and 666. Hence, any measures, such as rational or need-based application of pesticides, the choosing of selective pesticides, and the lowering of the action threshold, that favour the protection of natural enemies and parasites should be studied further and viewed seriously as a necessary component of biocontrol in the broad sense. The application of antibiotics is considered in the scope of biocontrol in its broadest sense by some people, but in reality antibiotic preparations via fermentation or artificial synthesis are similar to general chemical pesticides and might possess the same ill side-effects, thus being no longer an ecologically sound means of pest control. The possible development of resistance of target pests to living biocontrol agent needs special attention. Once again, ecological study focusing on the three-way relationship among crop, pest and enemy influenced by the physical environment forms the theoretical basis of biocontrol. Such study should be pursued vigorously.

Education in pest management

In progressing toward sustainable agriculture, IPM would naturally evolve to sustainable pest management. This is more difficult to deliver by normal extension mechanisms owing to its 'soft' and dynamic nature. Its implementation and extension are much more difficult than those of cultivar, fertilizer, or such singular techniques as pesticide or agrochemical application, It is a knowledge-based extension rather than a material-based one. The lack of awareness about IPM and sustainable pest management of most farmers, many agrochemical businessmen and even some of the extension workers and policy-makers is the socio-cultural constraint limiting the successful development of sustainable pest management. Training and education to deliver the new information as it is developed are of crucial importance in developing countries.

Towards the rational management of the insect pests of tropical legume crops in Asia: review and remedy

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Abstract. The productivity of legume crops, especially the pulses, has not increased markedly in 30 years. This is a serious matter in this time of exponential human population growth because legume crops provide essential diet components that are not present in cereals at a price that is affordable to the majority. The preferential allocation of research resources to cereal crops is one reason for this stagnation. I suggest that an international effort should be mounted to redress this situation. Most Asian legumes have in common a cadre of insect pests that are reducing yields to levels at which harvesting is not economic. The position is worsening because insecticide resistance in key production areas has rendered many species uncontrollable. The short-term remedy is to persuade farmers to reduce their dependence on insecticides. Long-term solutions should be aimed at a common policy centred on the principal components of integrated pest management (IPM) schemes. Governments should be supplied with information that will permit them to set priorities according to absolute crop loss indicators. These will in turn provide a rational basis for the subsequent development of regional strategies. The establishment of an IPM centre in Asia would support the facilitation of this ideal. Such an organization would become the focal point for collecting, developing and disseminating the information and technology needed to make a quantum leap in legume production.

1993 Crop protection and sustainable agriculture. Wiley, Chichester (Ciba Foundation Symposium 177) p 233–256.

There is in Asia a considerable amount of motivation towards developing strategies for integrated pest management (IPM) within the context of sustainable agriculture (see Kenmore 1993, Jayaraj & Rabindra 1993, Varma 1993, Nagarajan 1993, Escalada & Heong 1993). There is no doubt that this activity will continue to contribute to the story of increasing production, of rice in particular. As such, this will be cited as the major research-led agricultural success story of this century. So successful has it been that several countries in Asia that once imported their staple are now major rice exporters. Not only that, but scientists predict that by 2050 rice productivity will have reached 20 t ha^{-1} per annum from two growing seasons—enough to feed 150 people for one year (*The Australian* 30 April 1992). This is fortunate because data released before the June 1992 Earth Summit predicted that the world's population will double by 2050 (*Guardian Weekly* 3 May 1992). An extrapolation of current world population data (Food and Agriculture Organization of the United Nations) gives one the impression that there will be considerably more people who will want to eat rice and other cereal products by this time:

Population of:	World	50×10^8
	Asia	30×10^8
	China (People's Republic)	12×10^8
	India	9×10^8
	Indonesia	2×10^8

The problem

People, especially children, who eat only cereal products are not likely to be healthy. Such a diet does not include all the amino acids, lipids, vitamins and mineral salts that are necessary for body maintenance and disease resistance. Thus it is customary among those who can grow or afford to buy them to supplement the staple with meat, cooking oil, fruit and vegetables. The poor and the voluntary vegetarians, who together form the majority of the people of Asia, rely on several of the 20 or so legume crops to supplement their diet. Unfortunately, pulse production in Asia has not kept pace with cereal production or the growth of the human population (Table 1).

In considering future developments of IPM in the context of sustainable agriculture, I have restricted myself to considering legume crops and the farming systems in which they grow because: (1) their under-production in Asia does not bode well for the future well-being of the continent, (2) I believe the production of cereal products is assured into the foreseeable future; (3) I cannot imagine that the current deteriorating situation can be allowed to continue without concerted international action and I wish to encourage this process.

Insect pests are a major contributor to the stagnation in legume production. Not only are most of these crops inherently susceptible to a large and diverse cadre of insects, but insecticide resistance is increasing daily within this cadre. This means that insect pests are becoming more and more out of control as a result of the continuing elimination of natural control processes as more and more insecticide is applied in attempts to control them. Further details and examples are available (Wightman 1989, Legumes Program, ICRISAT 1991): space limitations preclude the discussion of case histories.

The potential tools needed for managing the insects are often well known, but only to scientists and then only on a theoretical basis. What is needed

TABLE 1 Population and production data for Asia

		1961	*1966*	*1971*	*1976*	*1981*	*1986*	*1991*
Population ($\times 10^{-9}$)		1.9	2.0	2.1	2.4	2.6	2.9	3.0
Cereal	Area (Mha)	239	249	260	268	272	271	306
	Production (Mt)	248	309	385	445	528	626	823
	Productivity (t ha^{-1})	1.04	1.24	1.48	1.66	1.94	2.31	2.69
	Per capita (kg)	131	154	183	185	203	215	274
Pulses	Area (Mha)	37	34	32	33	32	33	36
	Production (Mt)	23	19	29	21	20	22	25
	Productivity (t ha^{-1})	0.62	0.56	0.62	0.64	0.62	0.67	0.69
	Per capita (kg)	12.1	9.5	13.8	8.8	7.8	7.6	8.4
Pulse: cereal production (%)		9.3	6.2	7.5	4.7	3.8	3.5	3.1
Groundnut	Area (Mha)	9.2	10.6	10.8	10.4	11.4	13.0	13.0
	Production (Mt)	7.5	8.4	10.4	9.1	13.4	15.3	15.4
	Productivity (t ha^{-1})	0.82	0.89	0.96	0.87	1.18	1.18	1.18
	Per capita (kg)	3.9	4.2	4.0	3.8	5.1	5.3	5.1
Soybean	Area (Mha)	11.3	9.8	9.2	8.2	10.0	11.7	13.5
	Production (Mt)	7.0	9.2	9.8	8.1	11.2	14.7	16.0
	Productivity (t ha^{-1})	0.62	0.94	1.07	0.99	1.12	1.35	1.19
	Per capita (kg)	3.7	4.6	4.7	3.4	4.3	5.1	5.3

therefore is emphasis on on-farm implementation studies, technology evaluation and integration. In this case 'integration' includes breaking down the walls between scientific disciplines.

Tropical legume crops

Most of Asia lies in the tropics, but the legumes associated with the cooler regions —lentils, faba beans and sweet (green) peas—are included in the list of food legumes (Table 2). A description of the distribution and uses of legumes requires a treatise by itself (Purseglove 1968, Smartt 1976, ICRISAT 1989). In general, in East and South-East Asia legumes are most likely to be eaten as green vegetables. Green gram and soybean are often processed in the manufacture of noodles and fermentation products. In predominantly vegetarian South Asia, nearly all the legumes listed are eaten, but the pulses (dried seeds) are significant as supplements to the staple rice and wheat dishes. Groundnut and soybean are dominant sources of high quality vegetable oil but are also eaten in many forms.

Production levels have not approached the 1:9 pulse to cereal ratio (11% pulse) considered normal for Asia for many years (Table 1). The desirable 3:7 ratio (43% pulse) may never have been achieved on this continent (Hulse 1990). The production of legume oil seeds (groundnut and soybean) presents only a slightly brighter picture in terms of increasing productivity and the area sown. All production figures are not gloomy: soybean and groundnut production are increasing in India (FAO data) and Indonesia (Broto & Bottema 1990) (Table 1).

Current yields for most of the pulse crops are in the region of 0.4–0.6 t ha^{-1}. Fortunately, the achievable yield may be more than five times that amount, or more for chickpea, soybean, mung and groundnut (Smartt 1976). This huge yield gap indicates that there is at least the potential for considerable management-led impact on Regional legume production.

The conclusion we can draw so far is that the food-energy demand of the more disadvantaged sectors of Asian communities may be fulfilled into the next century. Despite this, malnutrition will be among the foremost factors that will sap the ability of the huge cadre of Asian labourers ('the poor') to grow staple supplements or earn the money to buy them. The inability of the poor to buy cereal supplements was already apparent 12 years ago (Bidinger & Bhavani 1980). The situation is getting worse as the Asian industrial revolution draws farming people from the land to the cities. Stable supply in the face of increasing demand is already leading to price hikes. The price of 1 kg of split pigeonpea (dahl) in southern India has increased from less than half a labourer's daily wage to more than a full day's pay in three years.

There are many reasons food legume production in Asia has stagnated for such a long time, for instance:

(1) The comparative lack of national and international investment in quality research that is directed at increasing legume productivity. There is certainly an imbalance in resource allocation that is probably associated with the politically sensitive nature of crops such as rice.

(2) The release of new varieties bred for high yield potential on research stations with high susceptibility to several pests in low-input conditions. Also the converse—a lack of varieties adapted to the biotic and abiotic features of specific environments and the needs of farmers.
(3) Slowness in the approval, release, multiplication and distribution of improved varieties by national programmes.
(4) Prestige—'real farmers grow rice'.
(5) Considering legumes as adjuncts to cereal-based systems, not as primary components.
(6) High cost, e.g. groundnut, and poor storage prospects of seed (mainly because of bruchid beetles—pests of all legume crops).
(7) The inherent intractability of the production problems (including insects) that result from the complexity and fragmentation of the farming systems, the often harsh environment and the number of legume species involved.

The insect pests

The core of the production problems lies in the last constraint and the associated implications for the farm economy. The most important production problem (after uncontrollable abiotic factors like drought and flooding) is a cohort of insect pests (Table 3). Its members regularly reduce the yield of legume crops to levels at which it is not in the interest of the farmers to harvest them. However, other components of the farming systems in which these crops grow are also involved. For instance, in India and Thailand, the heavy application of insecticides to cotton has enhanced the injury caused by *Helicoverpa* spp. and whiteflies to legume crops in neighbouring fields.

The problem created by these pests is different and considerably more intense than it was perhaps 10 years ago. Many insects are now out of control despite (because of) the liberal application of insecticides. The best documented example within the current context is that of *Helicoverpa* resistance to several insecticide classes in Andhra Pradesh (Table 4). A resistance factor of 10 is sufficiently high to consider implementing resistance management schemes. The data show that this has been exceeded manyfold in recent years.

Specialists from The Philippines, Vietnam, Indonesia, Thailand, Sri Lanka and India have reported that farmers apply insecticides to legume crops at least once a week to kill *Maruca*, *Etiella*, *Helicoverpa* and the large Heteroptera. The natural control process has been destroyed and the target insects are highly resistant to pesticides. Marketed produce must be highly contaminated with pesticides. Farmers can see no answer to the problem except to apply more insecticides—the insecticide treadmill (Legumes Program, ICRISAT 1991).

TABLE 2 Food legumes of Asia

Species and common names	Where commonly grown	Comments
Arachis hypogaea peanut, groundnut	Throughout Asia	Oil, food and process crop
Cajanus cajan pigeonpea, red gram, tur	India	Staple pulse
Canavalia ensiformis jack bean	Dispersed thinly throughout Asia	Low density pulse and green manure
Canavalia gladiata sword bean	India	Climbing habit; green pods and immature seed consumed fresh
Cicer arietinum chickpea	North Asia, northern India, Myanmar	Staple pulse; cold adapted, drought adapted
Cyanopsis tetragonoloba cluster bean	Southern Asia	Vegetable, fodder and green manure
Dolichos uniflorus horse gram	Southern India	A poor person's pulse and stock food
Glycine max soybean	Throughout Asia	Important oil and process crop, also grown as a fresh vegetable
Lathyrus sativus grass pea, chickling pea	Mainly India	Another poor person's crop; some genotypes have dangerous levels of a cumulative toxin
Lens esculenta lentil	North Asia, temperate China and at high altitudes in the tropics	
Phaseolus aconitifolius moth bean	Mainly India	Adapted to hot, dry conditions
Phaseolus angularis adzuki bean	East Asia	Grown in rice stubble; short-day adapted
Phaseolus lunatus lima bean, butter bean, Burma bean	Myanmar	Bush and climbing forms; widely adapted
Phaseolus vulgaris kidney bean, common bean french bean, snap bean, string bean (etc)	Throughout Asia	Green vegetable and pulse
Pisum sativum green pea, sweet pea	Throughout Asia	Temperate climate required (> 1200 m in the tropics)
Psophocarpus tetratonolobus winged bean, Goa bean	South-East Asia	Multipurpose crop adapted to moist tropics
Vicia faba Horse bean, faba bean, tick bean, broad bean	Northern Asia and temperate China	Vegetable and pulse crop
Vigna aureus green gram, mung	Throughout tropical Asia	Of great importance, eaten in many forms
Vigna lablab hyacinth bean, lablab bean	Mainly India	Climbing or bush forms of value as pulse and fodder; grows in a range of environments
Vigna mungo black gram	Mainly India, but also parts of South-East Asia	Eaten as a pulse or used as flour
Vigna sesquipedalis yard long bean	South-East and East Asia	Favoured vegetable crop
Vigna umbellata rice bean	Throughout Asia	Follows rice or sown to climb over mature maize plants
Vigna unguiculata cowpea	Throughout Asia	Not as popular as some other pulse crops, perhaps because of sensitivity to stem flies
Vigna subterranea Bambara groundnut	Only in South-East Asia	Of great potential because of its resistance to pests and tolerance to drought, heat and poor soils

Sources: Purseglove (1968), Smartt (1976).

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TABLE 3 The most serious insect pests of legume crops in Asia

The insects	*Distribution*	*Crops*	*Comments*
HOMOPTERA			
Aphis craccivora groundnut or cowpea aphid	Cosmopolitan	Most, if not all	Spread viral diseases, reduce plant turgor and remove essential nutrients from the plant
Aphids in general	Cosmopolitan	All	Many species of aphid carry non-persistent viruses that are transmitted by 'casual' probes of non-normal hosts
Bemisia (tabaci) whiteflies	Cosmopolitan	Most	Spread viral diseases, reduce plant turgor and remove essential nutrients from the plant
Empoasca spp. and other leaf hoppers (jassids)	Cosmopolitan	All	Spread viral diseases, reduce plant turgor and remove essential nutrients from the plant
HETEROPTERA			
Large bugs (Coreidae, Pentatomidae, Lygaeidae)	Cosmopolitan	All	By feeding directly on the developing pods these insects reduce seed yield at low densities. Many are large (>3 cm long) in the adult stage and difficult to kill with insecticides
especially: *Anoplocnemis phasiana*	India		
Clavigralla spp.			
Nezara viridula			
Piezodorus			
Riptortus spp.			
Small bugs (Miridae) *Creontiades* sp. *Eurystylis* sp. *Campylomma* spp.	Cosmopolitan	All	Destroy flower buds, have economic impact at low densities (e.g. one per groundnut plant)
THYSANOPTERA (thrips)			
Indeterminate species	Indonesia	Mung	Can eliminate seed yield of unprotected plants if crop sown at wrong time
Thrips palmi	India	Groundnut	Vector of bud necrosis virus
COLEOPTERA			
Bruchidae, including			A group of beetles associated with legumes before and after harvest: the most important storage pest of legume seeds
Callosobruchus spp.	Cosmopolitan	All	
Caryedon serratus	South Asia	Groudnut	
Acanthoscelides obtectus	Wide	Many	
Scarabaeidae white grubs	Cosmopolitan	Groundnut, chickpea	Major root pest of groundnut (and chickpea in Myanmar) but may attack
DIPTERA			
Agromyzidae			
Ophiomyia phaseoli bean fly	Cosmopolitan	*Vigna* spp. *Phaseolus* spp.	The major pest of seedlings
Melanagromyza obtusa pod fly	India, Thailand Vietnam	Pigeonpea	Larvae live in pod and destroy seeds
LEPIDOPTERA			
Helicoverpa spp. especially *armigera*	Cosmopolitan	Probably all	Major pest throughout the continent; pod borer and seed eater
Maruca testulalis	Cosmopolitan	Most, not soybean	Lives in more humid area; destroys flowers and young pods
Etiella zinckenella	Cosmopolitan	Probably all	Eats developing seeds
Lampides boeticus	Widespread	Many	Eats flowers and green pods
Amsacta spp. and other 'hairy caterpillars'	Southern Asia	Many	Polyphagous defoliators
Aproaerema modicella	Widespread	Soybean, groundnut	Leaf miners; major yield reducers but sporadic
Spodoptera litura	Widespread	Many crops	Polyphagous; mainly a defoliator but can attack developing pods

Sources: Singh (1990), Marwoto & Neering (1989).

TABLE 4 Levels of resistance to insecticides in *Helicoverpa armigera* taken from pigeonpea, chickpea and cotton in Andhra Pradesh and Tamil Nadu, South-East India

	Number of samples	*Resistance factors*[1]	
		1	*2*
1989–90			
Pyrethroid (cypermethrin)	7	27 (1–100)	572 (20–2100)
Organophosphate (quinalphos)	6	—	2 (2–4)
Carbamate (methomyl)	1	—	8
1990–1991			
Pyrethroid (cypermethrin)	23	12 (0.5–64)	157 (7–830)
Organophosphate (quinalphos)	4	—	3 (2–4)
Carbamate (methomyl)	3	—	15 (6–30)
Chlorinated hydrocarbon (Endosulfan)	3	4 (2–7)	—

Summarized from data of Armes et al (1992).
[1]Materials were applied topically to 30–50 mg larvae. 1, control strain from New Delhi; 2, control strain from Sudan. Data are the mean (and range) of samples that usually consisted of more than 200 larvae.

If legumes are to remain part of the diet of Asians something has to be done about these insects and the insecticides—now.

Rational pest management

I shall add little new to what has already been written by many erudite people (e.g. Brader 1979, Kenmore et al 1987, van Emden 1980) about rational approaches to pest management and related research in developing countries. I hope another rearrangement of some of these realities will not be amiss.

The essence of the problem is to make the investment into legume production a more attractive proposition to farmers—a multifaced proposition. For instance, there is a case for freeing irrigated land for legume production and switching emphasis to the comparatively neglected production of upland (dryland) rice (Maurya et al 1988). This scheme has merits: it would boost legume production and would make more efficient use of irrigation water (Wightman 1990).

Irrespective of the nature of any new schemes, an immediate reduction in the amount of insecticide applied to Asian legumes and associated crops is needed. This implies the provision of alternative pest management practices that will stabilize the situation at tenable levels of production. In other words, we need to apply the principles of IPM within the context of sustainable agricultural production. As the meaning of 'IPM' and 'sustainable' vary according to the individual and the context, the following definitions pertain to this paper:

A sustainable farming system is managed so that:
(1) its long-term productivity and quality and that of its environment are maintained at the status quo or are improved with time;
(2) annual productivity and/or profit are optimized;
(3) between season variation in productivity and/or profit is minimized at an optimum level.

IPM:
Management activities that are carried out by farmers that result in potential pest populations being maintained below densities at which they become pests, without endangering the productivity and profitability 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.

IPM activities can be divided into:
(1) growing varieties that have resistance to the pests characteristic of the agroecological zone of the farming system; (2) adopting farm management practices that counter the proliferation of pests but which may foster natural control processes; and (3) applying insecticides when needed in such a way that the objectives of IPM are not impugned.

Farmers, researchers and extension officers also need to develop an understanding of the applied ecology of the organisms involved to be able to evaluate the implications of the management options. It will be noted that these definitions and clarifying comments do not refer specifically to insects, but to pests, a term that covers all biotic crop production constraints. We are largely concerned with insects in this paper, as they tend to be the major biotic constraint in the current context, either directly or as vectors of viral diseases. It is sincerely hoped that 'integration' will involve all disciplines, sooner rather than later.

Insecticide resistance management (IRM) is pivotal to the whole process. There are two aspects that need to concern us: (1) farmers perceive the need to apply more and more insecticide because they cannot kill insects with lower, less frequent applications. This leads to the continuing destruction of natural enemies and the pollution of the target and downstream environments. (2) cross resistance within and across chemical classes will lead to the withdrawal by the agrochemical industry of whole groups of insecticides, including the so called 'soft' insecticides that have an important place within IPM schemes.

Immediate solutions: fire-fighting

Without question, farmers can be immediately responsive to demonstrations showing that they can withdraw from the insecticide treadmill without losing their livelihood. Procedures that describe to farmers exactly when they need to apply insecticides to several crops already exist. If followed, they will result in the reduction of insecticide application (e.g. Marwoto & Neering 1989, Wightman & Ranga Rao 1993, Wightman et al 1993).

However, many farmers may be understandably nervous of taking such a step. They will require a substitute for insecticides, perhaps in the form of a resistant crop variety. If so, sufficient seed should be immediately available. Such a variety may not give the highest possible yield but is more likely to give sustained production over time than a high-yielding variety supported by insecticides. The introduction of crop insurance schemes or other government-led incentives for non-sprayers may also be considered.

The simplest management tool is the decision not to grow a susceptible crop for one or more seasons or crop cycles. Group action within a community to switch production to another crop may lead to the decline in the local population of the key pests. The substitute crop could be the insect- and disease-resistant bambara groundnut (that is, admittedly, largely untried and 'undeveloped' in Asia), a green manure crop or a non-legume non-host such as chilli, castor or sweet potato. The implications are that a farming community would have to act cohesively and would have to be prepared to change crops again as problems build up. There would undoubtedly be downstream implications for markets and other infrastructural matters. Should problems arise, governmental support should be at hand to smooth out problems, in the name of sustainability and guaranteed food production within the Region.

Longer-term solutions

This covers activities that should be implemented now at a national programme and international level. A suitable time horizon is 5–10 years. The appearance of the following items in this list implies that some of these critical activities are not always the accepted procedural practice.

Government acceptance and support

The first step into the future of legume crops is for governments and their advisors to decide that action needs to be taken to reduce insecticide application. For instance, the Government of The Netherlands has decided to implement a 'Multi-Year Crop Protection Plan' that will, by 2000, halve the amount of insecticides applied to Dutch agricultural land, with a baseline of the 1984–1989 average (Zadoks 1991).

Definition of the legume pest problem in absolute terms

The second step is to define the current problems in terms of the distribution of the insects, their density ranges, the amounts of insecticides applied (and the modality of application) and other relevant practices. Estimates of the

reduced yield attributable to these and other constraints are needed to put them into perspective. This will require the initiation of farm surveys in some countries. The collation of the data collected within a central Geographical Information System (GIS) is a prerequisite for the development of an understanding of the continental pattern of the problem within agroeconomic zones. *It would be a considerable insult to common sense if this process was limited to insect pests.*

This information is needed to guide the planners of the Region through the advantages and disadvantages of sowing various legume crops in different seasons or within specific agroecological zones. For instance, chickpea can be grown in many environments without pesticide application. Pigeonpea, especially varieties with less than medium duration, are highly susceptible to insect pests in Thailand, Vietnam, Myanmar, Indonesia, Sri Lanka and India (e.g. Wallis et al 1988, Hong et al 1992). However, pod fly-resistant lines are currently available for relevant environments.

Monitoring the sociological and economic implications of changing farm management patterns to accommodate IPM

In parallel with the above, selected farmers and farms in stricken tracts of land (and those selected for initial implementation studies) should be assessed by economists from the outset to monitor the acceptability and relevance of proposed modifications in farm management. An evaluation of the concepts held by farmers about pests and how they deal with them should be an integral part of this process.

The development of national or regional IPM-related strategies

The third step is for agricultural planners to adopt a general strategy set that is simple and that can be applied, in principle, across the continent. Such a strategy might be based on the following concepts:

The rationalization of insecticide application. The use of insecticides should be managed and hopefully reduced by implementing insect resistance management (which is directly linked to the essence of IPM) (Forrester 1990), whether or not insecticide resistance has been detected[1]. Monitoring high risk populations for insecticide resistance would be a key feature of such a strategy[2]. Steps would thus be taken to ensure that farmers have the best possible advice about when to apply insecticides.

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[1]As far as I know, this is not happening in Asia.
[2]This is being done at or out of ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) Center, within the limits of staff and budget.

Improvements in the technology and practice of pesticide application should be promoted throughout Asia[1]. One approach to fostering this process is the encouragement of village pest management 'clubs'. In these, farm and pest management strategies are discussed and monitored within the community, with guidance from trained advisors if needed. This mechanism promotes ownership in the technology and synchrony among farm activities[1].

The exploitation of host plant resistance. Information concerning host plant resistance to pests should be collated and disseminated[1]. It is necessary to be clear about cases where no or little resistance exists in a crop species and/or the relevant 'wild' species so that priority can be put on the development of other strategies. When resistance to key pests cannot be integrated into the germplasm of a crop, biotechnological techniques could be considered with a view to introducing relevant resistance genes from another species[1].

? necessity to repeat footnote

see margin note above

Where necessary, breeders should be persuaded that, in order for 'their' products to be relevant components of sustainable agriculture, i.e. in farmers' fields, they should work with farmers and specialists in other areas of agriculture. This process will ensure the production of varieties that farmers recognize as being as or more acceptable than existing varieties, in terms of taste, quality (ease of harvesting, seed colour, oil content), yield and the other uses to which farmers put the crop (e.g. fencing, thatching, fodder)[1]. These varieties must be able to survive as a crop in farmers' fields without excessive applications of pesticide (Byth 1980, van Emden 1980). Public or private sector agencies must also be empowered to evaluate, multiply and distribute new varieties effectively.

refer to note above

If these two concepts can be applied successfully in practice, natural control processes would have a chance to recover. This, in turn, would mean that other management-related options had more impact.

Promotion of natural control processes. The degree of biodiversity within farming systems should be maintained or increased by activities such as agroforestry (provides nesting sites for predatory birds) and selective multicropping and weeding to provide refuges for arthropod parasites and predators. Organisms that cause disease in insect pests should be made widely available through mass production and distribution[1]. Other management techniques that reduce the impact of pests and improve crop production should be encouraged (by direct subsidies)[1]. These include the adoption of suitable irrigation procedures and mulching with shiny plastic.

[1] This process has started through the aegis of International Resistant Pest Management. This is occurring through the national programmes that are developing with the support of NGOs and the Inter-country Integrated Rice Pest Control programmes.

Our ability to make optimum use of biological means of crop protection depends on an understanding of the life cycles of pests and their interactions with crop plants. This can be achieved by: (1) setting up an international network of observers and traps (the nature of which will depend on the species) to document the times of year when attack by pests is most and least likely. (2) determining in more detail the relationships between pest density and crop damage[1].

It is also important that scientists and extension specialists are able to transfer the information to where it is needed. This requires the establishment of an international communication network of plant protection specialists[1]. There is also a need to develop software that will give real-time guidance to farmers about when to apply pesticides (Wightman & Ranga Rao 1993) and to IPM researchers about the best strategies to adopt given specific levels of host plant resistance, natural control and pesticide efficacy for a range of pests and crops (Dudley et al 1989).

Institutional considerations

Current international input

The present disposition of entomologists concerned with pests of legumes employed by international agricultural research centres in Asia is: Asian Vegetable Research & Development Centre (AVRDC), Taiwan, one International Scientist; ICARDA, Syria, one International Scientist; ICRISAT, India, one Principal Scientist, one Associate Principal Scientist and one National Scientist.

These institutes receive significant input from specialists from other 'Western' organizations and national programmes. With such a small core group of scientists the need for effective setting of priorities is paramount. There is, for instance, no place for the creation of competition with national programmes.

Several 'Western' agencies and non-governmental organizations also work with Asian national programmes on important research and extension problems related to IPM for legumes. There is no doubt that the knowledge generated by these interactions could be applied beyond the limits of the existing bilateral relations.

My impression is that, outside India (Sachan 1991), there are not many national programme scientists in Asia with responsibility for legumes' pest management, especially when compared to those working on pest management for rice. Those whom I know are dedicated and work hard within the constraints set by their budgets and the demands put on them by international cooperators. They need more support in view of the important task they have.

Future requirements

There are unpleasant connotations in not modifying the status quo. Given my views on why stagnation in legume production exists, I am duty bound to indicate how the situation can be improved. How can more legumes be made available to the people of Asia?

(1) Governments can import them, and pay for them by persuading their farmers to grow cash crops that enter international trade. This route to food legume security has a large pitfall: *these products or an acceptable substitute still have to be grown by a pest-confounded farmer somewhere.*

(2) Empower Asian farmers to increase their productivity, by adopting IPM. A general policy and constraint list is presented above, but IPM is a highly knowledge-intensive activity. A decision to put high priority on the need to collect and disseminate this information and to follow through with the appropriate action is needed at the international level.

What is needed is a pivotal (= Asian) research and training clearing house for legume IPM matters. This could be part of an existing institute (an International Agricultural Research Centre or a centrally placed National Programme or University), part of a regional agricultural research centre or of an Asian legumes research institute (if one of these attractive concepts should one day exist). It could also operate as a stand-alone 'International Plant Protection Institute'.

Irrespective of the affiliation, the functions of such an organization would be clear: to provide the facilities and infrastructure (including access to cooperating farmers, extension workers and research specialists) needed by plant protectionists from developed and developing countries.

The component roles and insect-related activities could include:

(1) Training scientists, technicians and extension officers in all aspects of legume pest management.
(2) Promoting multidisciplinary approaches to solving pest problems.
(3) Linking with supporting (if necessary) other IPM projects in Asia, e.g. FAO intercountry rich project.
(4) Providing library and literature search facilities.
(5) Preparing and distributing documentation written to meet the IPM requirements of the Region.
(6) Fulfilling the Regional need for a central insect collection and identification centre (Wightman 1988).
(7) Screening, banking and distributing legume germplasm known to have resistance to pests.
(8) Providing facilities and an infrastructure for breeders to undertake hybridization and multilocational trials.
(9) Providing the high-grade laboratory facilities needed for determining the mechanisms of host plant resistance, immunoassay and virus detection and description.

(10) Maintaining pest cultures for experimental purposes.
(11) Initiating a pesticide resistance monitoring laboratory.
(12) Maintaining a botanical garden of plants of the Region that have anti-pest properties.
(13) Plotting pest outbreak and danger areas and carrying out other GIS operations.
(14) Developing and providing software for statistical analysis, instructional and analytical models, and real-time, farmer-support (expert system) programs.

Conclusions

There is a pressing need to address the failure of the pan-Asian farming sector to increase legume production and productivity beyond the levels of the 1960s. The current trend of increased insect pest attack associated with the overuse of insecticides can only lead to further deterioration in an already grim scene. It is hoped that this analysis of the problem and the short-term and long-term solutions that are presented will lead to further consideration being given to the development of IPM schemes that are suited to the needs of the millions of smallholder farmers. This is an information-intensive process that requires coordination and cooperation in many directions. The development of an organization with a pan-Asian responsibility to ensure that this happens is fundamental in ensuring an up-turn in legume production.

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DISCUSSION

Neuenschwander: The important issues in legume production are to maintain adequate yields and to reduce dependence on pesticides. West African farmers get yields of about 300 kg ha^{-1} for cowpea. This yield is sustainable and there are not many problems with pests. My colleagues tell me that they can't increase yield unless they use other varieties. If they use other varieties, they have to spray them. The amount sprayed has been reduced considerably from what was used, let's say 10 years ago, but cowpea still needs three well-timed sprays, which for West African smallholders is very difficult.

To raise yields without using insecticides, we have to become much more enterprising, for instance in biological control. We have to jump even the continental perspective and become global: we have to try biological control by importing insects from different pulse crops from different continents. Cowpea is indigenous to West Africa and all our pests are supposed to be indigenous, although no serious attempt has been made to investigate their true origin. Some probably originated outside West Africa, which raises possibilities for biological control. We have some indications that this would work, but much more international collaboration is needed.

For such collaboration, the International Institute of Biological Control of CABI in London is trying to establish regional centres of biosystematics. The first is in Central America; IITA will become another regional centre of this group, which is referred to as BIONET. There is a conference in June 1993 on establishing this network of collaborating institutions. It is not specially for cowpea, but pulses are one area where the need is most felt.

Wightman: Earlier, we have discussed attainable yield and potential yield (Rabbinge, this volume). In Asia, current yields of legumes are about the same as in Africa, 300–500, perhaps 700 kg ha^{-1}. The yield potential is 3–5 t ha^{-1}, even 8 t ha^{-1}. The attainable yield is about half that, 2–4 t ha^{-1} in farmers' fields. This is the bright point: we can look towards a fivefold increase in yield. If this were not theoretically attainable, there would be no point in seeking increases in productivity by improved pest management.

Not all crops are affected by pests in the same way. Defoliators have little effect on pigeonpea and groundnut production. The sequence of attack is also important. For pigeonpea we can expect perhaps 90% destruction of seed by insects: but that's 90% of the seed which is left after the diseases have taken their toll.

You mentioned biological control and approaches to pest management. I am worried that as insects move around the world their genetic structure changes. What may be appropriate in one place simply may not work in other places. A prime example is the thrips vector of bud necrosis disease and tomato spotted wilt virus. There is tremendous variation in what happens in one alleged species and another. *Maruca* is pandemic; we have to find out whether *Maruca* in West Africa is the same species as *Maruca* in, say, Sri Lanka.

If we start at the position where a pest is a is a pest because of the overuse of insecticides, we have to find a substitute for insecticides, to wean farmers from their chemical prop. The first approach should be a search for varieties with more pest resistance than the traditional ones have. Once we have resistant varieties, the pest situation will stabilize a little. We can then look at farming systems and ways of improving natural control processes. This should again reduce insecticide use considerably. Although it is possible to apply insecticides within these systems as part of an IPM procedure, the goal is usually to reduce this component to almost zero. Once we have reduced insecticide use, we can look at conventional biological control—the introduction of new organisms. That is a viable sequence, but it doesn't prevent us trying to look at the possible endpoint, the enhancement of natural control procedures, from the very beginning. The research phase of biological control projects is pretty lengthy, after all.

Rabbinge: You mentioned the stagnation in the productivity of legume crops, especially pulses. This phenomenon occurs not only in Asia, but also in many places in Europe. For that reason, about 15 years ago, a Concerted Action was started in different countries in Europe to determine the reasons for stagnation of yield increases in legumes, especially in faba bean. There was also great variability in yields: the stability of yields in many places in Europe was very low. The European Community wanted to promote the production of faba bean as a replacement for imports of soybean from the USA. It was thought that the low yields were due to pests and diseases. However, investigations showed that it was not only the yield-reducing factors that were important, yield-limiting factors were too. Water and phosphorus are limiting during part of the growing season. If proper water management is achieved (that means water should not always be readily available; at some time during crop development, especially around flowering, there is a need for some stress, a little water shortage), one gets very high yields and stable yields. When nutrient management is not correct, pests and diseases simply amplify the instability and the yield depression. So if you are starting such a programme, it is important to consider not only the yield-reducing factors but also the yield-limiting factors.

Wightman: We are aware that the abiotic factors are extremely important. We even have quite a lot of evidence, which isn't always accepted, that the effects of pests on pigeonpea and groundnut are made worse by water stress.

Nagarajan: Industrialists in Bombay are considering manufacturing a pulse analogue, a synthetic pulse, similar to 'nugget' from soybean, which tastes like meat when cooked. Is ICRISAT considering any research on a pulse analogue for value addition to millet flour, for example?

Secondly, the extent of genetic diversity in pigeonpea is very narrow, primarily because it's a crop of the subcontinent. By using biotechnological tools, we should be able to generate more diversity in pigeonpea.

Wightman: I'm sorry I don't know anything about the pulse analogues.

The biodiversity of pigeonpea is fairly narrow, but there are several pest-resistant genotypes within the species. We have considered very carefully whether we should attempt to amplify the genetic resources of pigeonpea with specific genes from *Bacillus thuringiensis* (Bt) to make selected varieties resistant to *Helicoverpa*. So far, we have not used this approach, simply because we don't have the right Bt strains. In laboratory conditions, a species closely related to *Helicoverpa armigera* has become resistant to Bt in 27 generations. If we take five years to develop a suitable plant with the Bt gene in it, and it takes 27 generations (three years) for the resistance to break down, that is not a good investment. But there's so much work going on with Bt and new strains are steadily becoming available; so I regard this as being in abeyance rather than forgotten. There are other potential resistance mechanisms that may be tried in due course. Incidentally, I have been encouraged by what I've seen in the US. They have potatoes carrying Bt genes that are virtually immune to Colorado beetle, which is excellent.

Kenmore: I support your reluctance to use Bt genes for resistance to *Helicoverpa*. For 3–4 years, people from industry and some short-sighted academics have been saying 'All we have to do is switch in the DNA sequence encoding the receptor site like a cassette and we can take care of the resistance problems'. Gould et al (1992) have developed a strain of *Helicoverpa* in which the resistance to Bt is not dependent on binding site specificity. Darwin is still right: do not put Bt genes into crop plants. Make more virulent Bt that farmers can use to hit a pest population once when it's needed—that's fine. Make Bt more specific to different targets and more lasting in an environmental condition, but do not put it into the crop plant.

Nagarajan: What's the pest scenario with regard to the new hybrid pigeonpea?

Wightman: This is really a kind of dwarf pigeonpea. It is highly susceptible to insect pests; I don't think it can be grown without support from insecticides. As such, it cannot be part of a sustainable farming system.

Swaminathan: I agree with Dr Wightman about the inadequate research effort in legumes in the past. As far as varietal improvement is concerned, it is not just a lack of adequate scientific or breeding effort. There are inherent difficulties in combining yield and quality. The last 50 years work from various laboratories around the world trying to combine high protein yield with high calorie yield has shown that whenever we make a gain in calorie yield, there is a protein penalty. Whenever there is a protein yield improvement, there is a calorie penalty. We have to find a compromise between the two.

But there are crops, like peas in Europe and North America, for which very high yields have been obtained. Soybean is another case. In India, soybean is a new crop. In Tamil Nadu, for example, many farmers produce 4–5 t ha^{-1} of soybean, largely because they started with a completely new set of management procedures. They didn't have their own past memory as to how this crop should be cultivated. Similarly, there are reports from the CSIRO in Australia that some of the pigeonpea varieties taken from India have given very high yields, probably under conditions of good management in terms of plant population and plant protection. So we have to be realistic about what can be achieved through breeding alone or biotechnology; we should also consider crop management.

Varma: Your list of insect pests (Table 3) did not mention *Madurasia obscurella*, a beetle which is very common in India. Is it not a pest of grain legumes? Also, don't thrips cause some direct damage to grain legumes? You mentioned them only as a viral vector.

Wightman: The insects I listed are pan-Asian pests; the beetle you mentioned is rather more localized. Mung bean can be wiped out by thrips; in groundnut they cause only cosmetic damage, except as virus vectors.

Varma: For storage pests in pulses, people use vegetable oils, like groundnut oil, mustard oil, palm kernel oil, etc. These are very effective in preventing damage by beetles (Pereira 1983).

Wightman: Dusts and oils can be used to protect pulses from storage pests. This is rediscovered about every three months, if you look at the literature! Unfortunately, the message does not always get through to the farmers. There are still farmers who are losing pulse seed. This is one reason they don't keep their own seed—they think they are going to lose it to insects and moulds.

Jayaraj: In pulse production we need to have a policy decision in many developing countries, based on the successes and failures of the past. In pigeonpea, varietal improvement has not really made an impression, compared to other crops. As Dr Swaminathan mentioned, management is very weak in pigeonpea and in chickpea. For groundnut, the yield breakthrough has been remarkable. For soybean, cowpea, green gram (mung bean) and black gram, increased yields are being obtained. In peninsular India, where mung bean and black gram are grown after the rice crop, the yields are picking up. There are not many pest problems because of improved varieties. Yellow mosaic virus used to be a problem but there are now effective resistant varieties.

But in the case of both pigeonpea and chickpea, we have come to a dead end. Of all the grain legumes, the protein quality of these two pulses seems to be the poorest, though by food habits we prefer these two pulses in many Asian countries, particularly in India. The time has come to change, if possible, our eating habits, because of this dead end in improving pigeonpea and chickpea productivity. Or we should have a very strong programme for managing the pests and diseases, which compete with humans for protein in the form of grain legumes. Plant stand in the field is badly affected. Damage of pulses by beetles during storage reduces germination and then in the early stages of cultivation half a dozen pests cause extensive damage. Often only one quarter or one fifth of the field is covered with standing plants and subsequently this is affected by many viral diseases and so on. In India, *per capita* consumption of pulses has not increased in the last 40 years. So some policy decision is necessary for sustaining production of pulses. If we cannot make scientific advances, we should change the cropping pattern.

Wightman: I don't agree; there is terrific potential still in chickpea. For pigeonpea, the problem is finding an alternative crop that will grow in these harsh environments. Pigeonpea will grow where other crops won't grow.

Lakshmi: There is a genus called *Atylosia* Wt & Arn, which is a wild species. It is resistant to almost all insects and pests. It is a valuable germplasm material and very closely related to *Cajanus* (L.) Mill sp. Professor N.C. Sburamanyam at the University of Hyderabad, India, claims to have obtained a cross between *Atylosia* and pigeonpea (personal communication, 1990, with Professor M. K. Rao, who has seen this hybrid). Is it true that *Atylosia* can be crossed with pigeonpea and resistance genes transferred to pigeonpea?

Wightman: Today, anything is possible. *Atylosia* is a wild species, a very close relative of pigeonpea. Interspecific crosses have been made at ICRISAT, but they have not been successful as far as insect resistance is concerned. If Professor Sburamanyam has done this, we would be very interested to work with him and take it further.

Zadoks: I would like to challenge the plant breeders, represented by Mr Mishra. I think the breeders should breed a variety, hybrid or not, which is useful to farmers. But with the seed, they should also sell a recipe for integrated management of the crop. Is that a feasible proposition?

Mishra: There are All-India Coordinated Improvement projects for different crops. The resistant varieties and hybrids of different crops have been tested under certain sets of conditions. When the farmers adopt those hybrids or varieties, variation in susceptibility is observed. For maintenance of the genetic resistance, correct management practices need to be adopted along with the new varieties.

A pigeonpea hybrid ICPH-8 has been released from ICRISAT, but it is as susceptible to *Fusarium wilt* and *Sterility mosaic* as any variety developed from other programmes. Good hybrids and varieties require good management support to realize their yield potential.

As a seed company, we market seeds of hybrids and improved varieties. A leaflet giving guidelines for the adoption of better agronomic practices is supplied with each individual seed bag.