Tarimo: Because fewer pods are formed that are better filled.

Omran: DDT is banned but I see in your paper that it is still used.

Tarimo: It is used only on a very small scale.

Sandhu: How would you develop varieties that can attain high yields at low plant densities? The only means of doing this is to develop indeterminate types, but these would not be suitable for the short-growing seasons commonly prevailing in Tanzania.

Research on Groundnut Pests at ICRISAT

J. A. Wightman, P. W. Amin, G. V. Ranga Rao, and K. M. Dick*

Abstract

*Entomologists at the International Crops Research Institute for the Semi-Arid Tropics, Patancheru, Andhra Pradesh, India (ICRISAT Center) have identified 11 arthropod groupings or taxa as major field pests of groundnuts (*Arachis hypogaea *L.) in their mandate area. Their research is concentrated on 8 of these groupings and covers all relevant aspects of the contemporary pest control options. A common theme is rationalizing insecticide usage. A long-term, but achievable goal is the incorporation of multiple pest resistance into all cultivars released by ICRISAT. Termites, the thrips* Frankliniella schultzei *(Trybom), (a virus vector), the tobacco cutworm* Spodoptera litura *(F.), and the groundnut leafminer* Aproaerema modicella *(Deventer), have been selected as subjects of in-depth studies. The bruchid,* Caryedon serratus *(Olivier), has been identified as a potential pest of stored groundnuts in India. The kernels of groundnut genotypes are being tested for resistance to three other postharvest pests, the rust-red flour beetle* Tribolium castaneum *(Hbst.), the rice moth* Corcyra cephalonica *(Stnt.), and the warehouse moth* Ephestia cautella *(Walker), by means of techniques specially developed at ICRISAT Center.*

Sumário

Investigação sobre pragas do amendoim no ICRISAT. *Os entomólogos no Instituto Internacional para a Investigação de Culturas para os Trópicos Semi-Áridos, Patancheru, Andhra Pradesh, India (ICRISAT-Centro) identificaram 11 grupos de artrópodes (taxa), como pragas importantes no amendoim (*Arachis hypogaea *L.) na região em que trabalham. A investigação está concentrada em 8 destes grupos, cobrindo os aspectos mais relevantes das opções contemporâneas para o controlo de pragas. Um tema comum é a racionalização do uso de insecticidas. Um objectivo a longo prazo mas possível de atingir, é a inclusão de resistência multipla a pragas nos cultivares libertados pelo ICRISAT. As termites, as tripes (*Frankliniella schultzei *(Trybom), um vector de viroses), a lagarta do tabaco (*Spodoptera litura *F.) e o minador da folha do amendoim (*Aproaema modicella *Daventer) foram seleccionados para serem submetidos a estudos mais aprofundados. O bruquídeo* Caryedon serratus *(Olivier) foi identificado como uma praga potencial para o amendoim armazenado na India. A semente de vários genotipos de amendoim está sendo testada para a resistência contra outras três pragas de pós-colheita, como sejam a ferrugem, o gorgulho vermelho da farinha (*Tribolium castaneum *Hbst.), a traça do arroz (*Corcyra cephalonica *Stnt.) e a traça dos armazens (*Ephestia cautella *Walker), através de técnicas especialmente desenvolvidas no ICRISAT-Centro.*

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Submitted as CP No. 313 by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1987. Proceedings of the Second Regional Groundnut Workshop for Southern Africa, 10-14 Feb 1986, Harare, Zimbabwe. Patancheru, A.P. 502 324, India: ICRISAT.

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has responsibility for carrying out research aimed at improving groundnut (*Arachis hypogaea* L.) production throughout the semi-arid tropics (SAT) and wherever else groundnuts are grown. The clients are the scientists and extension workers of the national programs of the countries served by ICRISAT.

The constraints to groundnut production in the SAT are:

- soil related problems including drought, mineral imbalances, deficiencies or excesses, and inadequate nitrogen fixation by *Rhizobium* populations;
- inappropriate cultural practices,
- cultivars with limited yield potential;
- insufficient finances to buy fertilizers, good seed, and pesticides, and to pay wages;
- fungal and viral diseases;
- invertebrate pests; and
- inadequate marketing facilities.

ICRISAT's Groundnut Improvement Program is addressing the agricultural aspects of these problems. This paper is an overview of the recent, current, and planned research on invertebrate pests and their control. Our approach has been to identify the major pests or pest taxa in the SAT and to develop management techniques that are compatible with the cultural practices and financial status of the farmers concerned. Where possible we are seeking techniques that minimize their dependence on insecticides. Although pesticides have an important role to play in the control of some groundnut pests, we are aware that their over-application can lead to insecticide resistance, and will almost certainly eliminate many natural control factors. Furthermore, the correct insecticides and the means to apply them are often unavailable to many farmers in the SAT.

The Pests

Field pests either live underground where they damage the roots, pegs, and pods, or they feed on the leaves, stems, and flowers. The foliage feeders include vectors of virus diseases. We are directly involved with 8 of the 11 major pest taxa (Table 1) but see the need to extend our range of interest.

Pests of stored groundnuts tend to be pandemic and polyphagous. A succession of species can infest the product at all stages of the postharvest process from harvesting onwards. A project on this aspect of groundnut entomology has recently been initiated.

Our research is discussed in terms of control strategies rather than by considering each pest individually. However, it should be mentioned that the groundnut leaf miner, *Aproaerema modicella* (Deventer), the thrips, *Frankliniella schultzei* (Trybom), and the tobacco caterpillar, *Spodoptera litura* (Fabricius), have been selected as subjects of in-depth studies because of their importance within the SAT. *F. schultzei* has been identified as the major vector of tomato spotted wilt virus (TSWV) that causes bud necrosis disease (BND), which has devastated groundnut crops over wide areas of India (Reddy et al. 1983). The other two species eat the leaves.

Heliothis armigera is included among the pests because there is a possibility that its flower eating habits can delay harvest by extending the flowering period. If abundant, it is a serious defoliator but even when it is present in low numbers it may cause damage that goes undetected.

Hilda patruelis Stal. is in the list because it is a pest about which we need to know more. It occurs throughout southern Africa, especially in dry years, but is sporadic in appearance. It feeds on the upper roots of groundnut plants and causes the host to wilt and die. This could be because it removes water because of its sap-sucking habit. However, tests carried out in the laboratories of ICRISAT's Regional Program for Southern Africa in Malawi show that there is more than a physical response involved. The observations indicate the possibility that the insect injects a toxin into the host or that it may open the way to infection by a pathogen such as *Fusarium* sp (Weaving 1980, ICRISAT 1985a).

A survey over a period of 3 to 5 years is needed to determine the extent and intensity of the damage caused by this pest. It can be controlled with insecticides but they may be unavailable or too expensive. Weaving (1980) indicated that cracked soil around the plant favored its proliferation. Perhaps interplant hoeing would slow its spread. *H. patruelis* is attended by ants. What is the nature of this symbiosis and can it be exploited to manage this pest? There are many more such questions that need to be answered.

Management of Field Pests

Insecticide Control

In some parts of Africa, groundnut cannot be grown without pesticides being mixed with the soil before

Table 1. Major field pests of the groundnut crop in the semi-arid tropics.

Pest	Damage, distribution, and comments
Taxa and pest groups covered by research projects at ICRISAT Center	
Termites (especially *Odontotermes* and *Microtermes*)	Can eat all parts of the [illegible] root and pod borers; pods scarified by termites are prone to [illegible] diseases; problem extends throughout the SAT but is most serious in [illegible] Africa
Thrips	Present throughout [illegible] Asia; distort leaves and cause chlorosis. *Frankliniella schultzei* [illegible]
Aphids	Distort plants and [illegible] are vectors of virus diseases. The groundnut aphid [illegible] Africa
Groundnut leaf miner *Aproaerema modicella*	A major defoliator [illegible]
Tobacco caterpillar *Spodoptera litura*	A serious defoliator [illegible] Asia [illegible] pod borer
Jassids	Cause chlorosis and [illegible] disease, a problem [illegible] the SAT, especially [illegible]
Bud worm *Heliothis armigera*	Flower-eating habit [illegible] a serious defoliator in Asia
'Pod borers'	Includes millipedes [illegible] earwigs, [illegible] and wire worms. Present throughout the SAT
Taxa not covered by current research projects at ICRISAT Center	
Hilda patruelis	Feeds on roots close to the hypocotyl, causes the host to wilt; a special problem in drought years; restricted to southern Africa
Whiteflies	Cause foliar distortion and transmit viruses; mainly a problem in S.E. Asia.
White grubs (scarabaeid larvae)	Can destroy the root system, a special problem in light soils; crops grown in northern India are prone to attacks by these pests; a very widespread and often undetected pest

sowing. This procedure is needed to control termites, which can reduce yields by more than 50% (Sands 1960, Johnson et al. 1981). The termites live in large nests that can be several meters underground. These colonies are also widely separated, perhaps with only one or two ha[-1]. Attempting to destroy nests by physical means would involve major earth movements and would not necessarily prevent reinvasion from peripheral areas. Only persistent pesticides such as the cyclodiene insecticides endrin, dieldrin, and aldrin are suitable for controlling termites in this situation. However, this procedure may not be followed for much longer because the health authorities of consumer nations are becoming increasingly intolerant of pesticide residues in imported foodstuffs. Cyclodienes are highly soluble in the oil that makes up nearly 50% of the content of the kernels. Furthermore, they are highly toxic to mammals and create a hazard to the people involved with handling and applying them. Other types of insecticides (organophosphates, carbamates, and pyrethroids) will undoubtedly kill termites but they break down after several weeks in the soil, especially in tropical conditions. Ideally, pesticides applied for the control of soil insects should remain active for the entire crop season. There is a clear need for an alternative approach to this problem. However, this is not easy to find.

ICRISAT is joining with the Tropical Development Research Institute (TDRI), London, UK, and the University of Agricultural Sciences, Bangalore, India, in seeking alternative chemical-based methods for controlling termites. Initially, we plan to set up insecticide field trials in India to test some new chemicals, which are less toxic to humans than the cyclodienes, as well as slow-release formulations of well established, but short lived, insecticides. A fourth trial will test a new approach that has been developed by TDRI but which has not been fully tested in the field. This involves introducing either a slow-acting insecticide or a fungicide into nests by means of a cellulose bait. The target for both alternatives are the fungus gardens, upon which termites depend for their food. It is hoped that the insecticides will contaminate the fungus gardens via the organic matter collected by the foragers and kill the termites that subsequently eat it. Hopefully, the fungicide will kill the fungus "gardens" so that the colony starves. Treatments that prove successful in India will be tested in farm conditions in Africa.

A major research project at ICRISAT Center is primarily directed at determining the economic threshold and the correct control strategy for the groundnut leaf miner. We are using different intensities of insecticides to regulate the numbers of this insect, which is the main dry-season (mid-Dec to mid-Apr) pest in India. There are usually three or four groundnut leaf-miner generations per growing season, each one having a higher population density than the last. This means that the younger plants are not usually damaged by this pest. Our results indicate that yield loss does not occur unless there are more than 60 larvae per plant. The host is usually in the pod-filling stage by the time the pest has achieved this density.

The implication is that if leaf-miner densities reach more than 5 to 10% of the damage threshold (according to our estimates) at the end of the second generation, an insecticide should be applied when the adults are emerging from the pupal cases. This research will be continued for several seasons to confirm our data. We are also examining the influence of insecticides on the natural enemies of the groundnut leaf miner. A similar approach will be taken with other pests.

Host Resistance

As would be expected in an institute that has a major interest in plant breeding, considerable progress has been made in identifying and exploiting insect resistance in the 11 458 accessions in the germplasm collection (Table 2). We are seeking genotypes in which multiple pest and disease resistance is combined with satisfactory agronomic characteristics, such as high-yield potential and drought resistance. A team of entomologists, pathologists, and breeders has already succeeded in incorporating resistance to the thrips vector of TSWV into agronomically promising, advanced breeding lines.

Noteworthy genotypes are:

- Robut 33-1 (Kadiri 3): accepted by the Indian Council of Agricultural Research (ICAR) as a cultivar for the postrainy season in several states. This line apparently has some resistance to *F. schultzei* so that it suffers less from BND than the commonly grown cultivar TMV 2 (Amin 1985a).
- ICG 2271: identified by ICAR as a source of multiple pest resistance for breeding purposes. This genotype has resistance to pod-boring insects, pod-scarifying termites, thrips, jassids, and the groundnut leaf miner. In addition, it has a high-yield potential in the rainy season.

Other genotypes with high levels of multiple pest resistance are NC Ac 343, 2214, 2230, 2240, 2243. A "nursery" of insect resistant lines is being sent to 18 collaborators in 13 countries to determine their yield potential and the level of their resistance to pests in different geographical locations.

We are concerned that we have made little progress in finding resistance to *Aphis craccivora* Koch. This is because it is ephemeral at ICRISAT Center, so special field screens cannot be set up to select resistant lines. However, we found that in glasshouse conditions, aphid reproduction was reduced on NC Ac 2214, NC Ac 2240, NC Ac 343, and M 13 in comparison to susceptible control genotypes such as TMV 2.

The main reason for seeking resistance to *A. craccivora* is because it is the vector of the groundnut rosette virus (GRV), an important virus disease of groundnuts in Africa. As the "African" biotypes of *A. craccivora* are likely to be different from the "Indian" ones, we feel that Africa is the correct place to screen for resistance to this pest. Hopefully, the provision of improved facilities for the Regional Program in Malawi and cooperative ventures with other agencies will permit the number of genotypes tested to increase. Clearly, resistance to the vector and to the virus should be sought in parallel studies.

The preliminary experiments reported by Amin (1985b) and the research of other workers that he reviewed point to the existence of a high degree and a wide range of pest resistance within the genus *Arachis*. The groundnut cytogeneticists at ICRISAT Center are able to perform the chromosomal manipulations necessary for transferring "resistance" genes from wild to cultivated members of the genus *Arachis*. This is another field of research that will receive attention in the near future, with a view to finding sources of resistance to what may be the more intractable pests: *S. litura*, *A. craccivora*, and termites.

Research on the nature of resistance to pests indicates that it can be caused by physical and chemical factors. The presence of long, dense trichomes on the leaves of genotypes such as NC Ac 2214, 2230, and 2240 and the thick leaf-cuticle of NC Ac 2242 and 2243, for example, are associated with resistance to jassids *Empoasca kerri* Pruthi (ICRISAT 1985b). The trichome characteristics have a high degree of heritability and have been transferred to genotypes with favorable agronomic characteristics by normal breeding procedures (Dwivedi et al 1986).

We plan to investigate the chemical basis of resistance in the hope of being able to screen plant material for resistance to pests under laboratory conditions. This procedure would not be totally satisfactory by itself. However, it would avoid the need for relying entirely on field experiments, which are expensive and time consuming, as well as frustrating, if the insects we are interested in do not infest the fields in which the material is growing.

Cultural Control

In some situations farmers are able to reduce pest damage by adopting simple modifications of existing cultural practices. It has been known for a long time that increasing the plant population density reduces the incidence of GRV (Farrell 1976). The same is true for BND (Table 3).

Similarly, as with GRV (Farrell 1976), farmers who sow early in the season (i.e., as soon as, or even before, the "monsoon" rains fall) will avoid or suffer little loss from BND. Similarly, with postrainy season crops, the later the sowing date the greater will be the plant mortality caused by BND. The late-sown plants will be susceptible to the virus carried by thrips dispersing from the plants sown previously. Early-sown crops appear to be well established and less susceptible to the virus by the time viruliferous thrips are migrating.

Experiments at ICRISAT Center have shown that when groundnut plants are intercropped with millet, in particular, the incidence of BND is reduced (Table 4). An experiment to find out why this happens is currently in progress.

Another project has been designed to provide information about the interaction between the groundnut leaf miner and its host when grown under drought stress. There is a belief, in India, that this pest "prefers" to feed on plants suffering in this way. We are testing this hypothesis by measuring the density of this pest sown along a drought stress gradient. Pest density, haulm biomass, crop yield, and soil water deficit are being measured.

Enhancement of Natural Pest Mortality Factors

We do not believe that mass releasing of introduced parasites and predators and the inundative release of natural enemies is a practical proposition for controlling groundnut pests in the SAT; we are not involved in conventional "biological control" procedures. As the land masses involved are large and have a diverse fauna it is highly likely that a number of parasites, predators, and diseases are already present. Furthermore, rearing and release procedures would be costly because of the infrastructural problems associated with mass rearing, distribution, and monitoring the effects of such programs. It is far more important to design pest-control strategies that do not reduce the numbers of beneficial organisms already present.

Table 2. Groundnut genotypes with resistance to insect pests.

Pest taxon	Genotypes
Jassids	NC Ac 343, 406, 489, 785, 1337, 1705, 1741, 2142, 2144 2214, 2230, 2232, 2240, 2243, 2666, 2700, 17888, M13, Gujarat narrow leaf
Thrips	NC Ac 102, 343, 841, 1705, 1741, 1781, 2142, 2144, 2154, 2714, 2230, 2232, 2240, 2242, 2243, 2460, 2462, 2772, 7302, 15926, 17888, C-108, C-121, C-136, C-145-12, Gujarat narrow leaf, Robut 33-1
Pod scarifying termites	NC Ac 343, 1705, 2142, 2230, 2240, 2242, 2243, 10033, 17888, RMP-40
Groundnut leaf miner	Ah 477-1, 7215, C-154, CG-2145, 2157, 2187, 2232, GBFDS-17, 92, 93, 272, 273, M-13, NC Ac 343, 2491, RMP-40, S-7-2-14, TG-8 83/349/1
Pod borers	NC Ac 343 and 2240

Table 3. Effect of plant population density of groundnut on bud necrosis disease (BND) incidence, ICRISAT Center, 1980 rainy season.

Spacing (cm) Row	Spacing (cm) Plant	No. of seeds per hill	No. of plants per plot[1] Total	Healthy	Infected with BND	BND incidence (%)[2,3]	Ratio of healthy to diseased plants
75	15	1	200	92	108	53.6 (47.1)	1:1.17
75	15	2	392	275	117	29.8 (29.9)	1:0.42
60	20	1	187	99	88	47.0 (43.6)	1:0.88
60	20	2	348	200	148	42.1 (42.4)	1:0.74
30	10	1	522	300	222	42.6 (40.6)	1:0.74
30	10	2	1290	1044	246	19.1 (25.9)	1:0.23
15	5	1	1620	1138	482	29.7 (33.0)	1:0.42
15	5	2	3620	3218	402	11.1 (19.5)	1:0.12
SE			±92.5			(±2.25)	
CV (%)			15.6			(11.06)	

1. Gross plot size 7 × 6 m; net plot size 5 × 4 m.
2. Mean of three replicates.
3. Parentheses indicate arc sine transformed values.

Source: Amin 1983.

Table 4. Effect of intercropping of groundnut on the incidence of bud necrosis disease, 1982 rainy season, ICRISAT Center.

Crop combination[2]	BND incidence[1] (%) Days after emergence 50	62	75	Reduction in BND incidence over control (%)
Groundnut sole crop (TMV 2)	35	57	70	
Groundnut + pearl millet (BK 560)	25	37	47	33
Groundnut + sorghum (CSH 6)	32	48	60	15
Groundnut + maize (Deccan 101)	32	50	62	11
Groundnut + pigeonpea (ICG 1-6)	36	54	67	4
Groundnut + castor (Aruna)	39	57	70	0
Groundnut + sunflower (Morden)	31	48	62	11
SE	±2.6	±2.8	±1.9	
CV (%)	13.7	7.5	5.3	

1. Mean of three replicates, plot size = 300 m².
2. Row arrangements: 3 rows of groundnut to 1 row of pearl millet, sorghum, and maize, 5 rows of groundnut to 1 row of pigeonpea, sunflower, and castor. Spacing within rows: 10 cm for groundnut, pigeonpea, castor, 15 cm for pearl millet, 20 cm for sorghum, maize, and sunflower.

Source: Amin 1983.

At this stage we are concentrating on the groundnut leaf miner. There are about 25 species of parasites associated with this pest (Mohammad 1981) but we have not assessed their relative importance. In the 1984/85 postrainy-season crop at ICRISAT Center there was about 10% larval mortality caused by parasites in plots that were not treated with insecticides. In the 1985 rainy season the groundnut leaf-miner population remained low, presumably because there was about 90% parasitism in the first two generations. Thus, with this species at least, there is the potential for letting nature take its course, especially if pest-resistant cultivars are grown.

At first sight, our research plots appear to be devoid of predacious arthropods. This is to be expected of land that is intensely cultivated for growing rotation crops. However, we have caught "reasonable" numbers of hunting spiders (Lyniphiidae) and ground beetles (Carabidae) in pitfall traps, especially in those placed in unsprayed plots. These predators must be eating something and therefore should not be killed, because their diets probably include jassids and groundnut leaf miner moths.

S. litura is a serious groundnut defoliator in many parts of India and Southeast Asia. It has recently been identified as a pod borer in Haryana (northern India). This species is a major tobacco pest and attacks a number of other crops, including cotton. It has been treated with a wide range of insecticides for many years and is now resistant to organophosphates, pyrethroids, and carbamates (eighty-fold resistance to carbaryl) according to reports that have come from India and China (Ramakrishnan et al. 1984, Chou et al. 1984). Insecticide application should, therefore, be discounted as a long-term control strategy for this pest.

S. litura has a number of parasites and predators (Patel et al. 1971), but, perhaps owing to its sporadic appearances, they do not seem to have much impact on decreasing its numbers. It is, however, subject to a number of specific diseases (Kore and Bhide 1978, Dhandapani et al. 1982). Once the basic research on the biology of this pest has been carried out we shall look in this direction for developing a control method. Hopefully, the development of management strategies for other pests, that involve little or no insecticide application, will allow the parasites of this species to increase and perform a significant regulatory function.

Modelling

The advantages of simulating the interaction between a pest and its host during the development of pest management programs has been demonstrated by Gutierrez et al. (1975). *S. litura* has been selected as the subject of such a research project. This is because:

- it is a serious pest in Asia,
- ICRISAT Centre has the best facilities for carrying out the research in SAT Asia, and
- the complementary experience and training of our scientific staff is such that it is possible to execute an in-depth study of the type required.

This project, which is comparable to the one described by Bellows et al. (1983), is divided into a sequence of interconnected submodels (Figure 1):

- A study of the influence of temperature on egg, larval, pupal development, and oviposition rates in laboratory and field conditions throughout the year. The experimental approach accommodates both diurnal and seasonal fluctuations in temperature. The data will allow us to predict generation length from site-specific meteorological data and allow us to use ambient temperature records to drive the model.
- Within generation mortality. It is necessary to know the conditions under which larvae survive to the damage-causing stages (fifth and sixth larval instars).
- Quantification of the relationship between larval growth and leaf dry matter consumed ("energetics"). This phase is the link between the population dynamics study and the next aspect.
- Relationship between defoliation (i.e., larval consumption) and the loss in pod yield. The physiologists in ICRISAT's Groundnut Improvement Program have accumulated a considerable amount of the gravimetric data needed for modelling the growth of groundnuts. We shall investigate the influence of defoliation, as performed by caterpillars, on yield. One end point of this work—determining economic and damage thresholds for this pest on groundnuts—will have to take into account the genotype of the host and drought stress.
- Seasonal dispersal pattern. A network of flight traps in India has been arranged. They are baited with an effective synthetic male attractant. It should now be possible to obtain an impression of the migratory activity of at least male moths throughout the subcontinent. Early observations at ICRISAT Center indicated a positive relationship between the number of male moths caught and the number of eggs laid in groundnut crops 7 days later. This relationship has not been recorded since, and we want to know why.

The above aspects encompass a "basic biology" study. The following are the "applied" aspects.

- Host resistance: a long-term goal is to provide groundnut genotypes with resistance to *S. litura* for those areas that are subject to outbreaks. This process can be simulated and "tested" in a model of the type we are developing.

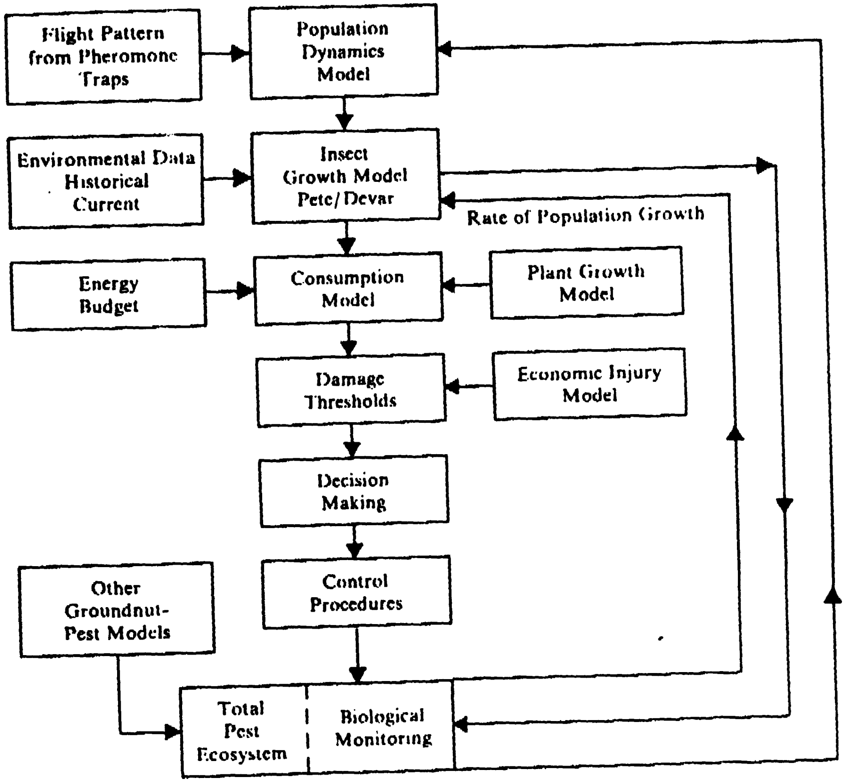

Figure 1. Flow diagram of the submodels that make up a simulation of the relationship between *Spodoptera litura* and the groundnut crop, including pest-management options.

- Induction of epizootics. One of the few realistic control options for this pest that is open to farmers is to artificially increase the level of disease propagules present in a crop. A study carried out by TDRI on *S. littoralis* attacking cotton in Egypt points to the need to develop local facilities for producing a purified virus (TDRI 1984). This aspect is under consideration as a long-term goal. Its implementation awaits an evaluation of the TDRI's project in Egypt.

The integration of the basic ecological data emanating from this research into a model of the plant-pest relationship will enable us to simulate the potential economic benefits of the applied aspects of this work, as well as forming a basis for an outbreak forecasting procedure. A long-term goal is to include in such a model a range of pest and other constraints to yield.

Decision Making

How resistant to a given pest does a genotype have to be before a farmer has no need to apply insecticides to avoid crop losses? This is a question that entomologists and breeders should endeavour to answer. To that end, we are currently working with Dr R. A. E. Mueller (Resource Management Program, ICRISAT) and Dr N. Dudley (Bureau of Statistics, Canberra) on a dynamic programming process that will enable us to do this. In our initial test we used basic field data from the groundnut leaf miner control experiment (Table 5) and "overlaid" it with a range of "resistances". We have assumed that resistance acts by reducing the rate of increase of each generation. Natural mortality (in real life mainly parasitism) ranging from 0 to 80% was introduced as an additional mortality factor at each level of resistance. The model has also been run with a number of insecticide "kill efficiencies". One spray of 95% efficiency is needed if there are four generations of larvae per season. There is no natural mortality and less than 70% resistance (Table 6). The need for insecticide application disappears if there is more than 60% natural mortality and at least 30% resistance.

This is a brief account of a piece of research that is in its early stages. It should be possible to extend this modelling procedure to other areas, e.g., resistance to disease and drought. This approach to decision making should be made available to research and extension workers in the SAT. Therefore, we are thinking in terms of converting it to a form that can be used with microcomputers.

Table 6. Combination of host-plant resistance and natural mortality and the number of sprays needed to avoid financial loss caused by the groundnut leaf miner *Aproaerema modicella*, as indicated by a dynamic programming model.

Level of natural mortality	Number of insecticide applications									
	Level of host plant resistance									
	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	[illegible]	[illegible]	[illegible]	2	2	1	1	1	0	0
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1	1	1	0	0	0
0.4	[illegible]	[illegible]		1	1	1	0	0	0	0
[illegible]		1	1	1	0	0	0	0	0	0
[illegible]	[illegible]	0	0	0	0	0	0	0	0	0

Identification and Control of Postharvest Pests

Our work on postharvest insect pests of groundnut has concentrated on

- The assessment of storage losses in India and the identification of the important pest species involved, and
- The development of appropriate methodologies for use in screening groundnut germplasm for resistance to the major storage pests found in the SAT.

Table 5. The parameters and assumptions used in a dynamic programming process used to indicate the levels of host resistance and natural mortality needed to avoid insecticide application on groundnuts without loss in revenue (based on unpublished data from ICRISAT Center).

Factor	Parameter or assumption
Plant density	200 000 plants ha^{-1}
Initial pest population	P = 20 000
Number of generations	4
Potential rate of increase per generation	X20
Damage threshold	P = 12 000 000
Relationship between pest density and yield loss	Yield loss is linear between P = 12 000 000–24 000 000; if P > 24 000 000 yield = 0
Efficiency of insecticide	95%
Levels of resistance	0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9
Levels of natural mortality	0, 0.2, 0.4, 0.6, 0.8

P = Population density as larvae ha^{-1}

Identification of Storage Pests in India

Very few attempts have been made in India to estimate losses to stored groundnuts caused by insects. A survey of farmers' stores in one area of Andhra Pradesh indicated that they do not suffer measurable storage losses because they generally sell their crop within one month of harvest. This is too short a period for sizeable pest populations to develop. These observations, in combination with the views of officials of oilseeds cooperatives, indicated that if problems exist, they would be confined to centralized storage sites.

A more detailed study was therefore carried out in the same area of Andhra Pradesh in a large warehouse attached to an oil mill operated by the State Oilseed Growers' Federation. Fifty sacks (total weight 1.5 t) of unshelled groundnuts were held in this warehouse for 5 months, during which time six samples were taken at monthly intervals from 10 bags chosen at random before each sampling date. The percentage weight loss caused by storage insects to each sample was calculated using the "count and weigh" method (Harris and Lindblad 1978). This technique allows damage by different species to be measured separately.

The most damaging pest was the groundnut bruchid *Caryedon serratus* (Ol.). This insect occurs in many parts of the SAT where it breeds on the seeds of common tree legumes such as *Tamarindus* sp and *Acacia* spp, as well as groundnuts. Previous reports of *C. serratus* causing heavy losses to groundnuts have come exclusively from West Africa (Davey 1958, Green 1959 and 1960, Conway 1983). Our results suggest that this insect may have a greater pest status in India than has hitherto been realized.

After 5 months, *C. serratus* caused, on average, 19% dry-weight loss of kernels. Populations of the other pest species infesting the experimental sacks—the rust-red flour beetle, *Tribolium castaneum* (Hbst.), the rice weevil, *Oryzaephilus mercator* (Fauvel), and the rice moth, *Corcyra cephalonica* (Stnt.)—remained low and contributed little to the total weight loss.

Large numbers of the lygaeid, *Elasmolomus sordidus* (F.), were on the sacks used in this experiment during their first 2 months in storage. This insect is known to be a pest of stored groundnuts in Africa (Gillier 1970, Conway 1976). Unlike other postharvest pests it can feed on kernels by piercing the shell with its moth parts. Its presence in heaps of drying groundnut plants at ICRISAT Center (K.M. Dick, J.A. Wightman personal observation) and in the warehouse indicates that it can infest the postharvest product at any stage up to processing.

The methodology used in this study represents a simple and relatively accurate way of estimating quantitative storage losses. Ideally, we should wish to see an extension of this work through parallel studies conducted in the other important groundnut-producing areas of India and the Asian SAT.

No attempt was made to assess the extent of qualitative losses in the groundnuts occurring over the 5-month storage period. Infestation by insect pests is known to affect the biochemical composition of stored oilseeds, for example, causing a decrease in thiamine levels and an increase in free fatty-acid content (Howe 1965). Oil pressed from nuts contaminated with insect larvae, dust, and frass will almost certainly be of poor quality and flavor. There is a need to determine in greater detail the relationship between population levels of the pest species, duration of storage, and the rate at which the biochemical changes occur that adversely affect flavor and oil characteristics.

Screening for Resistance to Storage Pests

We have developed methods for screening kernels for resistance to *T. castaneum*, *C. cephalonica*, and the tropical warehouse moth, *Ephestia cautella* (Walker). These species are polyphagous and are among the most important pests of stored groundnuts in the SAT. Resistance to *C. serratus* is being evaluated by TDRI (Slough, UK) in a parallel, collaborative project.

Studies on varietal susceptibility to *T. castaneum* were initiated by Dr P.W. Amin, who screened 526 genotypes to determine the degree of variability of this character. He identified at least one promising line, Ah 8418, which suffered significantly less damage than the susceptible check cultivar, APAU 4. Although further experiments have given useful information on the behavior of *T. castaneum* when infesting groundnuts, progress toward the development of a quick and reliable screening method has been hampered by the extent of variation between replicates of the same genotype. It is hoped that this problem will be overcome in future experiments.

An experiment in which 15 genotypes were examined for resistance to *C. cephalonica* provided more consistent results. The mean larval mortality was three times greater on the least su[redacted]ble than on the most susceptible genotype, and variation between replicates was small. Parallel studies are being carried out with *E. cautella* using the same genotypes.

Conclusion

It should be seen from this overview that the groundnut entomologists at ICRISAT are taking a broad view of developing pest-control procedures for the SAT. Many of our research plans are underway and the next year should see progress being made in the directions indicated.

There are still fundamental questions to be approached, especially at the farm level. For instance, we should know how farmers decide that they have a pest problem, and how effective their actions are (often insecticide application). Of course, we should also determine the damage thresholds of each pest in the multiplicity of situations under which groundnuts are grown, but that will take time.

References

Amin, P.W. 1983. Studies on arthropod vectors of groundnut viruses: report of work done from 1978-1983. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (Limited distribution.)

Amin, P.W. 1985a. Apparent resistance of groundnut cultivar Robut 33-1 to bud necrosis disease. Plant Disease 69:718-719.

Amin, P.W. 1985b. Resistance of wild species of groundnuts to insect and mite pests. Pages 57-60 *in* Proceedings of an International Workshop on Cytogenetics of *Arachis*, 31 Oct-2 Nov 1983, ICRISAT Center, India. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics.

Bellows, T.S., Owens, J.C., and Huddleston, E.W. 1983. Model for simulating consumption and economic injury level for the range caterpillar (Lepidoptera: Saturniidae). Journal of Economic Entomology 76:1231-1238.

Chou, T.M., Kao, C.H., and Cheng, E.Y. 1984. The occurrence of insecticide resistance in three lepidopterous pests on vegetables. Journal of Agricultural Research of China 33:331-336.

Conway, J.A. 1976. The significance of *Elasmolomus sordidus* (F.) (Hemiptera-Lygaeidae) attacking harvested groundnuts in the Gambia. Tropical Science [illegible]-190.

Conway, J.A. 1983. Notes on the biology and ecology of the groundnut seed beetle, *Caryedon serratus* (Ol.) (Coleoptera: Bruchidae) under field conditions in Senegambia. Tropical Stored Products Information 45:11-13.

Davey, P.M. 1958. The groundnut bruchid *Caryedon gonagra* (F.). Bulletin of Entomological Research 49(2):385-404.

Dhandapani, N.F., Janarthanan, R., and Kumaraswami, T. 1982. Epizootic occurrence of nuclear polyhedrosis viruses on *Spodoptera litura* F. Current Science 51:793-794.

Dwivedi, S.L., Amin, P.W., Rasheedunisa, Nigam, S.N., Nagabhushanam, G.V.S., Rao, V.R., and Gibbons, R.W. 1986. Genetic analysis of trichome characters associated with resistance to jassid (*Empoasca kerri* Pruthi) in peanut. Peanut Science 13(1):15-18.

Farrell, J.A.K. 1976. Effect of groundnut crop density on the population dynamics of *Aphis craccivora* Koch (Hemiptera: Aphididae) in Malawi. Bulletin of Entomological Research 66:317-329.

Gillier, P. 1970. Influences des attaques d'Aphanus sordidus sur la qualité des graines d'arachide. (In Fr.) Oléagineaux 25:465-466.

Green, A.A. 1959. The control of insects infesting groundnuts after harvest in the Gambia. I. A study of the groundnut borer, *Caryedon gonagra* (F.) under field conditions. Tropical Science 1(3):200-205.

Green, A.A. 1960. The control of insects infesting groundnuts after harvest in the Gambia. II. Field trials on the control of the groundnut borer, *Caryedon gonagra* (F.). Tropical Science 2(1):44-54.

Gutierrez, A.P., Falcon, L.A., Loew, W., Leipzig, P.A., and van den Bosch, R. 1975. An analysis of cotton production in California: a model for Acala cotton and the effects of defoliators on its yields. Environmental Entomology 4:125-136.

Harris, K.L., and Lindblad, C.J. 1978. Postharvest grain loss assessment methods: a manual of methods for the evaluation of postharvest losses. St. Paul, Minnesota: American Association of Cereal Chemists.

Howe, R.W. 1965. Losses caused by insects and mites in stored foods and feeding stuffs. Nutrition Abstracts and Reviews 35:285-293.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985a. Page 240 *in* Annual report 1984. Patancheru, A.P. 502 324, India: ICRISAT.

ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1985b. Page 218 *in* Annual report 1984. Patancheru, A.P. 502 324, India: ICRISAT.

Johnson, R.A., Lamb, R.W., and Wood, T.G. 1981. Termite damage and crop loss studies in Nigeria: a survey of damage to groundnuts. Tropical Pest Management 27:325-342.

Kore, S.S., and Bhide, V.P. 1978. Bacterial disease of tobacco caterpillar *Spodoptera litura* (F.). Journal of Maharashtra Agricultural Universities 3:34-37.

Mohammad, A. 1981. The groundnut leafminer, *Aproaerema modicella* Deventer (= *Stomopteryx subsecivella* Zeller) (Lepidoptera: Gelechiidae): a review of world literature. Groundnut Improvement Program Occasional Paper no. 3. Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. (Limited distribution.)

Patel, R.C., Patel, J.C., and Patel, J.K. 1971. New records of parasites of *Spodoptera exigua* (HB) and *Spodoptera litura* (Fabricius) from Gujarat. Indian Journal of Entomology 33:92-93.

Ramakrishnan, N., Saxena, V.S., and Dhingra, S. 1984. Insecticide-resistance in the population of *Spodoptera litura* (F.) in Andhra Pradesh. Pesticides 18:23-27.

Reddy, D.V.R., Amin, P.W., McDonald, D., and Ghanekar, A.M. 1983. Epidemiology and control of groundnut bud necrosis and other diseases of legume crops in India caused by tomato spotted wilt virus. Pages 93-102 *in* Plant virus epidemiology (Plumb, R.T., and Thresh, J.M., eds.). Oxford, UK: Blackwell Scientific Publications.

Sands, W.A. 1960. Observations on termites destructive to trees and crops. *In* Termite research in West Africa (Harris, W.V., ed.). London, UK: Department of Technical Cooperation.

TDRI (Tropical Development and Research Institute). 1984. Report, Apr 1983-Mar 1984. London, UK: TDRI.

Weaving, A.J.S. 1980. Observations on *Hilda patruelis* Stal. (Homoptera: Tettigometridae) and its infestation of the groundnut crop in Rhodesia. Journal of the Entomological Society of South Africa 43:151-167.

Discussion on Entomology Papers

Blair: Which soil insecticides are available in slow-release formulations?

Wightman: The insecticides that I know of are phorate, carbosulfan, carbofuran, and chlorpyriphos.

Blair: Might the formulation of chlorpyriphos in which the chemical is incorporated in plastic developed in Australia be applicable?

Wightman: This was developed originally for protecting sugarcane crops from white grubs and has been used in forest-tree nurseries in South Africa. If available and if reasonably priced it could be ideal.

Nigam: There are a few reports from India where they have tried to estimate yield loss caused by thrips in groundnut.

Wightman: True. The problem is separating the damage caused by one pest from another. There can be at least two species of thrips within a crop, as well as jassids and other insects.

Nigam: Will the threshold levels of different pests vary according to the variety?

Wightman: Almost certainly; it is important that when a cultivar is released it should be accompanied by a dossier including an indication of its susceptibility to a range of pests.

Gridley: Are there any indications that resistance to insecticides has broken down?

Gibbons/Wightman: No, testing in the USA and ICRISAT has not given any indication of this happening. We are aware that biotypes that can counteract resistance mechanisms can develop or may exist, especially in insects with short life cycles like aphids and thrips.

Ramanaiah: We notice that every year one pest i more important than the others, could yo comment?

Wightman: This is true for many crops. It is proba bly because low levels of natural mortality factor allow one pest to increase in numbers early in th season or suppress other pests in some way. The pe that achieves dominance early in the season ma cause so much damage that the crop is not a desi able host for other insects.