly before they have hardened (ICRISAT, 1988). They are also recognized as pod borers of lesser importance in southern Africa, where they damage 5–10% of the immature pods, some of which would not reach maturity by harvest time (Wightman, 1989).

Their importance in West Africa is related to the amount of damage they do, the unpredictable nature of the attack and because there is no control method available, irrespective of the socio-economic status of the farmers who have to contend with them. The literature reviewed by Wightman *et al.* (1991) indicates that the impetus of research carried out on the ecology and control of millipedes in the 1970s has not been maintained.

11.2.2 Insects that live on the leaves and flowers

(a) Orthopteroid orders – grasshoppers, locusts, crickets, mantids

Orthopteroid insects are frequently found in groundnut crops but, with the exception of locust plagues, no record of them achieving pest status has been located. Observation indicates that their presence in groundnut foliage is associated more with sunbathing than feeding. Mantids appear to be an exception. They can achieve relatively high densities in southern Africa (Wightman).

(b) Thysanoptera – thrips

Smith and Barfield (1982) list 18 species that have been associated with groundnut crops. Several species can be added to this list:

Megalurothrips usitatus is frequently encountered in the flowers of groundnut in Asia and southern Africa (Palmer *et al.*, 1990; Wightman *et al.*, 1990).

Scirtothrips aurantii was detected in terminal (folded) leaflets in Malawi (Wightman). *S. oligochaetus* has been found on groundnut in India (Palmer *et al.*, 1990).

Thrips palmi has been found in the terminal leaflets of groundnut in India and other Asian countries (Palmer *et al.*, 1990) and also lives in Australia and the 'Pacific' but has not been recorded from New Zealand and New Guinea (Houston *et al.*, 1991). *T. setosus* is known only from Japan and Korea (Reddy *et al.*, 1991).

Each species has a preferred niche – presumably the feeding site – within a plant. However, flower dwellers can be found in other parts of the plant before flowering occurs (Table 11.3).

Thrips can have pest status in groundnut crops as virus vectors and as leaf-eaters. We believe that thrips are also of considerable pest status because the (largely cosmetic) damage they cause induces farmers to apply insecticides unnecessarily (Lynch *et al.*, 1984; Ranga Rao and Shanower 1988; Reddy *et al.*, 1991). This results in outbreaks of other pests because of interference in the natural insect density control processes.

TABLE 11.3 *The distribution of thrips between flowers and leaf buds in the rainy and post-rainy seasons at ICRISAT Center, 1990–1991 (pooled data)*

	Total number of thrips observed (% in parentheses)			
	Rainy season		Post-rainy season	
	Leaf	Flower	Leaf	Flower
Scirtothrips dorsalis	9366 (97)	455 (26)	5274 (85)	153 (6)
Thrips palmi	148 (1.5)	102 (6)	792 (13)	361 (13)
Frankliniella schultzei	145 (1.5)	1202 (68)	118 (2)	2183 (81)

Thrips as virus vectors

Thrips can have pest status in groundnut crops as virus vectors and as leaf-eaters. They are vectors of the tomato spotted wilt virus (TSWV) and its Indian variant, the bud necrosis virus (BNV). The various isolates of this disease can cause widespread damage to groundnut in many countries (Reddy *et al.*, 1991).

Not all groundnut thrips are virus vectors. In India the most important vector is *T. palmi* (not *Frankliniella schultzei*, as was previously reported, although this species can be forced to transmit at a very low rate in laboratory conditions). *Scirtothrips* spp. are not vectors in India (Palmer *et al.*, 1990; Vijayalaksmi pers. comm.).

The most likely vectors in the southern USA are *F. occidentalis* and *F. fusca* (Reddy *et al.*, 1991; Culbreath *et al.*, 1992). Although *T. tabaci* is a vector of TSWV in other crops, it has not been linked with outbreaks of this disease in groundnut crops in the USA or elsewhere (Reddy and Wightman, 1988; Reddy *et al.*, 1991).

Thrips as leaf-eaters

Thrips can cause damage as a result of their feeding activity. The leaf-eating species are usually found between the folded leaflets at the stem tips. They cause little visible damage at the time of feeding. As the leaflets grow, the small lesions and patches of dead cells left by the thrips do not expand at the same rate (if at all) as the undamaged cells. This means that the most conspicuous leaflets at the top of the plant are contorted and have small holes in them. This damage is most apparent in young plants when temperature is not high enough to promote rapid growth, e.g. during spring in North America and the post-rainy season in India. The most acute case is that of *Enneothrips flavens* in Brazil. Increases in yield following insecticide application and attributed to the control of this species range from 35% to 50% (Smith and Barfield, 1982).

A debate about the economic status of thrips (mainly *T. fusca*) in southern USA seems to have reverberated around the peanut industry for many years (Lynch *et al.*, 1984). Turnjit (1988) added further light to the situation by indicating that in North Carolina no yield loss will occur until 40–50% of the leaflets are damaged, according to the variety, but then only in plants less than 4 weeks old.

The situation in India is not clear, mainly because the populations of the main leaf damagers (*F. schultzei* and *S. dorsalis*) cohabit with jassids (*Empoasca kerri*) and there is no method of separating out the relationships between density and yield losses attributable to each taxon. The impression is that thrips cause little yield loss, at least on the ICRISAT farm.

(c) Homoptera

Aphididae – aphids The aphid species most frequently linked with groundnut is *Aphis craccivora*, the groundnut or cowpea aphid. It occurs throughout the tropics and subtropics and has many hosts. It normally appears on groundnut crops in the early rainy season, when it can cause considerable damage to young plants. In recent years a second outbreak has occurred in the post-rainy season on the ICRISAT farm and this may be linked with a perceived air pollution problem (Dohman *et al.*, 1984).

This species is of particular significance because it is the vector of the (persistent) groundnut rosette virus complex in Africa. This disease can be crippling but has become less common in recent years, especially in southern Africa, where the widespread adoption of regulatory cultural practices (especially earlier and denser sowing than was once practised) may have limited its potential effects.

A. craccivora is capable of reducing the yield of groundnut crops by means of its feeding activity alone (Mayeux, 1984; Bakhetia and Sidhu, 1976). Our experience in southern India indicates that populations are regulated by coccinellids and other predators and rarely survive a spell of persistent rain.

As representatives of the aerial plankton that overflies agricultural areas, many 'other species' – such as *A. robiniae*, *A. gylycines*, *A gossypii*, *A. solanella*, *Myzus persicae*, *Macrosiphum euphorbiae*, *M. avenae*, *Rhophalosiphum padi* and *Lipaphis erysimi* – are implicated in the non-persistent transmission of most other groundnut virus diseases, including peanut stripe, cucumber mosaic, mottle and peanut stunt viruses. *A. gossypii* transfers groundnut streak necrosis disease (= sunflower yellow blotch virus) to groundnut in the Rift Valley area of southern Africa from *Tridax procumbens*, a common tropical weed (Saleh, 1991; Wightman *et al.*, 1990; Xu Zeyong *et al.*, 1991).

Cicadellidae or Jassidae – jassids or leaf-hoppers Jassids are a common feature of groundnut crops in most parts of the world. Perhaps they are so familiar that entomologists have not bothered to collect them, because only 20 species have been associated with the groundnut crop (Smith and Barfield, 1982; Wightman *et al.*, 1990). The economically significant genus *Empoasca* predominates – *E. fabae* in the Americas, *E. kerri* in India – but also *Jacobiasca formosana* in south-east Asia (but the latter two inadvertently omitted or not clearly referred to by the aforementioned authors) and *Austroasca alfalfae* in Queensland. The symptoms commonly include pronounced chlorosis followed by peripheral necrosis, a condition known as hopper burn.

There are no definitive accounts of the relationships between their density and crop yield. The main reason for this is the almost inevitable cohabitation with thrips and other insects in the early stages of crop development. The consensus in the USA, where experimentation has been in progress for about 50 years, is that the damage caused by these insects is cosmetic. Smith *et al.* (1985) indicated that the range of reduction in photosynthetic area among 14 groundnut genotypes was 3.8–28%. This is unlikely to have a direct effect on yield in view of groundnut's high leaf area index (> 5 after 40 days). However, the shading of the lower leaflets by damaged leaflets, which are usually on top of the canopy, may have a greater effect than anticipated.

Aleyrodidae – whiteflies Feakin (1973) does not mention whiteflies and Smith and Barfield (1982) indicate, correctly, that *Bemisia tabaci* is cosmopolitan but add no more. This confirms our suspicion that the observed outbreaks of whiteflies on groundnut in India and southern and south-eastern USA are a recent phenomenon (Shanower and Ranga Rao, 1988, Lynch and Simmons, 1993).

Bemisia tabaci epidemics have created problems associated with the overuse of insecticides in cotton crops in coastal Andhra Pradesh. The appearance of this insect on groundnut is considered to be associated with this general problem but may have been created by the local overuse of insecticides in groundnut. The situation is being monitored in view of the ability of this species to debilitate crops and spread virus diseases.

The situation appears to be rather different in the USA where the cotton strain (biotype A) has been replaced by the poinsettia strain (biotype B), which is capable of defoliating groundnut plants. This was first recognized in 1987 in Florida. Since then, the pest status of this species on groundnut has worsened as populations of the 'new strain' have increased in density and spread through Georgia and Texas (Lynch and Simmons, 1993).

LE 11.4 *Miridae associated with the groundnut crop in addition to those listed Smith and Barfield, 1982*

Species	Location	Source
Creontiades pallidus	Lilongwe, Malawi	J.A. Wightman (collected by sweep net, 1987; det. M.R. Wilson, CIE)
Creontiades sp.	Queensland, Australia	Rogers and Brier (personal communication)
Creontiades pallidifer	New Delhi, India	Singh *et al.*, 1990
Helopeltis sp.	Lilongwe, Malawi	J.A. Wightman
?*Taylorilygus* sp.	Lilongwe, Malawi	J.A. Wightman

(d) Heteroptera

Miridae Mirids can often be found in groundnut crops at low densities – perhaps less than one per plant. Smith and Barfield (1982) list 11 species belonging to eight genera from Africa, India and the USA. Table 11.4 shows additions to that list.

It is not often realized that this taxon can cause considerable damage at low densities. For instance, in an Australian glasshouse experiment set up in Queensland to demonstrate this point, Rogers and Brier (personal communication) found that two adult *Creontiades* sp. per plant reduced flower production by 86% over a 3-week period. Peg initiation showed a corresponding decrease of 87%. The plants resumed flower production 7 days after the mirids were removed, and produced more flowers and pegs than the unexposed control plants during the subsequent 4 weeks. However, it is envisaged that compensation is unlikely to be possible under the conditions of sustained attack that are likely to be encountered in field conditions, so that there are serious implications in finding mirids in a groundnut field. This is especially so in dryland agriculture where the cohort of flowers that produces the main crop results from a particular rainfall event that may not be repeated.

Damage in the Queensland experiment was typical of mirid attack to legume crops in that the flower buds were attacked at their earliest appearance and quickly became necrotic (Sorenson, 1936; Wightman an Whitford, 1982; Clifford *et al.*, 1983). The vegetative buds and other tissu were apparently not attacked in this way so that there was no distortion o the stems and leaves.

The potential of this species to cause damage is demonstrated by Singh e *al.* (1990). The mirid populations that they detected on groundnut in Ne Delhi peaked at just over one per plant in the rainy seasons of 1987 an 1988 and more than two per plant in the intervening summer crop. Thi species was present from the second week after sowing until about the po maturation stage. It is unwise to transfer the conclusions derived from th data of Rogers and Brier working in a glasshouse in Australia to field conditions in India but we suggest that the mirids detected in New Delhi had a marked effect on the rate of flowering and the subsequent yield. Clearly the mirids living in groundnut crops need to be looked at rather closely.

Pentatomidae and Lygaeidae Members of these families are often conspicuous in groundnut crops but we have not attributed yield loss to the 'big bugs'. Their feeding activity appears to be concentrated on the vegetative tissue, especially the growing points, which take on a limp appearance – hence the common name 'tip wilters'. Groundnut entomologists can ignore them, unless they are found to be attacking the reproductive tissues.

(e) Lepidoptera

There are many species of leaf-eating caterpillars found on groundnut plants – Smith and Barfield (1982) list more than 60 – and no doubt a concerted search would find many more. Of these, relatively few are of economic importance or limited to the groundnut crop. We wish to play down the importance of defoliators to groundnut crop production because natural control processes usually keep them at densities well below the economic threshold. However, apparently spontaneous flare-ups can occur and these are usually associated with the injudicious use of insecticides or other examples of suboptimal management.

Spodoptera spp. (the armyworms) are prominent in the list of potential pests, with *S. frugiperda*, *ornithogalli*, *latifascia*, *sunia* and *eridania* predominating in the New World. *S. littoralis* and *exempta* are associated with the groundnut crop in Africa and northern Asia, while *S. litura* extends across the remainder of Asia. *S. exigua* is cosmopolitan.

The heliothine genera can also be pests of groundnut over most of the crop's range, e.g. *Helicoverpa zea* in North America and *Helicoverpa armigera* in Asia, Africa and Australia. *H. punctigera* also feeds on groundnut in Australia but, unlike *H. armigera* (a flower and peg feeder), it is primarily a defoliator (H. Brier, personal communication). The arctiid hairy caterpillars *Amsacta* spp. and *Diacrisia obliqua* are sporadic defoliators in southern Asia. They can appear in devastatingly high numbers in newly emerged rainy season crops. They are polyphagous and, fortuitously, usually have one generation per year.

Gelechiids predominate among the leaf miners, rollers, webbers and tiers. *Aproaerema modicella* (= *A. nertaria*, *Stomopteryx subsecivella*, *S. nertaria*, *Anacampsis nertaria* and *Biloba subsecivella*), the groundnut leaf miner (Mohammad, 1981; Shanower *et al.*, 1993; Wightman *et al.*, 1990), causes widespread damage and is fairly cosmopolitan within Asia. It is known as a sporadic but potentially devastating pest with up to four generations in one crop cycle. It is oligophagous, with a clear preference for leguminous species, especially soybean and groundnut. Other hosts of [illegible]mercial importance include lucerne, pigeon-pea, mung bean and lab-[illegible]b. On groundnut, the first three larval instars are leaf miners; when it gets too large for this habit it becomes a leaf tier (or leaf folder). It pupates between the folded leaflets.

Anarsia ephippias (groundnut leaf webber) can be a pest in northern India. It webs the growing points and its feeding activity on the younger leaflets results in 'shot-holing' as the leaves mature (Bakhetia, 1977).

Acarina – mites

Smith and Barfield (1982) have 17 entries under Acarina, 10 of which are for *Tetranychus* spp. They are potentially a world-wide problem. The high reproductive rate and short generation time of these mites mean that they have a high potential for rapid population increase if the natural control processes are disrupted or if specific environmental conditions are severe. This happens when fungicides reduce the effectiveness of an entomophagous fungus, when inappropriate irrigation methods are applied and/or when insecticides kill other natural enemies (Campbell, 1978; G.V. Ranga Rao *et al.*, 1990). In Australia, the peanut mite *Paraplanobia* sp. appears in groundnut fields during periods of prolonged drought. Population densities crash after heavy rainfall (H. Brier, personal communication).

11.2.3 Post-harvest pests

The ecology and management of the post-harvest pests of groundnut have been discussed in full by Dick (1987b) and in Wightman *et al.* (1990). In general, the storage pests *per se* and the approaches to their management are common to many other products and so this aspect is not dwelt upon here. The emphasis is on several pests of the post-harvest situation in the groundnut crop that are particularly relevant to Africa and Asia.

Attention is drawn to the period after the crop is harvested and before it is 'plucked' and stored or bagged pending transfer to the market. During this time it is usually stacked or windrowed to allow it to dry in the sun and wind. This stage is critical in the production of a crop with high yield and good seed quality and one that will not become the origin of contamination with aflatoxin.

Unfortunately, the groundnut crop is not exempt from insect damage during this time. Termites can come from below and remove significant proportions (perhaps 30–40%) of the seeds and as much hay. *Odontotermes* spp. are the most conspicuous in this regard, especially in Africa (Logan *et al.*, 1990; Logan *et al.*, 1992). Pod damage at this stage can add to the risk that stored material will become infected with *Aspergillus flavus*, the fungal source of aflatoxin.

The other pest specific to the drying stage is the 'wang', *Elasmolom sordidus* (= *Aphanus sordidus*), a lygaeid, which can be found in surpri ingly high numbers within stacks of drying groundnut plants. All stages feed on the drying seeds by penetrating the pods with their mouthparts. The net effect is a marked decline in quality caused by the build-up of moulds and a rancid taste associated with the oxidation of oils to fatty acids. This insect can be transferred into storage structures, where it continues to cause seed deterioration.

The third species of note is the groundnut bruchid *Caryedon serratus*, which is restricted to groundnut as a post-harvest pest. The only other known host of commercial importance is the tamarind tree (*Tamarindus indica*), the pods of which are traded mainly within southern Asian communities. Groundnut stored in unbroken pods is usually safe from attack by most insects and diseases, except with this species. The eggs are laid on the pod, through which the neonate larvae dig to reach the seeds. Warehouse contaminations probably originate from field infestations. Although this pest was dealt with routinely in the heyday of West African groundnut exports, its significance in India has only come to light in recent years (Dick, 1987a).

11.3 APPLIED ECOLOGY AND ECONOMICS

Section 11.2 indicates that there are many different kinds of insect living on or under groundnut crops and that some are undoubtedly influencing the yield of the crop. The taxa and sometimes the species most likely to be reducing yield have been mentioned with more or less detail. The sectors of the many communities who have a stake in these matters (rich farmers, poor farmers, female farmers and mothers, teachers, agroindustrialists, extension specialists, researchers) will have a range of attitudes to these insects according to their vested interests.

Some would take every opportunity to get rid of them with pesticides, irrespective of their potential pest status; others would do so if they had the means to purchase pesticides. Perhaps a few would ponder upon methods of managing them without this drastic approach or would just like to have the time to sit in a field and watch them. We are mainly concerned with the section of this spectrum of interest that excludes the first category.

When trying to determine the status of the insects that live on a crop and deciding whether they are pests, neutrals or beneficials, for instance, it is necessary to have knowledge of their ecology and their influence on the yield of the crop. This section reviews what is known about those aspects of the applied ecology of the key pests that are fundamental to developing what we regard as rational management strategies.

11.3.1 Flight activity

t of the insects colonizing a crop originate from parental stock that oduced after flying into the field or its bordering vegetation. The same often true for virus vectors. Thus, when considering the risk of pest attack, it is necessary to know about the times of year when economically important insects are most likely to be flying, their pattern of movement within and between localities, the relationship between flight intensity and insect population density and yield loss, and the most effective methods of monitoring their flight. This has a direct bearing on pest avoidance (section 11.7).

(a) Monitoring flight activity

The most effective method of catching flying insects is to lure a fraction of the aerial population into a trap. Southwood (1978) discussed many ways of doing this. Non-specific methods such as light traps (groundnut leaf miner, Shanower, 1993), suction traps (for thrips, C.S. Gold, ICRISAT, personal communication) and yellow water (pan-) traps for aphids (Farrell, 1976b) have yielded reproducible results for insects living in groundnut fields.

Even better are traps that are attractive to single species. With regard to groundnut, this category is currently restricted to Lepidoptera, in particular *Spodoptera litura* (Ranga Rao *et al.*, 1991a,b), *S. frugiperda*, *S. exigua*, *Helicoverpa zea*, *Heliothis virescens* (Lynch and Douce, 1992) and the groundnut leaf miner (ICRISAT 1991b) for which synthetic pheromones are available. Traps enclosing virgin female moths have also been used to lure male groundnut leaf miner moths but are considerably less effective than the traps baited with the synthetic pheromone developed by NRI (Chatham, UK) (Table 11.5; and Nandagopal and Reddy, 1990). Such traps are satisfactory if it can be proved, or if it is accepted, that the catch of males represents the activity of the population as a whole.

(b) Flight activity and its implications

The main flight period of *Aphis craccivora*, the vector of the groundnut rosette virus, can be expected some 6 weeks after the first 'planting' rains in southern Africa. This was the basis of the recommendation that groundnut crops should be sown 'early'. This advice is tempered by the observation that a crop, once it has been established for 40 days or more, is much less likely to be adversely affected by this virus than are younger crops. Adherence to the appropriate management practices is probably the reason for the virtual non-appearance of this disease in southern Africa in the last 20 years.

Ranga Rao *et al.* (1991a) compared the data from light and pheromone traps set on the ICRISAT farm in their study of the flight activity of *S. litura*. The former was the standard monitoring procedure until the mid

TABLE 11.5 *Mean number of groundnut leaf miner caught in delta traps baited with experimental pheromone lures at ICRISAT Center during rainy season, 1991*

Lure type	Mean number of moths trapped in different weeks of exposure								
	1	2	3	4	5	6	7	8	9
'Small septa'									
Fresh	696	545	650	245	50	69	74	34	23
Continuously exposed	654	703	630	360	58	70	78	22	14
'Big septa'									
Fresh	922	800	856	468	72	108	137	38	22
Continuously exposed	990	804	573	326	32	30	22	34	19
Virgin female	195	185	40	84	11	52	14	9	6
Empty trap	7	20	7	5	2	16	3	1	3
SE	± 32.1	± 37.8	± 64.6	± 41	± 8.1	± 13.9	± 15.7	± 7.3	± 3.4
CV (%)	12	17	31	37	48	62	64	71	51

TABLE 11.6 *Relationship between log of number of moths caught (x) and log of number of egg masses (y) per 100 plants (Kumari, 1989)*

Site	y	r^2
1	0.019 + 0.445x	0.798
2	−0.220 + 0.535x	0.826
3	−0.070 + 0.474x	0.838

x – mean of three traps per site and two nights' data combined Data cover 38 observation periods between 1 February and 16 April 1989.

1980s. The pheromone traps consistently demonstrate a distinct peak of flight activity in March (just before harvest of the post-rainy season crop) that was not present in the light trap data. However, the implications are not clear because there was no corresponding increase in oviposition in groundnut crops at that time. This suggests that the females accompanying the males were 'flying through' the farm. Perhaps they did not recognize groundnut as a suitable host, or they may have been undergoing a long-distance dispersal flight and were not attuned to respond to a potential food plant.

In addition, the pheromone trap catches indicated that there was no clear cessation in flight activity during the hottest time of the year. This suggests that a period of aestivation cannot be assumed to be a normal event, as suggested by the light trap catches. A periodicity of flight activity corresponding to the generation length was also detected. This could be of relevance to the timing of sowing in *S. litura* endemic areas, as it is best not to sow at a time that will result in the colonization of the seedlings, which tend to be the only stage susceptible to this pest.

One such endemic area is the coastal strip of Andhra Pradesh, India, where groundnut is grown under irrigation from November to March. *S. litura* is the only insect pest during this period. It can cause extensive defoliation but this appears to be largely as a result of the disruption of natural control processes associated with excessive insecticide application. This area has been targeted as a test area for implementing IPM procedures based on damage forecasting via a pheromone trap network (Table 11.6).

Kumari (1989) also demonstrated similar relationships between moth catch and the density of small larvae (instars 1–3), large larvae and the number of damaged leaflets per 100 plants. There was a delay of 4 days between the appearance of the first moths in the traps and the detection of the first egg masses. The delay was 8 days for the small larvae and 20 days for the large larvae.

It is hoped that similar relationships will be established for the groundnut leaf miner now that a synthetic pheromone is available and trap technology has been made effective (Hall, Cook, Ranga Rao and Wightman, unpublished). Attention will be directed towards the establishment of determining relationships between the number of male moths caught per trap and the density of larvae in the next generation. The feasibility of mating disruption exercises can then be investigated.

The groundnut leaf miner has not been observed to undergo long migratory flights. Our observations on the ICRISAT farm indicate that it will move only a matter of 50 m from a high concentration area (for instance, in a soybean crop) to colonize groundnut. This means that distributions can be extremely uneven, even within a field.

Cockchafers (May beetles) are the adult stage of white grubs and have a species characteristic flight pattern that is related to mating, feeding and dispersal. The typical pattern is for adults to emerge at dusk over a period of about 3 weeks or more at a precise time related to the time that the sun goes over the horizon. First emergences occur over a period of 5–10 days. Individuals do not appear every night; the females presumably spend a day or so laying eggs in chambers, 10 cm or more below the soil surface (Farrell and Wightman, 1972). The median first emergence date may be related to temperature *per se* (day degree accumulation), a period of chilling followed by warming in temperate climes (Wightman, 1974) or, in the tropics, the onset of the rainy season (Yadav, 1981, 1991). In varying combinations and sequences, according to the species, weather conditions or the locality, the beetles:

- emerge from the ground (usually males before females);
- mate on the soil surface or on low-lying vegetation;
- undertake significant dispersal ('beeline') flights in a straight line for >50 m away from the original emergence hole;
- feed on surface vegetation;
- fly towards and aggregate around markers, such as tall trees or telegraph poles, and seek mates;
- fly to trees of a small range of species, and feed and mate on their foliage;
- either drop off or fly away from the tree when satiated or cold and, in the case of females, lay eggs wherever they land.

This stage in the life-cycle of the Scarabaeidae is of economic importance because it is during this period that the population is at its lowest density and greatest accessibility to humans, i.e. it is the best time to attempt a control strategy, if one can be devised.

Data sets on the host preferences and behaviour patterns of the adults are needed. This information would, for instance, guide farmers as to which tree species should be avoided or selected (as attractants or repellents) in farm-forestry projects in areas where white grubs pose a high risk.

[illegible] 11.7 *Degree-days (°D) required for completion of development from eggs* [illegible]gh to *pre-oviposition for* S. litura *(Ranga Rao* et al., *1989) and groundnut leaf* [illegible]ner *(Shanower* et al., *1992a)*

Stage	*S. litura*[a]	Groundnut leaf miner	
	°D	°D	Lower threshold temperature (°C)
Eggs	64	60.1	(12.3)
Larvae	303	327	(8.9)
Pupae	155	72.3	(14.7)
Pre-oviposition period	29		
Total			
Range	508–631		
Mean	(543)		

[a] Bred from egg masses found on the ICRISAT farm.

Temperature summation estimated from laboratory experiments carried out under constant temperatures.

11.3.2 Environmental factors

Environmental factors can work directly on the insect:

- Temperature regulates the development rate and can be a cause of mortality.
- Rain washes aphids off plants and promotes the high humidity that stimulates entomophagous fungi.
- Wind influences the stimulus, distance and direction of migratory flights.

The physical environment can have many indirect and often complex interactions via the soil and, through the soil and its water or nutrient content, to the plant and then the insect. Similarly, interactions between temperature, relative humidity and cloud cover or levels of ultraviolet radiation have observable effects (but without parameters) on the virulence of insect pathogens.

(a) Direct effects

One of the basic sets of information that should be available for key pests is the relationship between its development rate and temperature (Table 11.7). This is needed for matching insect damage or population models with plant or crop development models. Biotype differences can also be detected by comparing the relationship between temperature and the development rate of isolated or transient populations.

Light, well-drained soils, as opposed to heavy, waterlogged soils, favour the activities of *Elasmopalpus lignosellus*, especially when the weather is hot and dry. Similarly, white grubs in general prefer sandy soil (Smith and Barfield, 1982). An exception is *Holotrichia serrata*, which is most likely to be found in the heavier soils of southern India, in contrast to its northern counterpart, *H. consanguinea*, a denizen of the light soils of the Gangetic Plain.

The opposite pertains for the southern corn rootworm (*Diabrotica undecimpunctata howardi*). It proved particularly susceptible to dry soil, especially in the egg and first instar stage and when living in a sand medium (Brust and House, 1990).

(b) Indirect effects

Wheatley *et al.* (1989) investigated the response of groundnut to drought stressed hosts during the post-rainy season at ICRISAT Center. Four varieties of groundnut were grown across a drought stress gradient. The groundnut leafminer was most abundant on the most stressed plants. Jassids showed the reverse trend and this preference for a non-stressed host was also observed for jassids living on lucerne (Hoffman and Hogg, 1991). Thrips were at first most abundant on the least stressed plants, reversed this trend in mid-season and then reversed it back again before harvest, by which time the physical condition of the hosts had deteriorated. A further study might well investigate more closely the relative abundance and feeding site of the thrips species involved. Of the four varieties tested, NC Ac 343 (ICG 2271) proved to be the best to grow in times of potential drought stress *vis-à-vis* insect attack.

Several other aspects of this study were also of note:

- It was found that the groundnut leaf miner was able to withstand a midday canopy temperature of 47 °C.
- The source of the irrigation water – overhead or furrow – did not influence the distribution of the insects.
- An inspection of the bamboo plot pegs indicated that termites (*Microtermes* sp.) had a preference for a soil moisture of about the wilting point (12%).

Observations in another year on a similar drought gradient (Ranga Rao *et al.*, 1991c) showed that *Aphis craccivora* was most abundant on plants that were not drought stressed. This was in spite of being pounded with water from an overhead irrigation system.

Wheatley *et al.* (1989) found that the the groundnut leaf miner was at an advantage when its host was severely drought stressed. Extremes in precipitation also appear not to influence the survivorship of the larvae of this species. Shanower *et al.* (1992a) found no evidence that the extreme fluctuation in population density that is characteristic of this species was in any ed to rainfall events. Supplementary experiments showed that egg va survival were not influenced by artificial rain for periods and ities that exceeded the normal range of field conditions.

11.3.3 Influence of insects on groundnut yield and economics

The development of an understanding of the relationships between the feeding activity of insect populations and the yield of the host, with respect to the characteristics of the farm system within which it is growing, is a fundamental task facing all applied insect ecologists. In many cases, the importance of natural enemies in the life system of a potential pest means that the dynamics of three trophic levels have to be taken into consideration (Shanower *et al.*, 1992b). This implies the need for the construction of predictive models. Despite the importance of such sets of information, there are few reliable and published accounts relevant to pests of groundnut crops. This is unfortunate but is not surprising in view of the difficulty of assembling and analysing the necessary data sets.

The relevance of this topic to insect pest management as a whole is that these data are needed to establish parameters for the **economic threshold** – the density (or intensity, in insect days) of an insect population at which its activity results in the decline in the potential yield of the harvestable component(s) (pods and/or haulm) of a crop.

The economic threshold can be distinguished from the **action threshold**, which is the insect population density at which activity is needed to prevent the population density exceeding the economic threshold at some time in the future. Depending on the pest complex and the cropping system, the 'activity' could be:

- the commencement of hand picking or trapping the offending pest;
- the application of an insecticide;
- crop rotation; or
- deep ploughing, in the case of soil insect life systems.

A number of approaches have been adopted to secure relevant information depending on the circumstances. The 'circumstances' are often in fact governed by the inability of the entomologist to locate appropriate pest populations.

(a) Energetics and laboratory feeding experiments

Most animals can be considered as machines that convert food (consumption = C) into new body tissue (production = P), a process that exploits part of the potential energy of the food to fuel the animal's metabolism (respiration = R) of the food. Measurable by-products of this process also

include unassimilated ingesta (faeces = F) and excreta (U). The relationship is:

$$C = P + R + F + U$$

In the last 20 years there have been many studies of this relationship, especially with respect to the establishment of the trophic relationships of phytophagous insects. They usually include estimates of the gross ecological efficiency (P/C). This and other ecological efficiencies can be discussed in terms of dry matter, energy and, more rarely, essential nutrients, especially nitrogen, depending on the context of the study. For instance, because energy supply is rarely limited in terrestrial systems, trophic dynamics or system structure can be discussed in terms of the energy flow from one trophic level to the next (Grimm, 1973; Axelsson *et al.*, 1975; Axelsson, 1977; Schroeder 1978; Wightman, 1979; Bellows *et al.*, 1983). Energy (or carbon) units, rather than units of mass, are adopted as the common denominators when describing such systems because the 'concentration' of energy – i.e. the number of joules per unit mass – is species and possibly system specific. An extreme example is that of bruchid beetle larvae living on dried pulse seeds. The cotyledon of the host, the larval food, has an energy equivalent of 18.7 J/mg whereas bruchid larvae have up to 27.8 J/mg (Wightman, 1978).

The constraints to energy flow or the 'bottle necks' in biological systems are most likely to be revealed by studies of nutrient cycles. This is because (after water-related problems) nutrient excesses or shortages are the most common constraints on the components of biological systems.

Measurements of the mass of system components are applicable to studies where only changes over time are critical or where one component is of primary importance. For instance, leaf mass consumed by an insect can easily and accurately be considered in terms of the leaf area removed (Schroeder, 1984) because this is directly related to the amount of light energy intercepted by the host. Dry matter, or preferably ash-free dry matter, is usually determined because variations in the water content of most organisms (as influenced by environmental conditions) affect the precision of biomass estimates.

Over the years it has become apparent that when a phytophagous insect is feeding on a suitable host that is growing in stable conditions, the gross ecological efficiency is in the region of 0.14 (mass) and 0.18 (energy) (reviews by Edwards and Wightman, 1984; Wightman and Rogers, 1978). This ratio will vary according to host species (and the genotype, if there are variations in the level of allelochemicals within the species), the nutrient status of the soil in which the host is growing and the degree of drought (or water) stress (e.g. Mansour, 1981; Scriber, 1979a,b; Crawley, 1989). Thus if the mass of the insect is known, it is possible to calculate the amount of leaf material it has removed up to the time a measurement of mass (or length, which is a function of mass) is made. It is then a matter of

11.8 *Leaflet area, fresh weight, dry weight and dry:fresh (d/f) ratio of 20 leaflets from five groundnut genotypes (Wightman, unpublished data)*

	Mean cm^2	fresh wt g	dry wt g	d/f	mg (dry) cm^{-2}
Shulamit	199	4.88	1.49	0.305	7.48
VB	248	6.17	1.85	0.300	7.56
NC 7	196	4.98	1.42	0.285	7.23
A 46 L 10	215	5.43	1.62	0.297	7.52
A 81 L 18	184	4.62	1.45	0.313	7.88
Mean	208.4	5.22	1.56	0.300	7.53

arithmetic to determine the effect of an insect population on the biomass or leaf area index of a plant population or crop. This is the area in which plant or crop growth models and insect models interface.

Estimation of larval damage

As an example, in the case of *Spodoptera litura* larvae feeding on groundnut foliage, their maximum length is *c.* 40 mm, which means that they weigh 0.3 g dry (Rogers *et al.*, 1976) which is equivalent to about 1.4 g live weight). If P/C (mass) = 0.14, then C = 2.14 g.

Adopting the energy route gives a similar answer. Phytophagous insects have an energy content of about 23 kJ/g (e.g. Edwards and Wightman, 1984; Schroeder 1977, 1978, 1984), thus P = 0.3 × 23 kJ = 6.9 kJ. If P/C (energy) = 0.18, then C = 38.3 kJ. As leaves have *c.* 18.4 kJ/g energy content (Petrusewicz and Macfadyen, 1970), this indicates that one larva consumes 2.08 g of (dry) leaf during its development. As there are 7.53 mg (dry) per cm^2 of groundnut leaf (Table 11.8) the mean (2.11 g) of these two estimates is equivalent to 280 cm^2. Thus one larva consumes 20–30 leaflets during its development, depending on the size of the leaf and proportional mass of non-consumed vascular tissue.

Garner and Lynch (1981) measured the area of groundnut leaflet consumed by *S. frugiperda* larvae (fall armyworm) in Georgia, USA. Their main experiment showed that the mean leaf area consumed during the larval period was 94.6 cm^2 (which, following data in Table 11.8, is equivalent to 712.3 mg dry leaf). This is close to the cumulative consumption data of ± 100 cm^2 for the same species indicated by Smith and Barfield (1982).

The mean pupal mass was 177.5 mg. This means that the maximum larval weight was about 213 mg, because pupae weigh *c.* 20% less than fully grown larvae (Hagvar, 1975; Mackay, 1978; Wightman 1978). The dry weight to live weight ratio of phytophagous insect larvae is normally about 0.2 (personal observation) so that the dry weight of the fully grown larva was *c.* 43 mg. A P/C ratio of 0.14 indicates consumption of 304 mg, which is considerably less than the observed.

Data from ancillary experiments carried out by Garner and Lynch (1981) indicate that the disparity may be due to the age of the foliage with which the larvae were fed. Adopting the data from follow-up experiments certainly brings the model and experimental data closer to agreement. Larvae fed on 2-day-old leaves ate up to twice the area of leaflet, probably bringing the P/C ratio closer to 14%. Furthermore, the larvae developed more quickly, had a much lower mortality rate and finished somewhat larger than counterparts fed on leaves up to 40 days old. This indicates that antibiosis may have developed in the older leaves and was the cause of the low estimated P/C ratio.

However, the possibility of a disparity between a model and the experimental data calls for a re-examination of both. In this case we need to look at several factors:

- Is the P/C really 6% for *S. frugiperda* or is this an artifact related to the insects being fed old (and excised) leaflets?
- Are the Australian host data transferable to the US genotype?
- What are the equivalent experimental data for *S. litura* and other *Spodoptera* spp.?

It is certainly an indication that model data should be applied with circumspection, and preferably with experimental verification. Huffman and Smith (1979) present data indicating that *Helicoverpa zea* consumes 176 cm^2 of foliage of the cv. Starr. However, we do not have access to biometric data for this species.

(b) Simulation of defoliator damage in cage and field experiments

Continuing on the theme of conventional defoliators (which have attracted most attention from experimentalists), several groups have evaluated the effects of leaf removal by human or insect agencies on groundnut yield (e.g. Greene and Gorbet, 1973; Enyi, 1975; Smith and Barfield, 1982). The latter authors present a defoliation level (0–100%), by time (35–110 days after emergence) and by yield reduction (0–50%) response surface for a spanish variety. They conclude from this and other data: 'peanut is most susceptible to defoliation from 70–80 days post emergence and practically immune to yield reductions from defoliation prior to bloom initiation and near harvest.' Certainly, the figure they present and the other data they review support this conclusion.

At ICRISAT we released specially reared fourth instar *Spodoptera litura* larvae onto plants that were surrounded by a 20 cm high metal barrier that stopped their escape. This procedure was adopted to avoid the possibility of delivering a systemic shock to the plants' system by abrupt hand or mechanical ablation. In these experiments we have consistently found that defoliated after the seedling stage or early flowering stage were ant to attack. This was most marked in the rainy season. Plants even produced pods (amounting to 50% of the control yield) when they were completely defoliated from 10 days after emergence by the addition of two larvae per plant at 20-day intervals (Wightman *et al.*, 1990).

Similar experiments carried out by Sathorn Sirisingh and Manochai Keerati-Kasikorn (1986) in Thailand indicated similar insensitivity to defoliation by groundnut plants.

The clue to the disparity in the results from North America and Asia may lie in the genotype, their partitioning coefficients and sowing pattern. In the experiments in India we expect canopy closure after 20–30 days. The genotypes we experimented with (mainly spanish bunch) have a leaf area index of >4 by the time the vegetative stage is complete. This means that, in practical terms, after the crop has been in the ground for more than 30 days it can suffer at least 50% loss of leaf area before its photosynthetic capability is reduced. This statement ignores the photosynthetic capacity of the stems and petioles, which may be more than anticipated.

The principle behind cage experiments is to isolate plants from as many insects and natural enemies as possible and then infest them with members of the required species at whatever range of stage, time and density is required. Primary assumptions are that the introduced insects, whether reared or collected from another site, are healthy and are otherwise 'normal', as are the plants grown in cages. This approach has proved satisfactory for establishing the relationships between the densities of *Nezara viridula* and *Riptortus serripes* on soybean yield (Brier and Rogers, 1991) and *Helicoverpa armigera* on chickpea yield (ICRISAT Legumes Program, 1991b). However, the cage experiments with groundnut leaf miner at ICRISAT are believed to have given non-representational results because the fine cage netting needed to secure this species intercepted too much light, thereby changing the physiology of the plants.

(c) Field experiments

Experimental approach

Experiments in Thailand carried out by Sathorn Sirisingh and Manochai Keerati-Kasikorn (1986) indicate that the groundnut leaf miner is capable of more drastic yield reductions than *S. litura*. Their data indicate that, in the season under discussion, a heavy infestation (*c*. 40 per plant) in the first or second generation (flowering stage) reduced the yield from a potential 1.28 t/ha (site 1) or 0.95 t/ha (site 2) to 0.63 and 0.65 t/ha. The data also show that the control of fungal diseases increased the above potential yield by 25–50%.

The determination of the relationship between the density of groundnut leaf miner populations and groundnut yield has also been the objective of experiments carried out on the ICRISAT farm for 15 seasons (two per year). Although this species was present in most seasons, it only reached a density that could be described as damaging on three occasions. The essence of these experiments is to allow the population to build up to beyond our concept of an economic threshold and then to apply insecticides in such a way that we achieve a range of population intensities and control efficiencies. We then relate pest intensity to pod yield. These experiments cover about 1 ha and are conducted in such a way that there is a minimum of season-to-season variation.

TABLE 11.9 *Groundnut yield, groundnut leaf miner intensity and GLM parasitism as influenced by insecticide application (III° generation)*

Treatment	Stand yield (pods) t/ha	% parasitism 8 Apr 85	% parasitism 19 Apr 85	insect 'days'
Dimethoate (400 g) (8 applications)	1.78	3.1	0	76.9
Dimethoate (200 g) (3 applications)	1.70	13.6	33.9	752.4
Diflubenzuron (250 g) (3 applications)	1.43	20.5	42.5	1443.2
Dichlorvos (3 applications)	1.58	16.3	50.0	742.8
Control (no insecticides)	1.15	23.0	61.0	1617.0
SE	± 0.06	± 3.5	± 10.4	± 67.0

The number of insecticide applications refers to the whole season (110 days).
Insecticides were applied in 350 l water/ha.
Rates (g) are a.i./ha.

With this species there is the possibility of several combinations of events because it has three or four generations per growing season. It can therefore appear (and disappear) at any density between emergence and harvest and display considerable variations in density change during a season. We are, however, accumulating data that will enable us to put together a rational management outline (Table 11.9). They indicate that an insecticide application (e.g. dimethoate at 200–350 g a.i./ha) should be applied when there are five or more new mines per plant during the seedling stage, 10 new mines at flowering and 15–20 mines per plant up to 2 weeks before harvest, after which insecticide application will have little impact on yield.

Jassids and thrips often occur concurrently. Even if no other pest is present, this makes it difficult to determine whether there is a relationship between their intensity and pod or haulm yield. However, in the 1992 rainy season at ICRISAT there was heavy infestation of jassids with minimal thrips densities. The yield data (Table 11.10) indicate that there was a high [illegible]LE 11.10 *Cumulative effect of jassid* (Empoasca kerri) *damage (eight days [illegible] harvest) on haulm and pod yield of susceptible groundnut variety ICGS 44 ([illegible]st-rainy season 1991/92, ICRISAT Center)*

Insecticide applications (*n*)	Leaflets with jassid damage %	Dry haulm mass t/ha	Dry pod mass t/ha
0	60.0	3.26	1.73
1	31.3	3.20	1.91
4	17.0	3.55	2.14
SE	± 2.7	± 0.22	± 0.08

level of leaf damage by 8 days before harvest in unsprayed plots. However, the reduction in the number of damaged leaflets by means of four insecticide applications had no effect on haulm yield and little effect on pod yield.

Indications of the effects of soil insects on crop yields can be deduced from the results of experiments involving the application of insecticides to the soil. For instance, data provided by Kumawat and Yadava (1990) indicate a linear relationship between the density of larval *Holotrichia consanguinea* (white grubs) and plant mortality in experimental conditions in Jaipur, Rajasthan, northern India. There was a log–log relationship between density and pod yield.

Wightman *et al.* (1994) simulated white grub attack by cutting through the roots of groundnut plants (White Spanish) 30 or 51 days after emergence (in glasshouse conditions) (Table 11.11). The root systems regrew when the plants were cut after 30 days, although there was a considerable energy cost in terms of reduced pod yield. Plants cut at the later date did not regrow their roots. This was even more accentuated when the plants were drought stressed. The plants with roots cut 51 days after emergence were close to death at the end of this experiment.

This experiment demonstrated differential debilitation as a result of root damage from flowering to harvest. But seedlings can also be killed when attacked by white grubs (Bakhetia, 1982; Kumawat and Yadava, 1990). Apart from the loss in yield, the farmers' profits are further reduced because weeds are able to grow in the gaps. This reduces the opportunity for compensatory growth by the plants next to the spaces left by the killed seedlings. The potential role of compensatory growth following stand thinning may, in any case, be overestimated.

The extent and cost of seedling mortality and its management in northern India have been estimated by Bakhetia (1982). He demonstrated 1.3–2.6% plant mortality where seeds had been dressed with insecticides compared with 10.1% mortality where seeds were untreated. The overall yield was at least doubled by using insecticide seed dressings, indicating that there was considerable additional sublethal yield loss that was avoided by introducing insecticides into the soil as a seed coating.

TABLE 11.11 *Mean weight (n = 5) of pods produced when groundnut plants (variety White Spanish) were cut through the root at 10, 15 or 20 cm below the soil surface (0 cm = uncut control), 30 or 51 days after emergence when grown under drought stress or fully irrigated conditions*

Cut	Mean pod weight g/plant ± SE	
	Drought stress	No drought stress
Cut 30 days after emergence		
Depth of cut		
0 cm	12.92 ± 1.64	22.96 ± 0.86
10 cm	9.81 ± 0.14	14.19 ± 0.57
15 cm	11.17 ± 0.36	15.11 ± 1.10
20 cm	12.02 ± 0.09	15.91 ± 0.56
Cut 51 days after emergence		
Depth of cut		
0 cm	12.92 ± 1.64	22.96 ± 0.86
10 cm	7.73 ± 0.73	10.98 ± 1.08
15 cm	9.36 ± 1.52	13.93 ± 0.47
20 cm	8.99 ± 0.18	14.18 ± 1.50

Gough and Brown (1988) indicated that groundnut crops in the Atherton Tablelands of north-east Australia were equally sensitive to attack by white grub (*Lepidiota* sp.) Their data indicate that one larva per metre row (6–8 plants) of cv Virginia Bunch reduced crop yield by 381 kg/ha.

Within-stand compensation following plant mortality

Wightman and Wightman (1987) found that, in conditions typical of farming systems in Malawi, there was no within-row compensation by plants in stands that suffered up to 50% mortality once the stand had been above ground for 26 days. ('Compensation' is defined as an increase in the pod and/or haulm yield of plants in depleted stands, relative to plants in control stands that are not depleted.) Up to this time there was within-stand compensation for plant death only if there was >30% mortality after 17 days and >50% mortality at 26 days. These data refer to a crop that was harvested after 5 months. They indicate, at least in the conditions of this experiment, that compensatory growth of the pods and haulms in response to the death of neighbouring plants occurs only in earliest stages of stand development.

The empirical or trial-and-error approach

Because the end point of the process under discussion is the development of pest-management methods that are appropriate for the given [illegible], it is feasible to derive action thresholds by trial and error. For instance, in São Paulo State, Brazil, where thrips are the major pest and a serious constraint, farmers are advised to apply a suitable insecticide only when there are more than three thrips per leaflet on 20% of a random 200 leaflets taken from 1 ha. This procedure reduced insecticide applications from seven to two per season with an increase in yield and profitability (Snhr Dalmo Lasca, Director, São Paulo State Extension Service, personal communication). There is no experimental data to support this procedure, but it works.

Similarly, at ICRISAT, we set up in 1984–85 a series of ad hoc action thresholds to assist the farm manager's plant protection team before we had supportive data. For instance, we recommended that an insecticide (normally dimethoate at 200–350 g a.i./ha) should be applied for groundnut leaf miner control if the density exceeds five mines per seedling, 10 mines per plant at the flowering stage and 15–20 mines per plant up to 3 weeks before harvest, after which insecticide application is likely to have little benefit. Our experimental data (above) indicate that this rule of thumb had some merit.

11.3.4 Dynamic programming as a tool to guide research orientation

The action thresholds for the groundnut leaf miner just mentioned were the basis of a series of modelling exercises carried out to evaluate management scenarios for this pest. The exercise was based on a population dynamics model of this insect and contemporary village-level fixed and variable costs for southern India (Dudley *et al.*, 1989).

The scenarios covered issues such as: 'If a farmer has available varieties with 0, 10, 20 . . . 90% host plant resistance, how much natural mortality is required at each level of host plant resistance to eliminate the need for insecticide application?' The role of the market value in determining the optimal number of sprays was also investigated. The final conclusions from this piece of work are realistic and pointed to a difference between pest management in developed and less developed countries. They point to our need to make assessments of the effectiveness of farmers' insecticide application activities and, implicitly, the role and effectiveness of natural enemies (assumed to be inversely related to insecticide application activity) before it is possible to work out what level of host plant resistance to a given insect pest is needed.

11.4 HOST PLANT RESISTANCE

Host plant resistance, where it exists, can be made available to farmers as an effective and environmentally friendly component of pest management that involves little or no extra cost or effort than the normal purchasing, sowing and keeping of seed – 'technology in the seed'. It is thus part of the applied entomologist's job to detect and exploit it where feasible and rational.

As inferred, the cost to the farmer is small; however, the institutional costs are considerable and include the development and support of a germplasm collection, research farm and research facilities, many years of screening and selecting germplasm and probably about 10 seasons of resistance screening and selection of breeders' material. This is followed by on-farm testing and evaluation by farmers.

Of course, there is no guarantee that the traits sought exist in the germplasm of the crop species, its close relatives or, in the context of contemporary biotechnological feasibilities, any other species. There is also no guarantee that the breeders and other gene-shifters will be able to ensure that the desirable genes to manifest themselves in a variety that is adapted to the target environment. Thus, breeding for host plant resistance is primarily an activity of organizations that are stable, mission-orientated, well endowed and non-profit-making.

Many groundnut genotypes have characteristics that protect them from herbivores. This observation is based on the relatively small number of pests (as opposed to insects) associated with the above-ground parts of this species. (We have yet to come to terms with resistance to root-eating arthropods.) Lynch (1990) has made a notable contribution to groundnut science by listing the genotypes that are known to have resistance to many of the most important pests.

If a particular insect is established as being a major constraint in one or several agroecological zones, it is rational to consider the inclusion of host plant resistance in a groundnut management programme that includes the provision for breeding or selecting adapted varieties. If no source of resistance genes is known, it is necessary first to develop guaranteed screening procedures for distinguishing between resistant, susceptible and 'escape' plants or genotypes. Rationally, this process should also enable other characteristics of the screened genotypes to be assessed. Screening methods are not covered here but the general principles are described by Smith (1989).

Once resistance to one or several potential pests has been found, it is usually necessary to work with breeders to combine the relevant genes with a 'background' that is agronomically suited to the target environment. This procedure is made more efficient if it is possible to supplement the field screening of progeny by monitoring the presence or absence of the physical or chemical markers associated with the mechanism of resistance (Lundgren *et al.*, 1981, 1982).

11.4.1 What is host plant resistance?

Host plant resistance is a phenomenon that has evolved in most higher plants to permit them to coexist with or to avoid the many species of [illegible] herbivores that could exploit them as food. Viewed broadly, it [illegible] take several forms that are usually connected with the feeding activity [illegible] the free-living forms of the herbivores or the provision of food and shelter for their progeny.

1. **Repellence** (antixenosis, 'non-preference' or the turning away) of herbivores before they come into contact with the plant. This can be associated with, for instance, the release by the plant of physiologically active chemicals (kairomones) into its air space or with a physical factor that influences the herbivores' visual response to a plant (or group of plants), perhaps to the extent that it is not recognized as a potential host. Physical characteristics such as the presence or absence of trichomes on leaf or stem can also influence the way that an insect reacts to a plant when first approaching it.
2. **Antibiosis**, where the plant contains chemicals that, when tasted or ingested by a herbivore, prove to be antimetabolites (e.g. insect growth hormone analogues), repellents, antifeedants, or toxins (including the toxic manifestations of the genes from other organisms, such as *Bacillus thuringiensis*).
   (a) **Latent antibiosis** awaits being switched on by a challenge from a herbivore or by a systemic (within plant) or pheromonal (between plant) message. Latent resistance has not (yet) been detected in groundnut although it may exist; it is a factor in the resistance of tomato plants to *Spodoptera littoralis* (Edwards *et al.*, 1985). Further information about this phenomenon can be found in Kogan (1986) and Edwards and Wratten (1987).
   (b) **Temporary antibiosis** is only present during a particular stage in the development of a given organ or the phenology of a plant.
   (c) **Permanent antibiosis** is a characteristic of a given plant species or organ.

   Antibiosis can also take the form of the absence or masking of a feeding stimulant.
3. **Tolerance**, where the plant can continue to develop and reproduce despite being attacked by herbivores. The misuse of this term to denote low levels of antibiosis or an undefined aspect of the resistance phenomenon, in general, often leads to unnecessary confusion.
4. **Physical** (structural), where the plant has structures (trichomes, thorns) or surface characteristics (thick or waxy cuticle, or even a layer of water – Nwanze *et al.*, 1990) that interfere with a herbivore's ability to exploit it.

This is a development of the conventional view of host plant resistance in plants to herbivores, based on Painter (1951). The following could be added because they can be complementary or confounding:

5. **Avoidance (seasonal)**, where the plant's phenology (or a crop's sowing pattern) is such that its life-cycle (or a sensitive developmental stage such as flowering or seed swelling) does not coincide with the time of year when a key herbivore is active.
6. **Avoidance (spatial)**, where a plant has evolved into forms that grow (or are sown) outside the biogeographic or climatic range of a key herbivore.

However, in practical terms, avoidance is best considered as being an aspect of cultural control.

The genus *Arachis* displays several of these resistance factors.

11.4.2 Host plant resistance in *Arachis hypogaea*

(a) Resistance to *Aphis craccivora*

Although seedling pests in their own right, groundnut aphids have been highlighted as primary groundnut pests in Africa because of their ability to transmit the groundnut rosette virus complex (GRV). In one season (1975) they converted Nigeria from one of the world's leading groundnut exporting nations to relative obscurity in this regard.

Considerable energy and expertise has been devoted to breeding for GRV resistance *per se* but it is surprising (with the benefit of 40 years of hindsight) that the colonial authorities of the time did not follow up the discovery made by Evans (1954) in Tanzania. He found that several varieties, especially Asiriya Mwitunde (a name indicating that the variety belongs to the Mwitunde people of northern Tanzania), carried comparatively small aphid populations compared with the other varieties tested. This was associated with fewer and smaller GRV primary infestation sites. This clear indication of virus management by vector control was accompanied by significant yield advantages.

Unfortunately, screening of the East African genotypes in the ICRISAT germplasm collection has only revealed comparatively low levels of aphid resistance. Apart from the implication that important germplasm has not yet been collected or has been lost, this is now of less importance because two genotypes with high levels of aphid resistance, ICG 5240 (= EC 36892) and ICG 5725, have been detected (Wightman *et al.*, 1990). Field tests of ICG 5240 in Africa (Wightman *et al.*, 1990; Sithanantham *et al.*, 1991), India (Padgham *et al.*, 1990a,b) and China (Dr Xu Zeyong, personal communication) have shown that the level of aphid resistance remains high across continents. These experiments have shown sufficient intercontinental variation in aphid response to demonstrate the existence of biotypes of *A. craccivora*. Resistance is manifested by longer generation time and considerably diminished fecundity.

Field tests in the rigorous conditions of a GRV screening nursery in Malawi showed that after 40 days exposure (after which GRV has a minor yield) 14% of the 248 ICG 5240 plants were infected (control = festation, n = 749). At harvest time, 4 months after emergence, the ptibles had a >98% infestation, and ICG 5240 only 44%.

he next step in exploiting this resistance was to determine the mechanism. This has given us access to a method for screening the progeny of crosses between the aphid resistant genotypes and lines with agroecological adaptation that would complement or replace our bioassay technique.

These studies (carried out mainly at ICRISAT by scientists from the Natural Resources Institute, Chatham, UK) have shown that there is only evidence for antibiosis. It is temporary in that the factor is concentrated in the areas where the aphid is most likely to feed, i.e. the terminal leaf buds, leaflets and petioles. Electronic monitoring showed that the aphids fed for half the time on the phloem of ICG 5240 compared with TMV 2 (susceptible control). This is likely to reduce considerably the chances of absorption of the GRV virus by the vector (now known to be a complex of viruses, e.g. Murant, 1990; Murant and Kumar, 1990), which has an acquisition time of >4.5 h (Padgham *et al.*, 1990a; Padgham *et al.*, 1990b).

The analysis of phloem extracts from the petioles of ICG 5240 had 2–8 times the concentration of procyanidin than did the phloem of TMV 2. Further tests showed that there was a strong negative correlation (r^2 = −0.86) between the log procyanidin concentration in seven groundnut genotypes and the intrinsic rate of increase of aphids on those genotypes. Assays showed that a concentration of only 0.005% procyanidin in an artificial diet reduced honeydew production (equivalent to diet ingestion) by 50% (Grayer *et al.*, 1992; Kimmins personal communication). This implicates procyanadin in the resistance process, though not necessarily as the active component: it is, however, a convenient quantitative marker that is being used as an index of resistance level.

Thus resistance to the vector of GRV has been detected and the possible mechanism of resistance described. Vector resistance has been shown to be a valid method of managing the disease and there is a relatively simple method of detecting minute quantities of the resistance factor (or a precursor or breakdown product) in plant sap.

(b) Resistance to thrips and jassids

Lynch (1990) and Wightman *et al.* (1990) list more than 100 genotypes with resistance to thrips and/or jassids. Subsequent screening at ICRISAT has revealed several more – not detailed here, except that it is worth mentioning that ICG 5240 has high resistance to jassids as well as to aphids (above) and foliar diseases (Sithanantham *et al.*, 1990). However, at this stage in the development of pest management procedures for groundnut, it is more appropriate to develop varieties with high yield potential that also have resistance to key pests and groups of pests than to seek more resistant genotypes when plenty have already been identified. Table 11.12 indicates that this procedure has led to the combination of jassid resistance genes from ICG 5040 (low yield potential) and ICG 5043 (very low yield potential) with backgrounds conferring relatively high yield potential in research station conditions (Dr S.L. Dwivedi, Groundnut Breeder, ICRISAT). They now have to be tested in farmers' fields in appropriate areas.

TABLE 11.12 *The pedigree, yield and jassid score of 10 out of 18 groundnut varieties bred for jassid resistance and high yield, tested in the 1990 rainy season at ICRISAT Center (communicated by Dr S.L. Dwivedi)*

Variety (ICGV)	Pedigree	Pod yield t/ha	Jassid score*
87745 (SB)	ICG 799 × (ICG 799 × NC Ac 2214)	2.54	3.3
86455 (SB)	ICG 799 × (ICG 156 × NC Ac 2214)	2.40	3.0
86393 (VB)	ICG 1326 × (ICG 156 × NC Ac 2214)	2.48	3.0
86462 (SB)	ICGS 1 × NC Ac 2240	2.31	2.3
86522 (SB)	ICG 799 × (M 13 × NC Ac 2214)	2.20	3.0
86518 (SB)	ICG(PRS) 12 × NC Ac 2214	2.20	2.3
87430 (SB)	ICGS 6 × (ICG 799 × NC Ac 2214)	2.16	3.0
87252 (SB)	ICGS 7 × NC Ac 2214	2.15	2.0
87495 (SB)	F334A-B-14 × NC Ac 2214	2.12	3.0
87468 (SB)	ICGS 24 × NC Ac 2214	2.04	2.7
Controls			
High yielding susceptible:			
ICGV 87128 (SB)		2.36	7.0
Resistant parents			
NC Ac 2214 (ICG 5040) (VR)		1.51	1.0
NC Ac 2240 (ICG 5043) (VR)		0.39	1.0
Trial mean (total of 18 entries)		2.25	3.5
SE ±		0.17	0.2

Notes: SB = spanish bunch, VB = virginia bunch, VR = virginia runner;
*Jassid score 1 = no damage (chlorosis), 9 = >75% of leaves are chlorotic;
Data in parentheses are the ranking of yields within the experiment.

Screening for resistance to thrips and jassids in Thailand over a number of years has indicated that (NC Ac 343 × NC 17367) had the highest yields of the lines tested and multiple insect resistance. NC Ac 343, (NC 1107 × (NC 2232 × NC 2214)) and (NC 6 × NC 3033) had sightly lower yields but high levels of pest resistance (investigators were W.V. Campbell, Manochai Keerati-Kasikorn and Turnjit Satayavirut; the latter communicated this information). This agrees with findings previously reported for resistance to *Frankliniella fusca* in North Carolina in which NC Ac 343 and its derivative NC 6 were linked with thrips resistance (Campbell and Wynne, 1980).

TABLE 11.13 *Incidence of* Thrips palmi *and bud necrosis disease (BND) in an experimental trial carried out at Rajendranagar, near Hyderabad, 1992 post-rainy season (means of four replicates, data of Vijaya Lakshmi (unpublished); JI 24 = susceptible control)*

Days after sowing	Genotype	*Thrips palmi* *n*/25 terminal	BND incidence % of all plants
29	ICGV 86031	9.5	0
	ICGV 86338	9.8	0
	JI 24	29.8	0
44	ICGV 86031	9.8	0
	ICGV 86338	13.8	0
	JI 24	14.8	1.2
57	ICGV 86031	4.5	0
	ICGV 86338	4.3	0.6
	JI 24	5.3	3.6
70	ICGV 86031	1.5	0
	ICGV 86338	1.8	3.6
	JI 24	6.0	8.0
85	ICGV 86031	0.5	0
	ICGV 86338	0.5	3.6
	JI 24	1.0	18.7
99	ICGV 86031	0	0.6
	ICGV 86338	0	3.6
	JI 24	3.8	24.8
114	ICGV 86031	0	0.6
	ICGV 86338	1.3	3.6
	JI 24	2.0	33.6
132	ICGV 86031	0.3	1.2
	ICGV 86338	0	4.2
	JI 24	0	39.1

Resistance to the thrips vector (*Thrips palmi*) of the bud necrosis virus (BNV – a variant of the tomato spotted wilt virus (TSWV) that is found in the Indian sub-continent) is viewed as being an important key to the management of this disease in groundnut (Amin, 1985a; Reddy and Wightman, 1988; Reddy *et al.*, 1991). A variety of great potential in this respect is ICG 86031 which has resistance to the vector and to other insects (below) and has unconfirmed resistance to the virus. Field trials have indicated that ICGV 86388 also has resistance to the vector which results in low levels of BNV incidence (Table 11.13). In the USA, Southern Runner suffers less from TSWV than Florunner (Culbreath *et al.*, 1992).

High trichome density, distribution and length have been shown to be important resistance factors in genotypes such as ICG 5040 (NC Ac 2214) and ICG 5043 (NC Ac 2240) (Campbell *et al.*, 1976; Dwivedi *et al.*, 1986). However, the important line ICG 2271 (NC Ac 343) and its derivatives are not particularly hairy, so that presumably there is a chemical basis to its antibiosis. As in the wild species (below), a flavone glucoside has been linked with antibiosis in the cultivated species (Holley *et al.*, 1984).

tha

(c) Resistance to the lesser cornstalk borer (LCB)

In view of the importance of this insect to the peanut industry in the USA, it is not surprising that resistance to this species has been sought on several occasions. Smith *et al.* (1980a,b) screened 490 accessions in artificial conditions and indicated that varieties Early Runner, Florigiant, Florunner and Virginia Bunch were among the resistant lines. Field tests in North Carolina of an initial 120 lines with natural infestations (i.e. screening was carried out in realisitic conditions) were carried out from 1976 to 1981. PI 269116 ranked first or second for lowest peg and pod damage in the four seasons in which infestations were heavy enough to give good screening conditions (Stalker *et al.*, 1984). Tests carried out in North Carolina indicated that several lines are promising.

(d) Resistance to *Spodoptera litura*

The development of resistance to *S. litura* in suitable varieties has been regarded as being of high priority for Asian groundnut farmers for a number of years. The results of experiments carried out in 1986 and 1987 (Table 11.14) indicated the possibility that ICGV 86031 (breeder = S.L. Dwivedi, ICRISAT) had some resistance to *S. litura* combined with high yield in the post-rainy season. This hope was substantiated in further tests on the ICRISAT research farm and in farmers' fields in coastal Andhra Pradesh (southern India). In the limited trials so far carried out, farmers had sufficient confidence to grow this variety without protecting it with insecticides. They were rewarded with higher yields and lower variable costs than neighbours who grew locally acceptable varieties but applied insecticides to kill defoliators. PI 269116, PI 269118 and PI 262042 had resistance to this insect but none were outstanding (Campbell and Wynne, 1980).

Bioassays carried out with larvae as preliminaries to detecting the mechanism of resistance (independent tests by Ranga Rao and Dr D.E. Padgham, NRI) revealed no antibiosis effect on II–VI instar larvae when fed mature leaves of ICGV 86031. The main mechanism of resistance is currently thought to be tolerance, manifested as the enhanced ability of vegetative tissue to regrow following defoliation.

However, first instar larvae suffered 56% mortality when fed on ICGV 86031 compared with 12% mortality when fed on susceptible ICG 221. Padgham also found that newly hatched larvae had a marked propensity to vacate the leaves of this variety in the first two hours of free life. This

TABLE 11.14 *Effect of releasing two fourth instar* Spodoptera litura *larvae on the percentage defoliation (%d) (assessed after the larvae had pupated) and subsequent mean plant yield (y) in g per plant of five groundnut genotypes (the data are the means of five replicates; percentages were transformed to arc-sines for ANOVA)*

Genotype	Days after emergence									
	10		30		50		70		Control	
	%d	y	%d	y	%d	y	%d	y	%d	y
Post-rainy season										
ICGV 86031	86	10.0	58	11.7	37	15.0	22	18.8	–	18.3
ICG 5240	61	8.4	70	8.3	44	6.9	11	14.5	–	14.5
ICGV 86535	83	10.2	68	11.7	54	10.4	12	12.8	–	12.5
ICG 156	100	6.1	75	13.3	41	13.1	28	17.1	–	17.9
ICG 221	100	4.4	91	7.9	50	10.0	18	12.8	–	13.7
SE for: %d = ±1.6 (calculated via arc-sine transformation)										
g = ±1.3										
Rainy season										
ICGV 86031	100	4.5	45	9.2	64	10.8	35	10.8	–	11.4
ICG 5240	100	10.5	54	10.0	67	13.3	24	12.0	–	14.7
ICGV 86535	100	3.9	47	9.2	64	10.9	26	9.6	–	12.0
ICG 156	100	4.7	44	10.0	60	10.2	38	12.5	–	10.4
ICG 221	100	1.7	50	4.0	69	5.3	39	5.4	–	5.4
SE for: %d = ±0.5 (calculated via arc-sine transformation)										
g = ±1.1										

10 days after emergence (DAE) = seedling stage. 30 DAE = flowering. 50 DAE = pegging. 70 DAE = pod filling. Control plants had no insects and were insect-free throughout the experiment.

suggests that the resistance factor that influences the neonates is associated with the leaf surface, because their feeding activity is restricted to scraping the leaf surface. The antixenosis demonstrated by ICGV 86031 is likely to increase the first instar mortality that is characteristic of r-strategist noctuids (Kyi *et al.*, 1991) and will therefore contribute to the determination of the level of damage caused by the older larvae, among which mortality is comparatively low.

(e) Resistance to the corn earworm (CEW)

Campbell and Wynne (1980) report resistance to the CEW in Early Bunch and NC 6. The resistance in NC 6 affects larval development and is most likely to be indicative of antibiosis.

(f) Resistance to the southern corn rootworm (SCR)

Experiments in North Carolina carried out over nearly 20 years resulted in the development of NC 6 (= NC Ac 343 x VA 61R) which, with other NC Ac 343 crosses, competed favourably with Florigiant in terms of quality and price. It also had 10–20% of the damage caused by SCR and did not need protection from this pest under high infestation pressure (Campbell and Wynne, 1980).

(g) Resistance to the groundnut leaf miner

Resistance to the groundnut leaf miner has been as difficult to locate. This is mainly because of the sporadic nature of the infestations and difficulties in performing realistic screens on a large number of genotypes with artificially reared insects. The difficulties include the need to exclude the parasites but to allow plants to grow in a natural light regime without shading. The inference is that fine net cages (needed to exclude parasites) cut down the amount of light reaching the plants, and that supplementary artificial light appears to cause variations in the leaf chemistry that modify resistance factors (P.J. Moss, unpublished MSc thesis). An indoor screening process that gives a satisfactory degree of consistency has been developed. Progress has also been made with contributions by P.W. Amin, Dr R.V. Satyanarayana Rao, (Indian Agricultural Research Institute) and Ms P.J. Moss (University of Bath, UK) in that resistance (tolerance, antibiosis and physical) to this species has been detected. Tests have reached the stage where trials in farmers' fields are called for to evaluate the significance of this resistance in relevant conditions. Noteworthy genotypes are ICG 2271 (NC Ac 343), ICG 1697 (NC Ac 17090) and ICG(FDRS) 4. Anderson *et al.* (1990) found that NC Ac 2821 (as well as NC Ac 17090 and PI 405132) had resistance to the groundnut leaf miner when tested in Khon Kaen, Thailand.

In contrast to jassids and thrips, it appears that groundnut leaf miner moths are attracted to hairy leaves, as opposed to shiny (glabrous) ones for oviposition (R.V. Satyanarayana Rao and G.V. Ranga Rao, unpublished). Females are attracted to NC Ac 2214 (ICG 5040) for oviposition but the larvae that hatch subsequently suffer higher levels of mortality because of the antibiotic properties of this genotype. The latter appear to be associated with the exudation of relatively large volumes of sap when the plant is injured. The sap is 'gummy', inferring the possibility that the activity of the larvae may be impaired, but it also contains comparatively high concentrations of polyphenols which have been associated with resistance to *Spodoptera litura* in groundnut.

(h) Resistance to soil insects

Amin *et al.* (1985) reported that several of the lines that have resistance to jassids and thrips also suffered less from termite scarification than the other genotypes tested. Subsequent testing in Burkina Faso confirmed this finding in field conditions (Lynch *et al.*, 1986). Important lines include ICG 2271, ICG 5043, ICG 5044 and ICG 5045 (= NC Ac 343, NC Ac 2240, NC Ac 2242 and NC Ac 2243).

Resistance to white grubs has not yet been located in *Arachis*. Trials carried out with the above termite resistant lines in Australia, testing for resistance to the pod feeding *Heteronyx*, revealed no resistance (H. Brier, personal communication). However, resistance to white grubs has been found in other crops. Crocker *et al.* (1990) recorded considerable levels of resistance to *Phyllophaga congrua* in one wheat and four oat cultivars. Lucerne, lupins and *Lotus* are highly resistant to *Costelytra zealandica* (Farrell and Sweeney, 1974; Kain and Atkinson, 1970). Lucerne has been sown in New Zealand as a cleansing crop in dry, lowland pastures that have been badly affected by this pest since the beginning of this century. Lucerne is also resistant to *Heteronyx arator*, another white grub pest of pasture in New Zealand and Australia (King *et al.*, 1975).

11.4.3 Host plant resistance in *Arachis* spp.

Many *Arachis* spp., the 'wild species', have levels of insect resistance that approach immunity, i.e. insects walk away from them or, if confined on the leaves, die if they eat them or die of starvation rather than eat them. This phenomenon has been known for many years (Smith and Barfield, 1982; Amin, 1985b) but, unfortunately, the exploitation of this knowledge has been insufficient in view of the economic importance of some of the insect species involved.

The extent of resistance in the wild species is shown in Table 11.15 which summarizes the results of tests carried out at ICRISAT Center between 1988 and 1992. This represents a formidable amount of potentially exploitable material, especially when it is realized that the levels of resistance far exceed that detected in *A. hypogaea* to the more intractable insects. The inclusion of a root feeding species (jewel beetle) is an indication that a search for resistance to the soil insect pests of groundnut among the wild species may be justified.

It is also noteworthy that 6 of 18 (*A. hypogaea* × *A. cardenasii*) interspecific derivatives were resistant to the groundnut leaf miner in research station (open field) conditions in Tamil Nadu, India (Kalaimani *et al.*, 1989).

However, progress has been made in other directions in that a start has been made in determining the mechanisms of resistance in 14 species (Stevenson *et al.*, 1993a, b; Kimmins *et al.*, 1993). Bioassays (Table 11.16) indicated that the survival and growth rates were, in all cases, significantly lower than in the susceptible *A. hypogaea* control (ICG 221 = TMV 2). Estimates of leaf toughness ('biteability') indicated that physical factors may be components of this resistance phenomenon.

Bioassays of solvent extracts of the leaves of the most resistant species, *A. paraguariensis* and *A. chacoensis* and an F_1 hybrid (*A. chacoensis* × *A. hypogaea*) indicated the presence of biologically active (antibiotic) fractions which were quercetin glycosides that resembled chlorogenic acid. Subsequent tests have indicated the flavonoid diglycosides that are present in the leaves and may be the main resistance factors (Table 11.17).

Thus resistance has been found within the genus to reduce the effects of the serious above-ground pests in groundnut. In several cases, there is no scientific reason why this phenomenon should not be helping farmers in a number of countries. The gaps in our knowledge point to the need to find resistance to soil insects and to exploit the wild species.

11.5 NATURAL ENEMIES OF GROUNDNUT INSECTS

Not much is known about the dynamics of the natural enemies of groundnut pests. There are exceptions, but they are from the southern states of the USA and emanate from institutions which provide strong linkages between high quality research organizations and extension services that are well tuned to the needs of local farming systems. Elsewhere in the world we are somewhere between a zero knowledge base and the stage where research reveals the need to carry out more research rather than the solutions to problems.

11.5.1 North America

Smith and Barfield (1982) and Lynch and Douce (1992) are positive about the potential for the natural control of *Heliothis zea* (corn earworm) and

TABLE 11.15 Arachis *spp. tested at ICRISAT Center for resistance to* Aphis craccivora *(screen house), groundut leaf miner (GLM) (field), jewel beetle larvae (field), and* Spodoptera litura *(laboratory assay) with an indication of the level of resistance*

TABLE 11.15 *Cont.*

Collection number	*Arachis* species	Groundnut aphid	Groundnut leaf miner	Jewel beetle	Army worm
10002	*apressipila*	HR	S	–	HR
9990	*apressipila*	HR	R	R	–
9993	*apressipila*	HR	S	HR	–
30003	*apressipila*	HR	R	HR	–
30009	*apressipila*	HR	R	HR	–
30080	*batizocoi*	–	HR	S	–
30079	*batizocoi*	HR	–	–	–
30081	*batizocoi*	HR	HR	–	–
GKP 9667(316)	*batizogaea*	–	–	–	HR
36034Y0-1	*cardenasii*	HR	S	S	–
36034YF	*cardenasii*	HR	–	R	S
36019-1	*cardenasii*	–	–	R	–
36033Y	*cardenasii*	HR	–	R	–
GKP 10017	*cardenasii*	HR	–	–	–
10602	*chacoensis*	S	S	–	R
10602-5	*chacoensis*	–	R	–	–
10602(5)	*chacoensis*	–	–	–	HR
30109	*paraguariensis*	–	R	–	–
565-6	*paraguariensis*	–	S	–	–
HLKHe565-6	*paraguariensis*	–	–	HR	–
30134	*paraguariensis*	–	–	HR	HR
KCF11462	*paraguariensis*	–	–	R	–
30109	*paraguariensis*	–	–	–	HR
GKPSC30124	*paraguariensis*	–	–	–	HR
9634	*pseudovillosa*	–	–	–	R
12922	*pusilla*	HR	R	HR	–
114	*rigonii*	–	S	–	–
30007	*Arachis* sp.	R	HR	–	R
A77/113	*Arachis* sp.	–	–	–	HR
GKP9578(312)	*Arachis* sp.	–	–	–	S
GKP9797	*Arachis* sp.	–	–	–	HR
GKPSCS30135(21)	*Arachis* sp.	–	–	–	HR
GKP9893(321)	*Arachis* sp.	–	–	–	HR
GKP9629(315)	*Arachis* sp.	–	–	–	HR
GKP9572(311)	*Arachis* sp.	–	–	–	HR
9921(100)	*Arachis* sp.	–	–	–	HR
KG30012(339)	*Arachis* sp.	–	–	–	HR
GKPSC30116/19	*Arachis* sp.	–	–	–	HR
GKPSC30114	*Arachis* sp.	–	–	–	HR
GKPSCS30144(18)	*Arachis* sp.	–	–	–	HR
GKP9553(90)	*Arachis* sp.	–	–	–	HR
GKPSCS30135	*Arachis* sp.	–	–	–	HR
GKPSCS30138(3)	*Arachis* sp.	–	–	–	HR
GKP 10602	*chacoense*	–	–	–	IR
36025-1	*chiquitana*	–	S	HR	–
9530	*correntina*	–	S	R	–
K 7988	*duranensis*	HR	S	S	–
30074	*duranensis*	–	R	–	–
30065	*duranensis*	–	S	–	–
30067	*duranensis*	–	S	–	–
30070	*duranensis*	HR	–	–	–
HL 189	*glabrata*	–	–	–	HR
HLKHe571(91B)	*glabrata*	–	–	–	HR
A45/114	*hagenbeckii*	–	–	–	HR
A27/117	*hagenbeckii*	–	–	–	HR
2A5	*hagenbeckii*	–	–	–	HR
GK 30006	*hoehnei*	R	–	–	–
30085	*kemf-mercadoi*	—	R	HR	HR
35001	*kemf-mercadoi*	HR	–	–	–
30035	*khulaminii*	HR	S	HR	–
30063	*monticola*	–	S	–	–
7264	*monticola*	–	–	–	R
30008	*otavoi*	R	S	–	–
30017	*otavoi*	HR	S	–	–
GKPSBS30132(1)	*Arachis* sp.	–	–	–	HR
GKPSC30122	*Arachis* sp.	–	–	–	HR
GKPSC30120(13)	*Arachis* sp.	–	–	–	HR
Manfredi-5	*Arachis* sp.	–	–	–	HR
10038LL	*spegazzini*	–	S	–	–
30126	*stenophylla*	HR	HR	–	HR
HLK 410	*stenosperma*	HR	HR	S	–
HLK 408	*stenosperma*	HR	HR	S	S
HLK 409	*stenosperma*	–	HR	R	–
30011	*valida*	–	S	R	–
–	*villosulicarpa*	–	HR	S	–
–	*villosa*	–	–	–	HR
TMV 2	*hypogaea*	S	S	S	S
EC 36892	*hypogaea*	HR	S	S	S

HR = highly resistant; R = resistant; S = susceptible

TABLE 11.16 *Insects and mites to which resistance has been located among the wild* Arachis *spp. and interspecific derivatives (details are in Lynch (1990) or in Table 11.15*

Thrips	Campbell and Wynne (1980) Amin (1985b)
Empoasca spp.	Campbell and Wynne (1980) Amin (1985b)
Tetranychus spp.	Johnson *et al.* (1977) Leuck and Hammons (1968)
Lesser corn stalk borer	Kamal (1978) Stalker *et al.* (1984)[1]
Groundnut leaf miner	Table 11.15 Kalaimani *et al.* (1989)
Spodoptera spp.	Lynch *et al.* (1981) Kimmins *et al.* (1993) Table 11.15
Heliothis zea	Stalker and Campbell. (1983)
Southern corn rootworm	Stalker and Campbell (1983)
Root feeders	Table 11.15
Aphids	Table 11.15 Amin (1985b)

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[1] The authors noted that cultivated genotypes were as resistant as the wild species tested and suggested that there was no need to attempt to exploit the wild species for resistance to this species.

TABLE 11.17 *Flavonoid diglycosides in leaves of most resistant* Arachis *species*

Species	Flavonoid diglycosides	Concentration in fresh leaf (mM/g)
A. chacoensis	Quercetin 3-arabinosylgalactoside Quercetin 3-digalactoside	3.10 1.50
A. chacoensis × *A. hypogaea* hybrid	Total	2.50
A. paraguariensis	Quercetin 3-rhamnosylgalactoside Kaempferol 3-rhamnosylgalactoside	1.80 1.56
A. hypogaea (TMV2)	Quercetin 3-digalactoside	0.46

H. virescens (tobacco budworm) in the south-eastern USA. Egg parasites (*Trichogramma* sp.) giving 3–83% mortality, larval parasites (*Microplitis croceipes* and *Eucelatoria armigera*) and nuclear polyhedrosis virus combine to maintain defoliator population densities below economic status.

Smith and Johnson (1989) undertook a 3-year study, covering six discernible generations, of the population dynamics of *Elasmopalpus lignosellus* (lesser cornstalk borer, LCB) in Comanche County, Texas, basing themselves in fields of cv. Starr that had no insecticide applied, no irrigation and a history of LCB attack. They found that within-generation mortality ranged from 87.1% to 96.5%. Although larval mortality could be ascribed to an entomopox virus, a fungal disease, 13 primary parasite species and five species of predator, the main (key) mortality factors were 'unidentified' and density independent, and they influenced the eggs (average 7.4%) and first instar (average 53.8%). This is not an unusual feature of the population dynamics of R-strategist Lepidoptera (Kyi *et al.* 1991).

The implication of density independent mortality factors as being more important than parasites, predators and pathogens is consistent with the observation by Lynch and Douce (1992) to the effect that parasites and predators maintain LCB population densities at sub-pest levels except in seasons that are abnormally dry and hot. The host larvae are able to tolerate these conditions whereas the natural enemies are not. This results in outbreaks of the species in conditions where the crops are potentially least tolerant to additional stress. We now need to know the nature of the unidentified mortality factors and how or if they are influenced by the temperature and moisture content of the soil within the larval zone of activity. The possibility that changes in nutrient status of the plants that are associated with drought stress also favour the proliferation of this species (Wheatley *et al.*, 1989) has apparently not been considered.

The potential importance of spiders in groundnut fields is highlighted by a very detailed study carried out in Texas on irrigated and dryland fields that had not been treated with insecticides during the 1981 and 1982 seasons (Agnew and Smith, 1989). More than 25 000 spiders were collected, belonging to 18 families and 79 genera. Hunting spiders outnumbered web spinners by about 10 to 1. The list of prey is interesting because it includes a number of potential pests, such as mirids, larval *Heliothis* sp., jassids, and thrips. However, of the 220 prey records, 72 are of predacious insects (excluding Hymenoptera), including 38 spiders, and 21 are Hymenoptera (14 ants and 6 parasitica). This indicates that spiders confounded ecologist's concepts by operating in two trophic levels.

Earwigs (*Labidura riparia*) predominated in a 2-year study of arthropod predators in peanut fields in Alabama (Kharboutli and Mack, 1991). They ate caterpillar larvae (LCB, CEW and FAW). The exponential increase and decrease in their density was interpreted to be associated with the rapid exploitation of their food source and its subsequent exhaustion. The voracious and polyphagous red imported fire ant *Solenopsis invicta* was the next most abundant predator.

The stable and efficient operation of such natural control systems within agroecosystems is dependent on the presence or provision of off-season refuges that support a reservoir of hosts and their food plants. Such systems are also easily disrupted by insecticides to which, in our experience, spiders have a particularly low tolerance. We wonder to what extent the status quo for *Heliothis* spp. of the early 1970s still exists in commercial areas, and whether it could be improved upon by the exploitation of host plant resistance.

The results of recent research carried out at ICRISAT make us approach this notion with caution for two reasons. Firstly, it does not include reference to the potential confounding effect of host plant genotype on the rate of parasitism. Secondly, the fourth trophic level, which includes the parasites of parasites (hyperparsites), can also influence the success of natural control processes.

R.E. Lynch and J.J. Hamm (unpublished) demonstrated that, in the southern USA, the nuclear polyhedrosis virus (NPV) of *H. zea* was compatible in a tank mix with chlorothalonil applied for leaf spot control. The viability of the virus was reduced by about 60% but this did not prevent the initiation of epizootics in field trials. Subsequent population densities of the target species were maintained at below the economic damage level because natural enemies were not affected by the virus.

11.5.2 Asia

There is little doubt that, in insecticide-free conditions, natural control processes can have a marked effect on the densities of the pan-Asian defoliators. A list of the natural enemies of *Spodoptera litura* has been compiled (Ranga Rao *et al.*, 1993). It includes:

69 parasite species in 7 hymenopterous and 2 dipteran families
36 species of predacious insect in 14 families
12 species of spider in 6 families
4 species of protozoan
4 species of fungal pathogen
7 bacteria
4 viruses
5 nematode species

This probably represents the tip of the iceberg, because it represents what happens when a suitably qualified person with the means to observe, rear, collect, identify and report is in the right place.

The levels of larval and egg parasitism in *S. litura* are monitored on the ICRISAT farm (100–400 individuals or egg rafts) during each season. The data indicate that the tachinid *Paribaea orbata* is the most common larval parasite and that *Ichneumon* spp. and *Exorista xanthopis* also contribute to larval mortality. The rate of larval parasitism is 9.0% over eight seasons, but this includes two seasons where it reached 26.2% and 15.0%. Egg parasitism is not known to have exceeded 27.0%. The associated factors are the relatively low density of *S. litura* on this experimental farm (indicating that only the parasites with a highly efficient searching ability will have any impact) and the effectiveness of the insecticide applications.

Birds are known to predate *S. litura* larvae on the ICRISAT research farm. Cattle egrets removed 62% of the larvae released into unnetted enclosures (compared with netted enclosures). This may be an exaggeration of what happens in farmers' fields because the birds have learned that they may get food where they see the enclosures on our research farm. Cattle egrets are certainly present in farmers' fields in Asia and Australia and are known to include noctuid caterpillars in their diet (Siegfried, 1971). There is a need to learn more about the role of these and other birds as predators in groundnut and other crops.

S. litura is susceptible to viral diseases. We have heard verbal accounts of farmers in India spraying diluted suspensions made from diseased larvae to their crops. However, we have no details of the larval equivalents per unit area or the effectiveness of such activities.

Shanower *et al.* (1992) list 38 species of parasites known to be associated with the groundnut leaf miner. Seventeen of these were reared from larvae collected on the ICRISAT farm, and approximately half were known to be primary parasites. There were changes in dominance among parasite species during a season. For instance, in the post-rainy season 1987–1988, *Sympiesis dolichogaster* emerged from 26% of the parasitized larvae of the first groundnut leaf miner generation and declined to 12% and 16% by the third and fourth generation. *Stenomesius japonicus* emergences increased from 6% to 22% during the same period. The other species involved, which also emerged at higher rates as the season progressed, were *Goniozus* sp., *Chelonus* sp. and a group of three braconids – *Apanteles*, *Avga choaspes* and *Bracon* sp. The 'other species' group, at 40%, predominated by generation 4 and included unidentifiable species, some of which could have been hyperparasites.

This study also showed that:

- parasitism levels were not influenced by the genotypes – ICG 1697 (NCAc 17090) and ICG 799 (Kadiri 3 = Robut 33-1);
- insecticide application (dimethoate at 240 g/ha in 350 l water, once early in each caterpillar generation) reduced parasitism levels by 7–14%; and
- diseases accounted for up to 30% of the larval mortality (a new finding).

The latter observation indicated that a degree of larval mortality remained unaccounted for. This was assumed to be predation by carabids, e.g. *Chlaenius* sp. (Shanower and Ranga Rao, 1990) and spiders. The remaining

TABLE 11.18 *Influence of groundnut genotype on the rate of groundnut leaf miner parasitism at ICRISAT Center, rainy season 1992 (d = host density, % = percent parasitism) (data collected by Research Fellow M.L.J. Sison)*

Genotype	Leaf miner larvae per m² (d)	Parasitization[1] (%)
ICG 221	42	16
ICG 156	28	26
ICG 5240	26	26
ICG 2271	21	36
ICG 5040	78	80
ICGV 86031	31	22
ICG 799	51	30
ICG 5044	154	26
SEm	± 13.1	–

[1] Sample size: 50 larvae in each treatment.

questions about the interactions between host density, primary and secondary parasites and the mortality caused to all three levels by a range of insecticides, possibly applied at different times during the life-cycle of the caterpillar, remains as an example of a research project revealing further sets of problems. The contribution of the hyperparasites to the population dynamics of the herbivore is an important issue because we believe that the maintenance of a high parasitism rate (which can exceed 90%) is a lead factor in the management of the groundnut leaf miner.

Although Shanower *et al.* (1992) found that host plant genotype had no effect on the rate of parasitism (all species), this is not necessarily always the case. Observations at ICRISAT Center, on crops growing in an area that has never been treated with insecticides, indicate that host genotype and species can influence the level of groundnut leaf miner parasitism. Table 11.18 shows that, in a comparison of four genotypes, the rate of groundnut leaf miner parasitism was particularly low on aphid and jassid resistant ICG 5240, which is not known to be resistant to this caterpillar. Only ICG 156 is recognized as having a degree of resistance to the groundnut leaf miner.

Turlings and Tumlinson (1991) provide information to indicate that it is possible for chemicals released from a plant as a result of herbivore damage to attract parasites to the scene of the activity and thus to their host(s). There is a good case for following up this matter for groundnut in view of the clear effect of genotype on groundnut leaf miner parasitism.

The rate of parasitism (all species) also proved to be higher by 8% or 12% on soybean than on groundnut, depending upon whether the crops were sole crops or intercrops (Table 11.19). Host density was higher on the soybean, so that the higher rate of parasitism could be a function of the parasites' searching efficiency, i.e. under the relatively low host density in this experiment, the parasites were able to sting more hosts on soybean because they needed to search fewer leaves to find a caterpillar – a complex aspect of parasite ecology in its own right (Hassell, 1982).

TABLE 11.19 *Density of groundnut leaf miner larvae and larval parasitism on sole (s-) and intercropped (i-) groundnut (gnt) and soybean (soy)[1]: ICRISAT Center, data for 22 August (rainy season)*

	s-gnt	s-soy	i-gnt	i-soy	±SE
Larvae per 25 plants	3.1	4.7	3.3	6.3	1.3
Larvae/m² soil surface	46.0	183.0	52.0	243.0	22.0
Larvae/100 cm² leaf	9.1	19.4	9.7	26.7	1.4
% parasitism	36.0	47.7	31.4	38.7	2.6

[1] Plot size = 15 × 15 m, with seed sown in four rows on 1 m wide raised beds. Alternate beds of the two crop species were sown in the intercropped treatments. There were five replicates of the three treatments.

11.5.3 Africa

Weaving (1980) found that up to 56% of the eggs of *Hilda patruelis* are parasitized by *Psyllechthrus oophagus* (Hymenoptera: Encyrtidae). However, the rate drops considerably during the rainy season, which is when groundnut is grown.

Colonies of *Aphis craccivora* living on newly established groundnut crops (1–4 weeks after emergence) in Malawi were virtually without exception accompanied by (unidentified) syrphids, coccinellids and lacewings. Aphidioid mummies were also present. The aphid colonies died out within a week of this observation. The impression, as no data were collected, was that the predators were mainly responsible for this decline in aphid popuation density (observation by Wightman).

Later in the season, Wightman also noted the presence of high densities (up to one per 10 plants) of mantids in groundnut crops throughout southern Africa. They were of sufficient size (<7 cm body length) and density to warrant an investigation of their contribution to the natural control of potential groundnut pests in Africa.

The predominant arthropod life form, however, appeared to be ants. Members of genera such as *Pachycondyla*, *Myrmicaria* and *Platythyrea* were often abundant in groundnut fields and were seen in Malawi and Tanzania carrying caterpillars and other prey to their nests. Reimer (1988) found that thrips were eaten by ants (and anthocorid bugs, which are also common in groundnut fields in southern Africa).

Even less is known about the natural control of soil insects. In Malawi, ants were seen dragging a dropped live white grub larva, weighing approximately 3 g, along the furrow between two rows of groundnut plants. It is not known what happens when such an encounter between ant and white grub takes place underground. Wireworms are also recognized as the natural enemies of white grubs, but they can damage pods as well.

Ants are the natural foe of termites (Logan *et al.*, 1990). Wightman and Wightman (1988) found that the admixture of insecticides with the soil in groundnut fields can disrupt ant activity, whilst leaving termites unaffected. Whilst sampling the soil of groundnut fields for insects, Wightman found larvae belonging to the dipteran families (unidentifiable to species from larvae by the British Museum of Natural History) Scenopenidae, Mydidae and Therevidae. They are all known to prey on either Coleoptera larvae, *per se*, or arthropods and earthworms (Therevidae), and may, therefore, include white grubs in their prey.

A fungal disease, *Metarhyzium anisopliae*, the green muscardine fungus, is currently under evaluation for the control of the white grubs that attack groundnut in Queensland (Milner, Rogers and Brier, personal communication; Milner, 1989, 1992). After many years of evaluation, the selection of strains that are highly pathogenic to scarab larvae has allowed the application of this technique to proceed to the commercialization phase for pasture and sugar pests. The propagation and dispersal of the fungus is relatively simple. The successful outcome of the trials in Australia and the extension of the technology to Asia and Africa is the kind of breakthrough needed to give leverage on the almost intractable white grub problem.

11.5.4 Comments on the natural control of insects living on groundnut crops

It is known that the potential for natural control to make a major contribution in maintaining the herbivores living on groundnut at levels lower than action thresholds is high. Unfortunately, considerably less is known about the dynamics of the various processes. This is especially true of predation, where there is ample scope for applying immunological techniques to determine the nature and quantity of the prey of suspected arthropod predators (e.g. Giller, 1984; Stuart and Greenstone, 1990). Presumptive vertebrate predators could be studied by more conventional techniques involving trapping and faecal analyses.

11.6 INSECTICIDES

We are, in general, somewhat diffident about emphasising the application of insecticides for reducing the density of foliage feeding insects, except at the seedling stage, and perhaps to the soil. The data available indicate that mirids, as destroyers of flower buds, are also an exception and, where feasible, should be eliminated if present in crops during the flowering stage, at least in the more determinate varieties.

Since 'peanut entomological literature is replete with the effectiveness of insecticides in reducing pest populations and to increasing peanut yield,' (to quote Lynch and Douce, 1992), we shall not go into the details of the many insect/insecticide options. We shall instead look at areas that are not covered so well.

Although no documentation referring specifically to groundnut has been located, the 'Green' environmental lobby in the USA is putting pressure on the agroindustry as a whole to reduce pesticide usage. Without entering the rights and wrongs of such matters, this will undoubtedly push the groundnut industry towards exploiting the resistance that already exists in NC 6 and the genotypes and species discussed in section 11.4. It is fortuitous that excellent co-operation between discipline scientists in the south-east of the USA has led to the identification of such a choice of material. This review also signals an increase in interest in the process of natural control among groundnut entomologists in the USA since the late 1980s.

Our impression is that *A. hypogaea* is naturally resistant to many insects and that many of the insect pest problems on groundnut are induced by insecticides (or suboptimal management procedures). Tait and Napompeth (1987) provide many examples of how insecticide use in the less developed countries has created more problems than it has solved. Circumstantial evidence for this is Wightman's observation, during a survey of groundnut fields in southern Africa, that he only found significant defoliation (by *Helicoverpa* sp. and *Spodoptera littoralis*) on two research stations where insecticides had been applied in response to minor defoliation.

Amin (1988) stressed that, up to the mid 1960s, there were many fewer insects recognized as groundnut pests in India than there are today. This must be attributed to changes in groundnut management, and one such change is the increase in insecticide application.

Ranga Rao and Shanower (1988) found that 70% of farmers visited in a post-rainy season survey of groundnut fields in Andhra Pradesh, India, had applied insecticides to their groundnut crops, mainly in response to the appearance of groundnut leaf miner. Heavy users had crops with bad defoliation by *S. litura* and *Helicoverpa armigera*, but their crops were in no better condition than neighbours who had not applied insecticides. The latter had little defoliator injury but may have had reduced yields (though not necessarily submaximal profits) as a result of groundnut leaf miner activity. This was attributed to the destruction of the natural control process by insecticides. Our experience at ICRISAT is that areas of groundnut fields that have had insecticides applied to them always suffer more from defoliators (Table 11.20). The failure by farmers to eliminate

TABLE 11.20 *Damage by defoliators to groundnut in plots treated and untreated with insecticides: consolidated data from ICRISAT Center (experimental plots) in post-rainy season only*

	Percentage of leaflets with defoliator damage	
	With insecticides	No insecticide
1984–85	7.0 (8 × dimethoate)	0.3
1985–86	9.0 (8 × dimethoate)	5.3
1986–87	20.7 (8 × dimethoate)	5.8
1987–88	5.7 (2 × monocrotophos)	2.9
1988–89	2.8 (1 × monocrotophos)	1.7
1989–90	1.7 (2 × monocrotophos)	1.5
1990–91	1.9 (2 × monocrotophos)	0.3

the target Lepidoptera implies that these defoliators were no longer susceptible to the insecticides (carbamates, organophosphates and pyrethroids applied singly or as ad hoc cocktails). Insecticide resistance in both of these species in this area has been documented (Ramakrishnan *et al.*, 1984; Armes *et al.*, 1992).

Unfortunately, it is not possible to rerun history and perform controlled experiments on such matters, but it is possible to attempt to reverse the process. Prior to 1984, insecticides were applied to groundnut crops on the ICRISAT farm in response to the perceived needs of the scientists (breeders, physiologists etc.) involved, reacting to what was often minor damage. This resulted in a treadmill effect, to the extent that eight or nine applications were being made per season (D.S. Bisht, personal communication). In the 1984 post-rainy season this process ceased and insecticides have only been applied at the behest of a groundnut entomologist, according to thresholds that have been slowly relaxed. The result is that there has been a steady decline in the average number of applications made per season and the number of pest outbreaks (Table 11.21). The unfortunate result is that it is now difficult for breeders, entomologists and virologists to screen for resistance in realistic conditions. Table 11.21 indicates a reversal in the downward trend in the amount of insecticide applied to groundnut in the 1989 rainy season. This corresponded to increased levels of insecticide application in response to heavy outbreaks of *H. armigera* on chickpea and pigeon-pea that probably diminished the level of the natural control process across the whole farm.

11.6.1 Flower pests

What is not shown in Table 11.21 is that, often, only one low rate application of dimethoate was applied at the start of a season (5–12 days after emergence) to kill thrips and jassids. Whilst even this may not have been necessary in economic terms, it served certain cosmetic needs of a research station. It is suspected that this regime would eliminate the mirids, which attack early and can have a marked impact on the flowering, without jeopardizing the natural control process. This is because the major potential defoliators have not established themselves by this stage so that there is no attendant cohort of parasites and predators. (These comments arise from discussion with D.J. Rogers and H.B. Brier, Queensland Department of Primary Industries.)

TABLE 11.21 *Insecticide (kg or l formulated product) applied to groundnut fields on the ICRISAT Center Research farm (source D.S. Bisht, Farm Manager)*

Season		Total area (ha)	Total applied (kg or l)	Mean ha^{-1}	Materials
Up to 1984		20–30	>200	*c*.9	
1984	Rainy	20.00	102.10	5.10	Di, En, Dv, Mc
	Post-rainy	30.00	123.50	4.12	Di, En, Ca, Dv
1985	Rainy	13.90	50.00	3.57	Di, En, Dv, Mc
	Post-rainy	29.73	65.75	2.19	Di, En, Dv, Mc
1986	Rainy	22.00	44.63	2.03	Di, En, Dv, Fe, Lo, Mc
	Post-rainy	31.41	31.20	1.00	Di, En, Mc, Fe
1987	Rainy	29.90	32.00	1.07	Di, Dv
	Post-rainy	34.75	36.25	1.00	Di, Dv
1988	Rainy	17.14	20.57	1.20	Di
	Post-rainy	26.90	31.55	1.17	Di
1989	Rainy	20.00	66.80	3.30	Di, Qu, En, Ca, Dv
	Post-rainy	19.95	36.5	1.92	Di, Qu, Dv
1990	Rainy	No data			
	Post-rainy	24.00	62.4	2.60	Di, En

Ca = carbaryl, Di = dimethoate, Dv = dichlorvos, En = endosulphan, Fe = fenvalerate, Lo = Lorsban, Mc = metasystox, Qu = quinalphos

11.6.2 Soil insects

Currently there is no proven alternative to insecticides for the control of soil insects, other than the promise presented by certain resistant genotypes and wild species (NC 6 against *Diabrotica* is the exception). *Elasmopalpus* remains a problem insect in the USA, especially in dry seasons, but can be controlled by granular formulations of a range of insecticides (Smith and Barfield, 1982). However, as they are best incorporated in the soil prior to sowing, they must be applied prophylactically. This is also the conclusion arrived in India for the control of white grubs where phorate is the preferred insecticide (Yadav, 1991 publication), although Bakhetia (1982) found that seed dressings of other insecticides were effective for white grub control. The best yield response was achieved when the insecticide was mixed as seed dressing with thiram, for the control of *Aspergillus niger*, the cause of collar rot (Bakhetia *et al.*, 1982).

Logan *et al.* (1992) sought alternatives to cyclodiene insecticides for soil insect control by comparing the effects of aldrin, chlorpyrifos and carbosulphan on termites, white grubs and other insects living on or under groundnut stands in India and the Sudan. Chlorpyrifos was, in general, the most effective in that it gave as good results as aldrin, especially in a slow release formulation. The only problem was that residues were found in the seeds after harvest. Isofenphos granules were not as effective as chlorpyrifos for controlling soil insects, but could have a place in pest management programmes because the systemic effect of this material considerably reduced the incidence of groundnut leaf miner caterpillars.

11.7 CULTURAL CONTROL

The concept of cultural control covers all management activities a farmer could execute that are not included under the headings of the preceding three sections. At the same time, cultural control may also include these activities because they are very much intertwined and invariably involve management decisions. It is when we come to this area that we should begin to be able to consider catalysis in the form of insect densities stabilized below economic levels resulting from the simultaneous application of two or more pest management tools. However, before integration is considered it is necessary to review some of the management options that could be considered by groundnut farmers.

11.7.1 Intercropping and habitat diversification

Risch *et al.* (1983) reviewed the relationships between agricultural diversity and pest incidence. They concluded that the benefits, in terms of species abundance and outbreak suppression, were more likely to be associated with interference with insect dispersal activity than enhanced natural control. This may point to the need to design systems specifically to assist the proliferation of natural enemies. This means providing food (nectar sources) for parasitoids and refuges for arthropod predators (sometimes called 'weeds'), and considering an agroforestry component in the farming

system to encourage birds, apart from the other benefits. This is why we stress that there is a close link between cultural control and natural control.

Low (or no) technology farmers have diversified their farm systems probably since farming began, largely to ensure that they have something to harvest at the end of the season. Sowing groundnuts between rows of a cereal (maize, pearl millet or sorghum) is common in parts of Africa but is not apparently practised so often in Asia. The indications are that the density of thrips, jassids and groundnut leaf miners on groundnut is reduced by this practice (Wightman and Amin, 1988; Muthiah *et al.*, 1991). Farrell (1976c) found that, in Malawi, a groundnut–bean (*Phaseolus*) intercrop reduced the incidence of GRV because the aphids became hooked on leaf hairs on the bean leaves as they moved from one row to another. Farmers in southern India sow castor at a low density in groundnut fields to attract female *Spodoptera* moths to its leaves for oviposition. The egg masses are easily detected on castor leaves and can be destroyed by hand.

It is our experience that cowpea and groundnut are not good companions because of the risk of the spread of *Aphis craccivora* from cowpea to groundnut. Also, the practice of juxtaposing soybean and groundnut, which is common in Indonesia, could lead to a bad attack of groundnut leaf miner in the groundnut crop. This insect prefers soybean (Table 11.19) but can transfer if the time of soybean harvest corresponds to the pupal or adult stage. We exploit this process by growing 1 m wide beds of soybean around our experimental plots. They are pulled up and left to dry on the soil surface during the pupal stage so that the moths leave the dying plants and oviposit on the groundnut plants.

A stand can also be diversified by sowing more than one genotype of the same species in alternate rows or beds, as a mixture or in some other pattern. To our knowledge, this process has not yet been attempted with groundnut, but it appears to be viable in chickpea where a high yielding but pest susceptible variety was 'protected' by a lower yielding variety with high pest resistance (ICRISAT, 1992).

11.7.2 Mulching

(a) Organic mulches to protect the harvested product

Farmers in Africa commonly windrow the newly harvested plants to permit sun-drying. *Odontotermes* frequently penetrate the piles of drying plants and damage the haulm and seeds. This can reduce the pod yield by as much as 30% or 40% and, of equal importance, increase markedly the subsequent levels of aflatoxin contamination.

Ipomaea fistulosa (morning glory bush) is a common roadside plant in India. Unlike most plants in this environment, the leaves are not eaten by nsects or goats. Observation of this fact led to a possible approach

TABLE 11.22 *Effect of organic mulches on the percentage and level of pod scarification by termites* (Odontotermes *sp. and* Microtermes obesi*)*

	Pods scarified (%)	Scarification mean score (0–4)
Neem cake	2 (0.02)	0.04
Ipomaea	7 (0.07)	0.14
Celosia	17 (0.17)	0.38
Sunn hemp	59 (0.66)	1.69
Bare ground control	36 (0.37)	0.88
SE ±	(0.02)	0.06
F-value	156.4**	118.7**

Plot size = 200 × 50 cm
20 replicates
Neem cake mulch = 2.5 cm thick; others = 5 cm thick
Scoring: 0 = no scarification
1 = 1–25% of shell surface scarified
2 = 26–50% "
3 = 51–75% "
4 = 76–100% "
(Figures in parentheses are arcsine-transformed value of radians)

to protecting pods as they dry on the ground after harvest. The idea of using a mulch made of the chopped *Ipomaea* leaves and stems was extended to the possibility of using other plants that are not attacked by termites for the same purpose. The results (Gold *et al.*, 1989; Table 11.22) indicated that the *Ipomaea* mulch and neem cake gave drying pods a high level of protection from termites. A mulch made of *Celosia argentea*, a common weed that survives in the vicinity of areas of high termite activity on the ICRISAT farm, gave some protection, but sunn hemp increased the level of termite activity, compared with bare ground. A subsequent experiment (ICRISAT, 1991a) indicated that the long-term benefits of using *Ipomaea* to discourage the surface activity of termites were negligible compared with a neem cake mulch. A neem cake mulch applied to row crops was then shown to have no beneficial effect on yield or foliar insect management – and was very costly (Ranga Rao *et al.*, 1991).

The data available indicates that selected organic mulches could reduce the termite and aflatoxin problem associated with field drying that has concerned farmers and traders alike for many years. There is no evidence to link such mulches with benefits to the growing crop. However, our experiments were not exhaustive in this respect and there is ample scope to investigate the link between enhanced crop water economy (reduced soil evaporation) and weed management associated with mulching and the ability of the plant to tolerate insect attack.

Grainge *et al.* (1985) indicate that *Ipomaea* spp. have anti-fungal and anti-insect (bruchids, 'bugs', various Homoptera and flea beetles) properties. This is clearly a fertile area for further investigation.

(b) Synthetic mulch to reduce virus vector incidence

The ability of a shiny (reflective) or white mulch to protect crops from aphids and the viruses they transmit has been known for many years. The theory and practice are well established (Kennedy *et al.*, 1961; Kring, 1972; Smith and Webb, 1969). Winged aphids respond positively to a short-wave radiation source (such as the sky) when they are ready to initiate their dispersal flight and whilst they have sufficient stored energy to sustain this flight. When 'fatigued' or 'hungry' they react positively to long-wave radiation such as that reflected by vegetation. Thus, whilst they are in the early phases of their flight they respond to the major source of short-wave radiation – the sky – but are confused and repelled when they receive a (reflected) sky signal from the ground when in the end-of-flight host-seeking stage. Presumably, they then fly on to the field of a non-mulching neighbour.

When it comes to protecting a crop from a non-persistent virus (e.g. peanut stripe virus) there are only two options: growing a resistant variety, if one is available, or preventing the vector coming into contact with the crop. Clearly the information about aphids' flight physiology is of fundamental value for protecting a crop from a non-persistent virus, which can be transmitted during just a few seconds' probing by a viruliferous aphid. With persistent viruses (e.g groundnut rosette virus) there are more options but avoidance is still one of them (A'Brook, 1964).

Xu Zeyong *et al.* (personal communication) have shown that plastic mulches may be a viable method of protecting groundnut crops from the non-persistent peanut stripe virus, for which farmers currently have no satisfactory management procedure. The data so far available (Table 11.23) indicate the potential benefits of this approach in terms of reducing the number of aphids alighting in a crop, virus incidence and yield, even though the reporting years were quite different climatically. Dr Xu Zeyong has indicated that the plastic material is available at prices that are within the economic bounds of groundnut farmers in the People's Republic of China. The benefits in yield increase indicated in Table 11.23 are almost certainly related to the lower virus incidence but may also be associated with lower levels of fungal disease (some foliar diseases are initiated by spores splashing up from the soil surface onto the leaves), weed management and a reduction in the amount of water evaporating from the soil surface. These matters are open for further evaluation.

Reflective mulches or aluminium strips painted on a black plastic mulch have recently been shown to protect narrow-leafed lupin and summer squash from non-persistant viruses by repelling the aphid vectors (Jones,

TABLE 11.23 *Influence of sheets of silver and transparent plastic used as a mulches on the number of aphids caught in yellow pan traps placed in the plots, peanut stripe virus (PStV) incidence and yields in field trials in Wuchang, Peoples Republic of China, communicated by Dr Xu Zeyong, Oil Crops Research Institute*

	Silver plastic mulch	Transparent plastic mulch	Bare soil control
Yellow pan catches (aphids per season)			
1990	37	31	268
1991	5	59	404
Virus incidence (%)			
1990			
8 weeks after sowing	14.7	18.1	37.7
12 weeks after sowing	88.6	89.0	99.5
1991			
8 weeks after sowing	1.5	3.9	21.6
12 weeks after sowing	5.5	10.0	42.9
14 weeks after sowing	17.8	27.4	93.6
Yield (t/ha)			
1990	3.5	3.6	2.7
1991	1.8	2.1	0.7

1991; Lamont 1990). Shiny plastic mulches are used in Thailand (for instance, in vegetable seed nurseries) for weed control and water conservation.

It is likely that cultural practices will need to be modified to accommodate a reflective mulch if they include recommendations to ensure rapid canopy closure. This is because the mulch can only work if a sufficient area is exposed to the sky. However, as we anticipate that the mulch will also act as a weed control agent, this should not matter. Early canopy closure is usually recommended to reduce the number of weedings needed – and to make the crop less attractive to immigrant aphids, a role we anticipate will be taken on by the shiny mulch (A'Brook, 1964; Farrell, 1976a).

This is a good example of why and how pest management should be approached in a multidisciplinary manner. The preimplementation (research) phase needed for the further development of the shiny mulch technique clearly needs input from agronomists, weed scientists, virologists and entomologists.

11.7.3 Irrigation management

The likes of Smith and Johnson (1989) make it clear that the lesser corn stalk borer is not likely to achieve pest status under irrigated conditions. The same is partially true of the groundnut leaf miner (Wheatley *et al.*, 1989) but not for the groundnut aphid, which proliferated in the wetter end of the drought stress gradient despite being pounded by water from an overhead irrigation system (Ranga Rao *et al.*, 1991c).

It also appears that the source of irrigation is important. The only outbreak of red spider mite on the ICRISAT farm in recent years was associated with furrow irrigation combined with insecticide application. Neighbouring fields, which were either irrigated with sprinkler and sprayed with a similar insecticide regime or irrigated with a sprinkler and received no insecticide, had no mite outbreaks (densities ranged from 13–110 mites per 50 leaflets). Overhead irrigation reduced the mite density from 6323 to 1282 per 50 leaflets in the outbreak field in a matter of days (Ranga Rao *et al.*, 1990) without recourse to pesticide application. This reduction was sufficient to allow the labourers to harvest without suffering from skin irritation caused by the mite.

11.7.4 Avoidance

Groundnut, being an annual or short season crop, depending upon the genotype and where it is grown, relies mainly upon immigration to provide its quota of foliage feeders. (Possible exceptions are the noctuids and hairy caterpillars that aestivate or hibernate as pupae in the soil.) In line with our data indicating that the older a crop is, the less likely it is to be damaged by insects, it would appear to be a rule of thumb to sow groundnut crops early, before pests have a chance to multiply on their winter/hot/dry season hosts and start the migration process. This is by now conventional wisdom for groundnut in southern Africa, where crops sown with the break in the dry season avoid groundnut rosette virus (section 11.7.2(b)). It is likely that co-ordinated early sowing by government behest in Malawi is responsible for the virtual elimination of this disease in that country.

A similar phenomenon exists in the USA where the corn earworm passes from corn to groundnut, soybean and cotton in late July and August. Sowing the crops early (early to mid April) diminishes the damage caused by this insect (Lynch and Douce, 1992). Early sowing is also likely to reduce the risk of damage being caused by the lesser corn stalk borer (Mack and Backman, 1990).

Our experience with thrips at ICRISAT is mixed. It is not unusual for early sown crops to be badly affected by bud necrosis virus and later sown crops to be unscathed. At the other end of the season, early or timely harvest is called for to avoid termite attack and to reduce the time that the mature crop is exposed to other pod-eating pests, including mammals (Lynch *et al.*, 1986). A delay in harvest is therefore likely to increase aflatoxin incidence.

Some cultural practices are believed to promote pest outbreaks. For instance, the development of irrigation systems in many areas of the semi-arid tropics during the last 30 years has allowed farmers to extend their operations beyond the rainy season. This unquestionably has had a major positive impact on agricultural production. Unfortunately there are some negative effects that would not have been anticipated by the planners. For instance, Yadav (1981) notes the proliferation of white grub damage in northern India where supplementary irrigation prevents soil drying out. Desiccation and soil heating as a result of drought probably affect the grubs more than groundnut plants.

Until perhaps 30 years ago, in southern India *Spodoptera litura* was limited to being a pest of tobacco. It is presumed (Amin, 1988) that its adaptation to groundnut and other crops in southern India was a result of its being exposed to these erstwhile single season crops for more of the year than was the norm under rainfed conditions. It is not unusual to see crops at all stages of development from June to March. A short close season (April to May) gives some respite, except in parts of Tamil Nadu where groundnut is grown all through the year. Groundnut leaf miner and *Spodoptera litura* are particular problems in these areas, as is *Helicoverpa armigera*, which has only recently been recognized as another (induced) pest of groundnut in southern India.

11.7.5 Soil preparation and related cultural practices

Yadav (1981) indicated that deep ploughing can reduce white grub damage, especially during the pupal stage. The 'mode of action' clearly involves the physical damage to the insects as well as disruption of the grubs' environment and their exposure to the sun. Birds are often seen following the plough, presumably to pick up exposed insects (Syamsunder Rao, 1992). The practice of ploughing in the cool of the night, which is made possible with the introduction of the tractors that are a characteristic of the 'white grub belt' of northern India, does not contribute to white grub control. Firstly, birds do not hunt at night; secondly, the grubs are not exposed to the burning and desiccating effects of solar radiation.

Mack and Backman (1990) compared the effects of conventional tillage (ploughing and disking before sowing), reduced tillage (sowing into wheat stubble with a combined subsoiler and seed drill) and 'no-till' (sowing into burned wheat stubble) on insect densities. The tillage system had no effect on the population density of the pest and beneficial insects sampled.

Farmers in Nigeria said they were able to control termites by a number of processes: drumming; burying dead animals, cassava meal, fish guts or the contents of torch batteries in their fields; and introducing soldier ants into the termite nests (Malaka, 1972). There were several other methods involving growing plants or their extracts (*Sanseveria libericum*, *Ocimum basilicum*, *Parkia clappertoniana*, *Vetivera nigritana*, *Digitaria* sp., *Cymbopogon* sp., and *Pennisetum purpureum*) that are worth evaluation.

11.7.6 Other methods

Farmers may use a wide variety of other methods of managing their pests that may be beyond the ability of scientists to evaluate under controlled conditions. Such practices include making smoky bonfires around fields to disrupt the evening post-eclosion flights of *Amsacta* spp., burning hand picked blister beetles on fires lit close to fields (the beetles may release an alarm pheromone) and collecting and killing cockchafers during the crepuscular feeding and mating forays to specific trees. Such practices, when combined with other cultural activities, may help to sustain insect densities at levels below which they become pests. The benefits of other, technology based approaches, such as trapping noctuid moths in ultraviolet light traps, releasing egg parasites or catching male moths in pheromone traps, have also yet to be proved of value.

A new approach to aphid control has been described by Harrewijn *et al.* (1991). They achieved perfect or almost perfect protection from insects and the vectored virus diseases of potato crops by covering the growing plants with an ultrafine polypropylene net. The management of non-persistent viruses, such as the peanut stripe virus in Asia, remains an unsolved problem, especially, as in this case, the virus is seed-transmitted. Clearly, the technique of covering crops with such a fine web, which is still under investigation in Holland, could become a viable protection method for farmers' groundnut crops in Asia. However, details of cost and availability have not reached us and we suspect that both could be constraints to its widespread adoption. The technique may have a special application in seed or research farms because of the need to provide virus-free seed for farmers and researchers.

11.8 RESEARCH RELATED TO INSECT PESTS OF STORED GROUNDNUT

A number of insects feed on stored groundnut but perhaps only one is specifically associated with this product, at least in Africa and Asia – *Caryedon serratus*, the groundnut bruchid, borer or 'weevil'. The biology and management of this and the other species have been discussed in detail by Dick (1987b) and Wightman *et al.*, 1990. This section simply updates what has gone before.

Ranga Rao *et al.* (1987) reported that a black carpet beetle, *Attagenus fasciatus* (Dermestidae), was found in groundnut stores in India. This species is one of the few capable of penetrating the pod (as a neonate).

Most groundnut storage pests gain access to the seed of the unhulled product via broken shells and testa.

11.8.1 Resistance

One way of limiting the activity of such storage pests is to seek genotypes with resistance factors in the shell. Entomologists have located such genotypes and it is for others to decide whether to attempt to breed such traits into commercial varieties.

The pyralids *Plodia interpunctella* (the Indian meal moth) and *Cadra cautella* (the almond moth) are of particular concern in commercial and farm stores in the south-eastern states of the USA. Kashyap and Campbell (1990) tested 39 *A. hypogaea* hybrids (including established varieties) for resistance to these species. They found, with a little variation, that breeding line 10-P10-B1-B1-B1-B1-B2, variety NC 7 and entries with NC 343, NC 2214 and NC 2232 in their parentage were among the most resistant to both species. Assays were made of oviposition preference, larval development and damage.

Advanced breeding lines have been screened for resistance to *Caryedon serratus* (256 lines) and *Corcyra cephalonica* (306 lines) at ICRISAT Center to discover whether a given line is likely to be more or less resistant to storage pests (Mittal, Wightman and Dwivedi, unpublished). Most varieties tested were neither particularly resistant nor susceptible to either insect. Seventeen were more resistant than the most resistant control to *Caryedon serratus* and 26 had resistance to *Corcyra cephalonica*.

11.8.2 Protecting stored seed

Farmers in developing countries often have to pay a large premium when buying groundnut seed because they are not able to store their own seed from one season to the next without loss of quality as a result of mould and insect infestation. An attapulgite-based clay dust applied to groundnut pods (0.5% w/w) limited the ability of *Corcyra cephalonica* to reproduce to any significant extent (Mittal and Wightman, 1989). This was not a total surprise as the principle that an inert dust can protect stored food stuffs from insects has been demonstrated for a number of scenarios (Shawir *et al.*, 1988). As fungi also reduce the quality of stored seed, we substituted a dust formulation of a number of fungicides (at 3 g/kg) for the clay dust. *C. cephalonica* did not propagate with these treatments (ICRISAT, 1991, pp. 87–88). *Caryedon serratus* was not as responsive to the fungicide dusts, in general, as it was to the attapulgite clay dust. However, the formulation of thiram (75 WDP) that was tested could be substituted for the dust. This experimentation was not continued in on-farm conditions but the information was made available to the Indian National Agricultural Research Program and to the general public via a newspaper article stressing that seed from pods treated with a fungicide should not be eaten unless thoroughly cleaned.

11.9 INTEGRATED CONTROL OF GROUNDNUT PESTS

We define **integrated pest management** as one or more activities that are carried out by farmers that result in the density of potential pest populations being maintained below levels at which they become pests, without endangering the productivity of the farming system as a whole, the health of the farm family and its livestock, and the quality of the adjacent and downstream environments.

One such farmer activity could be sowing an alternative to a particular crop because the latter could not be harvested without using excessive amounts of pesticide or without a high risk of suffering excessive crop loss. Examples in the case of groundnut are few but include the situation in parts of Tanzania and Malawi where this crop is not grown because of the risk of hilda attack.

The keys to the management of insect pests of groundnut are minimizing insecticide application (or, in the case of many African farms, maintaining the current zero to minimal level) and exploiting host plant resistance, combined with cultural practices, especially those that enhance natural control processes. For instance, Campbell and Wynne (1985) demonstrated that NC 6, which has resistance to thrips, jassids, *Heliothis zea* and *Diabrotica undecimpunctata howardi*, can be grown without yield loss penalty (in North Carolina) with no or minimal insecticide application – compared with Florigiant.

Unfortunately, there may always be pests that will cause damage in certain years. Examples are *Elasmopalpus lignosellus* in the USA and the groundnut leaf miner in Asia. Perhaps it is only coincidence but the biological success of both of these insects is favoured by hot, dry conditions. Both can be controlled with granular insecticides incorporated into the soil at sowing, i.e. well before a pest attack can be forecast. The answer to the management of these insects may have to wait until farmers can rely on long-term (6–8 week) weather forecasts.

11.9.1 IPM for groundnut farmers – current and future prospects

As has been made clear, we do not exclude insecticides from IPM. If this is generally accepted, it follows that pest management specialists are obliged to provide farmers or their advisors with the means of deciding when to apply insecticides selectively and which are most appropriate to alleviate or avoid a given condition. Such a scheme has been in place in Georgia (USA) for over a decade (Douce, 1982). It involves information exchange at farmer meetings, publications, field scouting and pheromone traps for monitoring key insects. Lynch and Douce (1992) indicated that, in its early stages, participants benefitted by a yield bonus of nearly 1 t/ha (27%) for an increased outlay of $22/ha per season for pesticides. A more recent evaluation showed that the major participants were spending less on pesticides than non-users and were maintaining high yields.

This indicates two features that should be components of well run, extension lead IPM schemes: routine monitoring of impact of recommendations, and continuous attempts to improve the advice provided, especially if faced with a labile pest scene.

The development of IPM schemes for groundnut is not limited to developed countries. In the Philippines (San Mariano, Isabella) an IPM programme involving pesticides, an egg parasite and *Bacillus thuringiensis* and resistant variety BPI Pn-9 gave higher yields with less pesticide application than no treatment controls and farmers' practices (Campbell *et al.*, unpublished).

The process of developing a similar programme for southern India has been initiated. In many districts there is a clear seasonal sequence of events:

1. Farmers apply insecticides early in the season in response to jassid and thrips symptoms.
2. This reduces the density of parasites and predators (including birds that will only stay in or around a farm if there are at least a few insects to eat).
3. Because of 2, groundnut leaf miner densities increase.
4. Farmers apply insecticide to kill the leaf miners.
5. The level of natural control is reduced even further.
6. Outbreaks of *Spodoptera litura* appear.
7. More insecticides are applied.
8. At this stage insecticide resistance almost certainly occurs so that higher concentrations, cocktails or over-frequent applications have been reported.
9. More severe *S. litura* outbreaks occur, accompanied by the appearance of *Helicoverpa armigera* and white flies.
10. Stages 7–9 are repeated until the crop is harvested or abandoned.

A parallel situation has been reported from Vietnam (ICRISAT, 1991a) where farmers have been known to apply insecticide to groundnut every day and still have crops that are completely defoliated by *S. litura*.

We believe that this treadmill effect can be avoided at the very beginning. Farmers apply insecticides because they want to protect their large financial investment in groundnut seed from (cosmetic) jassid and thrip damage. There is available a variety (ICGV 86031) that has high yield potential along with resistance to jassids and thrips (and, therefore, bud necrosis virus) and defoliators, as well as foliar disease. We are testing this variety in key areas on the farms of lead farmers. Although our experience at ICRISAT indicates that pest outbreaks can be reduced by holding back on insecticide application (Table 11.21), we see the need to give farmers the confidence to get off the treadmill. We hope that the provision of a new, suitably adapted variety will be accepted as an alternative to a heavy insecticide application regime.

We are not as confident of being able to subdue the groundnut leaf miner with host plant resistance at the same time as the other potential pests in this environment. However, we have evidence that our action thresholds for insecticide application for leaf miner control are realistic and can be handled by farmers, and that the parasite cadre is sufficiently robust to survive limited and selective insecticide application (Table 11.5). Continuing research will cover the role of pheromone trapping in dealing with this problem and the possibility of exploiting wild species genes.

This reflects the importance of developing varieties with multiple pest constraint resistance. Even though there may be varieties with higher yield potential, they may never achieve it on farm because pests and the farmers' reaction to them would not allow it. Similarly, a single constraint approach to pest management, followed to the exclusion of consideration of the needs of the system as a whole, can also lead to sub-optimal solutions. For instance, there is little logic or acknowledgement of the principles of IPM to be found in developing a variety that has resistance to a single constraint, such as a virus disease, that hits seriously in a particular zone in only one season in 10 or 20. It is more sensible to concentrate on multiple insect resistant lines that reduce the risk of one-in-two season insect outbreaks and give perhaps 70% virus control via vector resistance. We have also indicated that a general need for groundnut is foliar disease management, with insect resistance being required in specific agroecological zones.

We agree with Lynch and Douce (1992) that the future of IPM for groundnut crops will involve computer modelling. This will emphasize, even more, the need for IPM researchers and practitioners to adopt multidisciplinary approaches. For instance, those interested in pest damage need to be able to discuss leaf eaters with physiologists in terms of depleted leaf area indices and disturbed source–sink relationships in the case of root feeders.

It will be noted that there is in this chapter data that form the basis of a forecasting system for a defoliator (in this case *S. litura*) management. Here are its components, with cross-references to appropriate sections.

1. Flight intensity of migrant moths is monitored by means of a district-wide network of pheromone traps (section 11.3.1(a)). Trap data are reported daily to a central facility.

   (Alternatively, scouts could visit fields to count eggs or egg masses. This is not a preferred procedure because it gives farmers less lead time to prepare to treat their fields during the first instar.)

2. Data for each trap or group of traps are entered into a software package that, on the basis of those data and on a given day for a daily cohort, will estimate:
    (a) the density and date of first day fourth instar larvae and of the moult from third instar to fourth instar based on current prediction models and daily mean air temperatures for the district (sections 11.3.1(b) and 11.3.2(a));
    (b) the total leaf area removed per day of that cohort during instars IV–VI (from the energetics model in section 11.3.3(a));
    (c) the effect of the insect-induced reduction in leaf area on pod production (via a crop model running off the same meteorological data as the insect population density model) (section 11.3.3(b)).
    (d) whether the data for the cohort of that day, combined with the information from previous cohorts, will result in a yield reduction caused by the cumulative activity of the IV–VI larvae (note that the level of resistance to the defoliator in the various genotypes growing in a particular district would have to be taken into account in this stage and if antibiosis retards larval development in 2(a);
3. Output would be in the form of advice to farmers in the village or watershed to apply insecticide, covering:
    (a) the selection of materials to be applied;
    (b) the preferred date;
    (c) the rate, as well as linked advice about harvest dates, etc.

Certain strategies should be built into this third stage. The first is **the application of low rates of insecticides to conserve natural enemies, early in the season**. Ideally, farmers should apply insecticide just as the eggs hatch. This is when the larvae are at their most susceptible to insecticides, so that much lower rates than would be used against larger larvae can be applied. This strategy is fundamental to the conservation of natural enemies. However, it is not easy to achieve, because sharp eyes and constant surveillance are required. Farmer participation would be needed to build confidence in the timing of this procedure,which would be based on a physiological constant.

We are aware that populations can explode later in the season if the correct action is not taken early enough. This means that fall-back strategies are required. We look to **the exploitation of insect pathogens and perhaps selected natural insecticides to supplement them**.

We are also aware that the misuse of insecticides has resulted in the development of chronic levels of insecticide resistance in developing countries. This can be offset, with the co-operation of the agrochemical industry, by a planned approach to the phasing of given insecticides and **the alternation or rotation of active ingredients to avoid or manage insecticide resistance.**

There is a final component in this management system:

4. The information should be returned to the farmers within hours by whatever means are available: radio, television, telephone to village leaders of 'pest management clubs' or, simply, a person on a bicycle.

This covers an approach to managing *S. litura* that could drastically reduce the amount of insecticide applied in several parts of Asia, without endangering the productivity of the farming systems concerned. The basic data is available but needs integrating and verifying in farmers' fields. Others crops that are susceptible to *S. litura*, such as tobacco and vegetables, could also be integrated. Virtually all of the relevant information is available for the groundnut leaf miner which could be 'added on', perhaps even including a function relating pheromone-trap catch data to larval densities once it has been established. Soil insect management requires a different approach involving soil sampling and will not be discussed here.

11.10 CONCLUSIONS

Throughout this chapter we have indicated where there is scope for further research activity and where significant progress has been made. We have distinguished the need to set two kinds of priority – research and economic – on the grounds that specific insects can remain of great (potential) economic importance, even though researchers have provided all the information (within the bounds of the current technology) needed to manage them. Clearly, if and as the fruits of research become accepted as on-farm practice, the economic status of an insect should diminish: *vide Aphis craccivora*.

This is why we have divided the priority ranking of pests in Table 11.24 between economic and research. This table, which is presented as a basis for thought stimulation, challenge and discussion, as much as for information, indicates the need to pay considerably more attention to the soil zone than it has been given in the past. A comparison of Table 11.24 (here) with Table 6 in Smith and Barfield (1982) indicates where progress has een made – for instance, in our understanding of thrips and their relationhip with groundnut management – and where recent research has uncoered the need to put emphasis in new directions, for instance white grubs.

Since Feakin completed the third edition of her comprehensive handook in 1973, there has been a considerable consolidation in our knowldge of groundnut insects. It is clear that, in the USA, groundnut IPM has assed from the research to the implementation and extension phase. ooking at the American scene from a long distance, there appears to be a eed for integration across political boundaries and deciding where comon goals have been achieved, where voids in knowledge appear and who an best fill them.

In less developed countries, it is possible to detect all levels of progress.

TABLE 11.24 *Major groundnut pests of the world with an indication of their ranking in terms of the need to carry out research on them and their economic importance in the relevant agroeconomic zones together with an indication of current and potential management solutions*

	Importance		Current solution	Potential solution
	Research	Economic		
Millipedes	1	1	None	?
White grubs	1	1	Insecticides (India) None in Africa	Resistant genes in *Arachis* spp. Slow release insecticide formulations *Metarrhyzium* Cultural control Resistance to scarification
Termites	1	1	None in Africa Insecticides in Asia	?
Hilda	1	1	None	?
Pod borers (wireworms, false wireworms, doryline ants, earwigs)	1	2	None	?
Elasmopalpus lignosellus	1	2	Granular insecticides Irrigation	Host plant resistance
Diabrotica	2	2	Insecticides	?
White fringed weevil	2	2	?	?
Miridae	1	2	None	Host plant resistance
Thrips:				
Brazil	2	1	Insecticides	Host plant resistance
as TSWV/BNV vectors	3	2	Host plant resistance	Host-plant resistance, especially via wild spp. genes
Spodoptera litura	1	2	Insecticides (excess)	Natural and cultural control via IPM
S. frugiperda and *S. exigua*	2	2	IPM via pheromone traps monitoring (USA)	
Heliothis zea	2	2		Potential for natural control plus cultural control to obviate need for insecticide
Groundnut leaf miner	1	1	Insecticides	Host plant resistance, especially via wild species genes IPM, including pheromone trap monitoring
Hairy caterpillars	2	2	Insecticides and cultural practices	?
Aphis craccivora	3	3	Cultural	Host plant resistance
Jassids	3	3	Insecticides (if anything)	Host plant resistance

Ranking (scale of 1–5): 1= of greatest importance

Unfortunately, the pest spectrum and the farming systems (and their economics) in the USA (and Latin America) are so different to those in Africa and Asia that it is not easy to see direct ways of transferring suitably modified technology. On the other hand, recognition that the high levels of insect resistance in NC Ac 343, 2240, 2214, etc. (which were developed at North Carolina State University from irradiated material) are effective outside the USA and are heritable has given entomologists and breeders a 'flying start'. These and other more recently identified sources of host plant resistance, and hopefully genes from the wild species, will surely form the basis of the successful management of groundnut pests in the future.

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